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## HEAVY HAUL OPERATIONS IN RAILWAYS

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**ASIAN INSTITUTE OF TRANSPORT DEVELOPMENT**

## Contents

## Heavy Haul Operations in Railways

Heavy haul, as the name implies, means moving large volumes of traffic per unit of transport. In the case of railways, this is achieved by increasing axle load of rolling stock and a train-consist comprising larger number of wagons. For optimum advantage, heavy haul operations are generally confined to dedicated lines. The tracks are built to upscaled standards suitable for a particular operating environment. The combined effect of these attributes is reduction in the unit cost of transport. At the same time, it results in maximising the utilization of costly infrastructure.

In the case of railways 'metal runs on metal' so that frictional resistance is barely one-sixth of other modes of land transport. Hence, it consumes one-sixth of the energy per tonne kilometre consumed by any other mode of land transport. Therefore, improving the capacity of the railways has a beneficial impact on sustainable economic development. Indeed, heavy haul operations provide a perfect solution for moving large volumes of goods in the most energy-efficient and economic manner.

Heavy haul concept originated in the US, where the railways were faced with a serious threat to survival in the 1970s when more and more freight traffic was opting for road in view of capacity constraints on the railways. High axle loads and longer trains, however, enabled the existing network to be utilised much more intensively. This made it possible for the railways to reduce their transport costs and hence tariffs, thereby regaining their market share. This brings out the fact that technological upscaling has been the key driver of the heavy haul operations.

Today, US railroads run trains with axle loads between 30 and 35 tonnes and trains of 15000 tonnes. BHP Billiton of Australia holds the record with axle load of 38 tonnes and a train-consist of 682 wagons. The train, carrying a gross load of 99732 tonnes, is hauled by 8 locomotives distributed at 5 locations within the train length of 7.353 km! The heavy haul railways form an exclusive club consisting of certain railways in US, Australia, Brazil, South Africa, Canada, Nordic countries, China and Russia.

In the recent past, the Indian Railways, faced with capacity constraints and a fast-growing demand for transport capacity to keep pace with economic growth, took the first step by increasing axle load in wagons from 20.32 tonnes to 22.9 tonnes, thereby allowing an additional payload of 10 tonnes per four-axled wagon.

This single step brought about a major increase in freight loading. The Indian Railways, encouraged by the outcome, has announced its intention to construct dedicated freight corridors with 25 tonnes axle load, a move towards a heavy haul regime.

The Asian Institute of Transport Development realised that an issue of the Asian Journal on heavy haul systems and operation would be most appropriate at this juncture. It was felt that inputs from the world's leading experts on heavy haul would provide a valuable insight for planning dedicated freight corridors in a cost-effective manner. Since heavy haul comes with its own set of commandments, it pays to remain within the technical boundaries prescribed by the practitioners of heavy haul.

When the wheel rolls over the rail, the contact area is very small and the full load of the train gets concentrated at a number of individual contact points corresponding to the number of wheels. The magic lies in controlling the stress at these points in such a way that the forces remain within required levels allowing the train to run safely. The rail-wheel interaction is thus the single most important point of attention for success in heavy haul operation.

The above implies that both the track and the rolling stock have to be studied as a single system so as to keep stresses always within control limits. The present issue of the journal has, therefore, focussed its attention on obtaining inputs on track and rolling stock, their design, performance monitoring and maintenance. The operations and the areas of current research are also vital to heavy haul practices and as such are covered in the issue.

We have been privileged in receiving inputs from eminent experts like Sergey Zahkarov, an authority on rail wheel interaction from Russia and J.S. Mundrey of India in the area of track technology, rail wheel interaction, the metallurgy, defects and their avoidance.

Rolling stock design, its performance monitoring and maintenance systems have been covered by two of the leading authorities, Harry Tournay of Transportation Technology Control Inc. (TTCI), US and Russell Donnelly, BHP, Billiton, Australia and his co-authors Murray Lynch and Mike Darby.

Track maintenance systems need specialised equipment and Plasser & Theurer, are the recognised leaders in the field of track machines. An article by Rainer Wenty of Plasser & Theurer on machines needed for heavy haul railways provides an insight in this area.

David Peltz of GE transportation, in his article brings out how intelligent control of locomotives through Locotrol, allows successful operation of long trains. Loco control which has been around for many years has made significant contribution towards heavy haul, fuel economy, safety and braking efficiency.

Technology being the key driver of heavy haul, new frontiers are being explored every day and Roy Allen, President, TTCI and his co-authors Scott B. Harvey and Semih Kalay are arguably the best placed to write on the current research in this field. Their contribution indicates the direction in which heavy haul technology would be moving in the future.

Our effort has been to bring the views of internationally acclaimed experts on a common platform and we hope that this issue of the journal would serve as a reference capsule for students and practitioners of heavy haul. More specifically, it would be useful for those who are planning entry into the heavy haul ambit. We recognise that this publication covers only a limited area of heavy haul technology. We will, however, endeavour to cover more aspects of technology and operations in subsequent issues.

I was privileged to be associated as an Editor with this issue of the journal as a member of the Institute's faculty. In this task, I acknowledge the guidance received from my peers, particularly K. L. Thapar, Chairman of the Institute.

Sumant Chak
Editor

# DEDICATED FREIGHT CORRIDORS ON INDIAN RAILWAYS TRACK AND BRIDGE STRUCTURES

*J. S. Mundrey**

## 1. NEED FOR DEDICATED FREIGHT CORRIDOR

With the accelerated growth of Indian economy it has become necessary to enhance the railways' transport capacity to meet the increased traffic demands. Most of the trunk routes on Indian Railways are already running to a saturated traffic condition. It has, therefore, been decided to have dedicated freight corridors for the speedy movement of goods. Dedicated freight corridors have the advantage that they can be designed to meet the specific requirements of specialized rolling stock for their movement at the designated speeds. The throughput of traffic on such corridors can be quite high, without any interference from the running of high/low speed passenger trains.

For achieving throughput of traffic, dedicated freight corridors across the world are usually designed for the movement of high axle loads wagons. However, heavy axle loads, 25 tonnes or more create their own problems in their movement. An association of world railways operating with heavy axle loads has been formed to deliberate on the issues connected with the heavy haul traffic.

Heavy Haul Association of the World Railways have defined heavy haul operation in the following terms: "Heavy haul railway operation is defined as a system with: 25 tonnes or greater axle loads, a minimum of 20 million gross tonnes annual traffic and/or the operation of unit trains, in excess of 5000 tonnes load." We presume that dedicated freight corridors of Indian Railways will come under the definition of heavy haul operation.

The track and bridge structures on heavy haul railways are usually designed to meet the specific traffic environment, particularly in reference to axle loads, dynamic augment, traffic density, speed of operation, rolling characteristics of the goods stock, traction and breaking forces, etc. The maintenance and monitoring systems have also to meet their specific needs. In the following paragraphs, the norms that need to be followed in the design, construction and maintenance of track and bridges on dedicated freight corridors have been spelt out.

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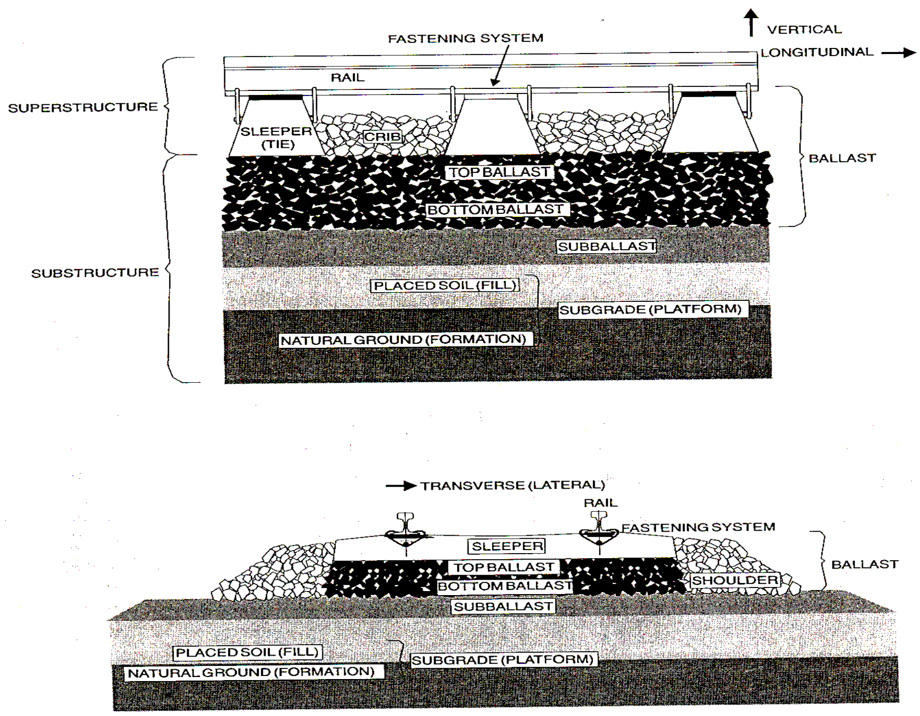
## 2. TRACK STRUCTURE

Ballasted track structure essentially consists of the following components:

- Rails;
- Sleepers;
- Sub-Ballast/blanketing material;
- Rail to Sleeper fastenings;
- Ballast;
- Formation and drainage.

Figure 1 shows the various components of ballasted track structure:

**Figure 1**




At stations, turnouts form an important constituent of the track. In addition, there are other important items of track structure, such as level crossings, insulated joints, switch expansion joints, buffer stops, etc. The railway alignment and grade also play an important role in the design of track structure as well as in the hauling power of the locomotives.

### 2.1 Rails

Rails are usually designed to meet the requirement of flexural bending stresses and rail/wheel contact stresses, encountered by them during their service life. Longitudinal bending stresses in rails are calculated by the following formula:

$$Xi = 42.33 \quad cm$$

$M_0 = 0.319\ P \times X_i$ cm-tonne

$$F\ (comp) = \frac{M_0}{Z_{comp}} \text{ tonnes/cm}^2$$

$$F\ (tension) = \frac{M_0}{Z_{tension}} \text{ tonnes/cm}^2$$

$$d = \frac{9.25P}{4\sqrt{IU^3}}$$

*Where:*

$X_i$ = the distance from the load to the point of contraflexure of the rail in cm.

$M_0$ = the bending moment in cm tonne immediately under an isolated load P tonne on one rail

F (comp) = the consequent compressive stress in the rail-head, under the load P, in tonne per square cm.

F (tension) = the consequent tensile stress in the rail-foot, under the load P, in tonne per square cm.

d = deflection of track in cm

P = Load on one rail in tones

$$\sqrt[4]{\frac{I}{U}}$$

I = Vertical moment of inertia of rail section in cm4

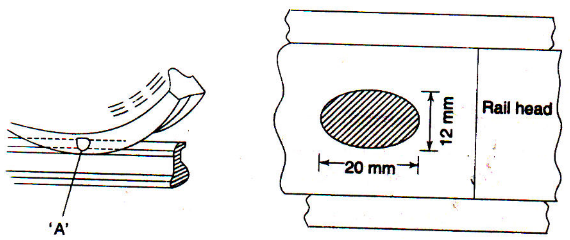
U = Track modulus in kg/cm/cm

Z = (comp) = Section modulus of rail in compression cm3

Z (tension) = Section modulus of rail in tension cm3

I, the moment of inertia of rail is reduced by 10 per cent to cater for the loss of section of rail in service

As may be seen in this formula, stresses on rails get affected by static loads, loading pattern of the wheels, dynamic augment and track modulus. As most of these parameters would vary in the case of rails used in freight corridors, it is difficult to calculate the bending stresses in rails at this stage, but it appears 60 Kg, 90 UTS, UIC rails presently used on Indian Railway tracks will be able to meet the requirements.




***Rail wheel contact stresses***

With increase in axle loads and reduction in wheel diameters, the rail wheel contact stresses have assumed considerable importance. Very high contact stresses develop in the immediate vicinity of the rail wheel contact zone which at times lead to plastic flow of metal in the rail head. Maximum contact shear stress which occurs in the transverse direction at right angles to the rail is calculated by the following formula given by UIC/ORE.

$$T_{max} = 4.13$$

$T_{max}$ = maximum shear stress in kg / mm2
Q = static wheel load in Kg increased for on-loading on curves. This on-loading is taken as 1 tonne (1000 Kg)
R = wheel radius in mm (fully worn condition)

On freight corridors, with 30 tonne axle loads, contact shear stresses on 60 kg 90 UTS rails are expected to be well within acceptable limits.

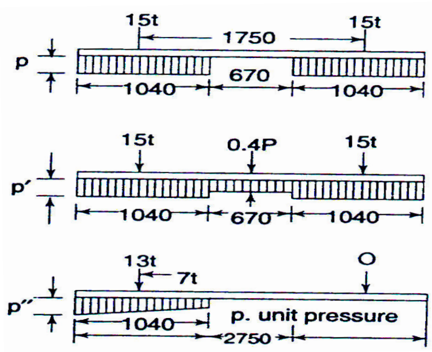
## 2.2 Concrete Sleepers

In the case of Indian Railways, broad guage concrete sleepers are designed to meet the following conditions:

- Vertical load at rail seat: 15 tonne. This assumes an axle load of 22 tonne with appropriate distribution of load and its dynamic augment;
- Lateral load 7 tonne.

Figure 2 gives the loading diagram for broad guage concrete sleeper of Indian Railways. For freight corridors, the concrete sleepers presently used on Indian Railways will need to be redesigned to meet the higher loading requirements. Presently, center-to-center spacing of concrete sleeper is prescribed at 60 cm for heavy density high speed routes on Indian Railways. This spacing may be brought down to 55 cm, to reduce the bearing pressures on ballast and formation.

**Figure 2: Loading diagram for concrete sleeper**




## 2.3 Rail to Sleeper Fastening Systems

Rail to sleeper fastening systems presently used on Indian Railways have a toe load of about 1000 Kg. This should meet the requirement of freight corridors as well. A new design of rail pads will, however, have to be evolved to withstand heavier loads and higher impact effects.

## 2.4 Ballast and Formation

Our standard ballast/sub-ballast cross-sections, as are being adopted on long welded rail tracks, will meet the requirement of railway freight corridors.

Formation, however, would need special attention, particularly where the alignment has to go through the stretches of bad soil.

Drainage is an important requirement of track structure. Any expenditure incurred in improving the track drainage pays enough dividends during the service life of the track; special attention is to be paid to railway yards and also to deep cuttings and high banks.

## 2.5 Alignment and Grades

Alignment and grades are important in the operation and maintenance of the railway system. It has generally been found that curves over three degrees, create maintenance problems; over five degrees, they have to be specially monitored and maintained. Grades should not be steeper than 1 in 200, as they cause problems in the haulage of trains.

## 2.6 Recommendations of Heavy Haul Association

Many combinations of track components with varying strength characteristics are possible in the design of track structure. Heavy Haul Association (HAA) have made certain recommendations taking into account both the theoretical design calculations and practical aspects of rail usage. These recommendations, for the axle loads of 30-34 tonne and for traffic densities varying from 20-50 GMT are given in a tabulated form. In these tables, not only the track structure has been indicated but certain recommendations about track maintenance and monitoring frequencies have also been brought out.

From these tables, it can be seen that 60 Kg UIC rails will generally meet the requirement of freight corridors on Indian Railways. Even upto 50 GMT of traffic, only standard rails have been prescribed. Premium rails or head-hardened rails are recommended only for curves.

## 2.7 Continuous Welding of Rails

To obtain the desired service life and to reduce the maintenance costs, all rails in heavy haul operation are required to be welded continuously. The rails have to be welded through turnouts and on bridges. Switch expansion joints are provided wherever the long welded rails have to be isolated, maybe at long girder bridges without ballast decking. Special high strength switch expansion joints, made out of full web rails, are now available in world markets for installation at such locations. All rails have to be laid without holes. Any hole made in the rail, even a small hole by signaling/electrical department, has to be improved in fatigue, by special fatigue improvement technology.

### 2.8 Turnouts

Turnouts on heavy haul operations need to be specially designed to meet the stringent traffic requirements. They are strengthened to carry continuously welded rails through them. Usually, cast manganese steel crossings with weldable legs are adopted. On very high density routes, it may be advisable to have swing nose crossings.

The turnouts should cater for a relatively higher speeds on turnout curves, so that minimum time is lost in the crossings of trains. A speed of 75 KMPH on turnout curves would probably provide a good solution.

### 2.9 Level Crossings

As far as possible, level crossings should be avoided by providing road/ over/under bridges. Wherever their provision is inescapable, the road surface should be properly designed to transfer the road traffic loads safely to the track formation, without damaging the concrete sleeper. New technologies are now available where high quality polymer concrete slabs can be used as a road surface. These slabs can be removed during the tamping operations, to be placed back in position after the maintenance work is over. The use of such slabs allows the continuity to be maintained in the maintenance of tracks and provides a good surface for road vehicles.

## 3. BALLASTLESS TRACK STRUCTURE – ITS RELEVANCE FOR FREIGHT CORRIDORS ON INDIAN RAILWAYS

In the conventional ballasted track, impact forces of the running trains are absorbed by the elastic deformation of the ballast and the formation underneath, approximately 50% by each of them. In the ballast, the forces are absorbed by way of a change in the composite contact relationship among the ballast particles. This change is cumulative in nature. The major part of the track maintenance work consists of correcting the surface geometry by rebuilding the deformed ballast. Unless ballast is replaced by some other material, having truly elastic properties, no tangible reduction in the track maintenance inputs can be visualized. The formation underneath also does not behave in truly elastic manner and therefore track levels are required to be brought up by increased input of ballast. To make the permanent way, reasonably permanent in nature, ballastless track systems have been evolved.

In the case of ballastless track, the track rests on solid foundations either of rock or concrete slabs, which do not settle under traffic. The elastic characteristics of the ballasted track are simulated by providing suitably designed track assemblies in which elastomers play an important role. Such tracks do not require any maintenance except the replacement of elastic assembly components after serving for their lifetime. Adoption of ballastless track is particularly advantageous in tunnels and viaducts where concrete bed forms an integral part of the sub-structure. This provides considerable scope in the reduction of tunnel construction cost as ballastless track allows for the reduced tunnel diameter. Similar scope exists in the construction of ballastless track on viaducts.

### 3.1 Advantages and disadvantages of ballasted and ballastless track

| [illegible] Track | |
|---|---|
| **Advantages** | **Disadvantages** |
| [illegible] | [illegible] |
| [illegible] geometry | [illegible] times in tunnels ar |
| Availability of highly mechanized | [illegible] affected with p |
| [illegible] 50 years in tunnel | [illegible] required |
| [illegible] geometry | [illegible] both rails and whe |
| Reasonably good maintainability with | Deep ballast cushion means i |
| [illegible] to lateral and | [illegible] |
| [illegible] construction defects | [illegible] |
| | track machines causes enviro pollution |
| | Track deterioration relatively |

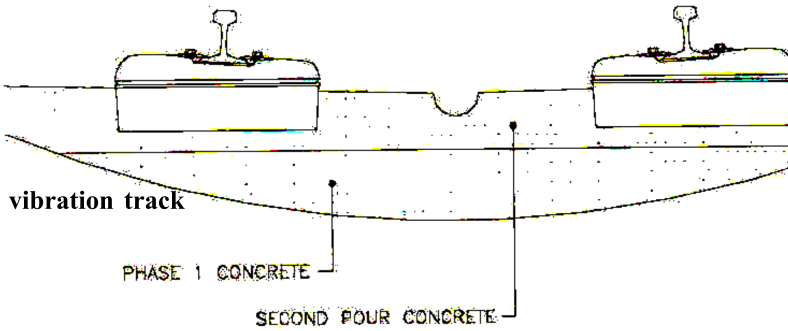
As in most of the cases disadvantages outweigh the advantages gained with ballastless track, its application on heavy haul lines has been very limited.

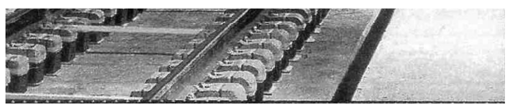
### 3.2 Types of Ballastless Track for possible use on Freight Corridors of Indian Railways

The following two types of ballastless track structures have potential for their possible use on freight corridors of Indian Railways. These are (i) low vibration track (LVT) system (Figures 3 & 4) and (ii) slab type ballastless track with cement maxphalt mix (Figure 5).

**Figure 3: The low vibration track (LVT) system**

**Figure 4: Low vibration track**

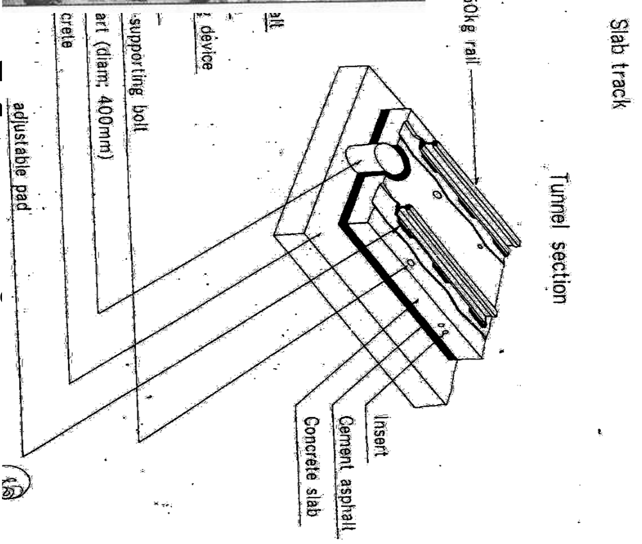


Note: Figure 3 dipicts the photographs and Figure 4 shows the cross-section of this type of ballastless track.

This type of track structure has been used in the Channel Tunnel. Similar track structure has also been adopted in tunnels in Switzerland.

**Figure 5: Slab type ballastless track with cement maxphalt mix as the main elastic medium - Japanese design**




This type of track structure has (Japan) and on some new lines in Italy

### 3.3 Other Un-conventional Tracks

Following three types of tra structures have also been projected by th promoters for use on heavy haul lines. Th experience has, however, been very limit

***Tubular track***

Figure 6 shows a typical tubul track. Limited trial with such a track h been made in South Africa on the railw line serving heavy mining area.

***Framed concrete sleepers***

This track structure has be developed by Technical University

GRAZ (Austria) under the guidance of Dr. Klaus Reizberger. Such a track is under trial in Austria for the last five years and has shown promising results.

***Ladder track system***

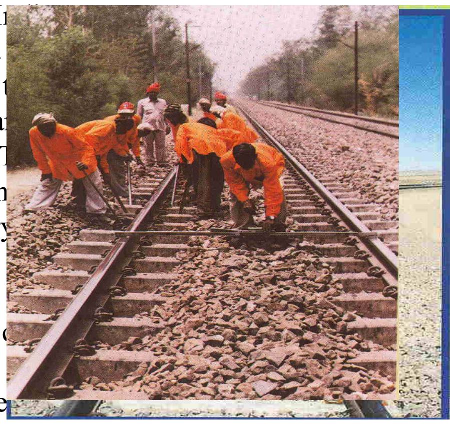
Figure 7 shows a typical ladder track system. This type of track structure is under trial in Japan. Tests carried out under 35 tonne axle load have shown positive results.

**Figure 7: Ladder track system**

## 4. TRACK MAINTENANCE AND MONITORING SYSTEMS FOR FREIGHT CORRIDORS

The track monitoring and maintenance systems for dedicated freight corridors on Indian Railways will have to be considerably different from what is prevalent on I Railway tracks. IR, in spite of having a fleet of modern sophisticated t maintenance machines, employs more tha hundred thousand unskilled gangmen. T gangmen carry their track mainten operations with century-old tools at very level of productivity (Figure 8).

**Figure 8**



A maintenance system for freight c the following objectives in view:

- The operational time allotte uld be brought down to the bare minimum. With the modern track structure of long welded rails and concrete sleepers, the frequency of track maintenance can be significantly reduced; track tamping machine being deployed after 3 to 5 years.
- The track work should be fully mechanized so that quality output can be achieved in the least possible working time.
- Track monitoring system should provide an objective assessment of track conditions. Most of track maintenance planning work should be based on the results obtained from the track monitoring system.
- All track maintenance works should be planned; emergency attention to tracks should be few and far between.

- All trackmen should be skilled workers, properly trained to carry out good quality work. Strenuous track work should be carried out with the help of small and bigger track machines.
- A good communication system should be the *sine qua non* of such a system so that full advantage is taken of the track maintenance windows and also for dealing with emergencies.

## 4.1 Prerequisite for an Efficient, Cost Effective, Mechanized, Track Maintenance System

For the successful working of a mechanized track maintenance system, it is essential that the track structure is made to a standard so that it does not require attention on day-to-day basis. Continuously welded rails on concrete sleepers, being laid on dedicated freight corridors, would satisfy this requirement.

Further, it is necessary that the locations, which normally require frequent attention, are given special treatment at the construction stage itself. These are:

- Locations where settlements could occur on account of poor soil conditions.
- Approaches to bridges and level crossings
- Curves and transitions
- Alignment at switches and crossings
- Erratic bends and kinks in rails, particularly at welded joints
- Drainage conditions, particularly in station yards and deep cuttings
- Bad welds with inadequate structural integrity or with poor geometry
- Switch expansion joints (SEJ) of LWR and breathing lengths
- Insulated joints
- Unauthorized track crossings and tresspassing

Adoption of the following measures is, therefore, considered essential for successful implementation of an efficient and economic mechanized maintenance system.

### *Formation stability*

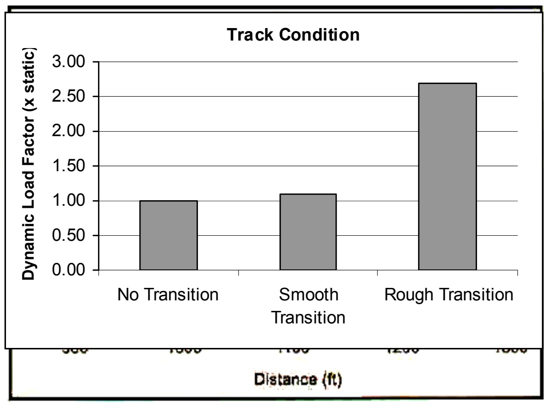
A fool-proof system to ensure formation stability must be adopted. Wherever the track geometry gets frequently disturbed, unstable formation may be the main cause of such deterioration. It is therefore necessary that at such locations cause of unstable formation is investigated and permanent measures taken at the earliest possible time. Sub-ballast/blanket may be provided where necessary.

### *Approaches to bridges and level crossings*

At bridge approaches, the track sub-structure changes from embankment and local subgrade to a bridge structure on open/well/pile foundation. The track on bridge may or may not have a ballast bed. In either case, the track on the bridge is typically much stiffer than the track at the bridge approaches. Also, the track at the bridge approaches can be softer than the surrounding track due to drainage issues or embankment settlement. Figure 9 shows a track stiffness profile (track modulus calculated from in-motion deflections measured using TTCI's Track Loading Vehicle).

As illustrated, the track-stiffness change from bridge to the approach track is very high, approximately by a factor of two (Figure 10). The bridge has a track modulus of above 10,000 lb/in/in, compared to about 5000 lb/in/in for the approach track. Abrupt change in track stiffness can lead to running-surface discontinuities that result in high dynamic loading and track degradation. Dynamic simulation modeling of the bridge approach condition suggests that the combination of stiffness change and running surface defects can generate dynamic loads of two to three times static loads at typical freight train speeds.

**Figure 9**




For the maintenance of track at the approaches to bridges, the provision of approach slabs on major bridges should certainly be of great help. Other measures, such as provision of granular back-fill material duly compacted, increased ballast cushion, and adoption of increased sleeper density on two to three rail lengths on either side of the bridges, should also be taken to improve maintainability.

On level crossings and approaches to level crossings, proper drainage and ballast conditions will improve their maintainability. The level crossing surface, which could facilitate ease of maintenance of both road surface and rail track, should be adopted. The possibility of adopting Bodan level crossing system, in which the load from the road vehicles is safely transferred to the rails, may be considered. These road units can be easily renewed and also removed, when required, for the working of the on-track tamping and other track machines.

***Curves***

Apart from laying the curves to the desired level of accuracy, it would be advantageous to increase the sleeper density on curves to the extent possible. This system is being adopted on the British Railways to achieve uniformity of attention on straight and curved tracks and thereby avoiding the need for more frequent deployment of heavy track machines on curves.

***Switches and crossings***

Thick web tongue rail switches, weldable CMS crossings should be adopted at turnouts, to permit the continuation of welded rails through station yards. It is essential that a high degree of accuracy is achieved in their layouts. It will be very difficult for the maintenance gangs to rectify badly-laid switches and crossings.

***Rail kinks***

Bends and kinks left in the rail at the time of initial linking can seldom be corrected by the maintenance gangs. Any amount of effort to eliminate such bends and kinks in rails, before laying, will bring handsome rewards. The right time to rectify such rails is before welding. Rails, which cannot be straightened, should be rejected outright.

***Track at station yards***

The track at the station yards is usually a source of bad spots, mainly on account of the poor drainage conditions. The station yards, usually laid on level ground or easy grades, do not permit natural flow of rain water. It is essential that the drainage system for each station is carefully analyzed, to ensure quick discharge of rain or flood water. It may be advisable to have paved drains, which can be easily cleaned, and have discharge outlets at as close intervals as possible. Underground drains should be provided where surface drains alone cannot meet the requirements.

***Rail welds***

All rail welds must conform to the tolerances laid down for that purpose. There should be ultrasonic testing of welds to ensure their integrity. All rails should also be ultrasonically tested before welding.

***Switch expansion joints (SEJ)***

The ballast and drainage condition at these joints must be given special attention. Efforts are to be made to continue the welded track at bridges and other restrictive locations to avoid the installation of SEJs to the extent possible. The possibility of having SEJs manufactured from full web rails should be explored. Such SEJs are quite strong and are usually adopted on heavy haul lines.

***Glued insulated joints***

The technology of glued insulated joints has considerably advanced on the world railways. The glued insulated joints are now available, which match the service life of the parent rails. Such joints may be used on the freight corridors.

***Fencing of railway tracks***

It will be desirable to have the track completely fenced so that public access to the track is avoided. Much of the track maintenance efforts on Indian Railways go into the rectification of damage caused by public loitering on the track, disturbing the ballast section and stealing the track components.

**4.2 Additional Measures to Improve Maintainability**

The following measures may be taken to obtain longer life from track components and improve maintainability of track

- Explosive hardening of CMS crossings. This will help in obtaining increased life from crossing assemblies under heavy axle load environments of freight corridors;
- Rail lubrication/rail grinding.

Many of the heavy haul railways of the world deploy rail lubrication and rail grinding equipment in a big way for the maintenance of rails. A judicious combination of lubrication and grinding is useful to get the maximum life out of rails and wheels. In case it is possible to limit the curvature to 2 degrees, there may not be much need for grinding and lubrication. Sharper curves would, however, need their deployment. It will be desirable to watch the wear pattern of the rails for a few years, before going in for grinding operations.

### 4.3 Structure of the Track Maintenance System

Assumptions made in deciding the structure of the track maintenance system:

- With the standard of construction adopted on dedicated freight corridors, the track formation will be stable and free from any formation-related problems. Whenever during service any bad formation patch is noticed, that will be suitably treated to avoid any increase of maintenance load on the system;
- Concrete sleeper track with full ballast cushion of good quality ballast and an efficient drainage system will place little demand on the track maintenance machinery;
- Continuously welded rail structure will be adopted throughout the railway line, including turnouts, curves and bridges to the extent possible. This will considerably reduce the maintenance effort needed for SEJs and the breathing lengths of LWR;
- Thermal stresses in CWR tracks will be monitored by employing modern stress-measuring equipment such as Rail Scan developed in Hungary. De-stressing of rails will be carried out as soon as the thermal stresses go beyond the acceptable range.
- Skilled category staff capable of handling and carrying out multi-disciplinary duties will be deployed on track maintenance works, after being properly trained for the jobs they would be required to handle. A proper training programme will need to be organized for enhancing their skills to the required level;
- A clear window of about three hours duration, during daylight hours, will be available for the working of the track maintenance machinery. In addition, passage will be allowed for the fast-moving track machinery, usually moving at the speeds of the goods train to move from one place of work to another;
- Every crossing station will be provided with a separate siding for the stabling of track machines and for the camping of track maintenance staff;
- A good level of communication will be available between the track maintenance units, permanent way staff and the centralized traffic control, to obtain maximum working time for the track maintenance work and also during emergencies;
- Accident relief vehicles will be suitably equipped so as not to put undue strain on the track maintenance units;
- Work of a seasonal nature, requiring comparatively large input of unskilled labour, will be carried out through the agency of contractors or by engaging unskilled manpower, directly. The works, which may

be farmed out to the contractors, are listed below: (list is indicative not exhaustive):

- Cutting/building up of the cess
- Attention to drains
- Cutting/pruning of trees
- De-weeding operations
- Overhauling of level crossings
- Carrying out formation rehabilitation works
- Removal of boulders, etc.
- Ballasting
- Shallow screening of ballast if warranted
- Labour for de-stressing of rails
- Gap adjustment on SWR, if any
- Assistance in clearing slips and restoration of track due to breaches, accidents and other emergencies
- Loading and unloading of materials

### 4.4 New Track Maintenance System: A Departure from the Traditional Norms

Track maintenance system on Indian Railways still hovers around the traditional sectional gangs having a beat of about 6-7 km. These gangs are a legacy of the past when there was enough justification for their deployment. Track in the olden days usually consisted of jointed rails, joined by fish plates, laid over wooden/iron sleepers, with rigid fastenings. Such tracks required frequent attention on day-to-day basis. Eighty per cent of track maintenance effort was devoted to the maintenance of rail joints. Rigid fastenings under high frequency vibrations often got loosened and at times fell off the sleepers. They were required to be checked and fixed in position quite frequently. The track structure was light. It was possible for the gangmen to lift/level and align the track with conventional tools such as beaters, iron rods, etc. The situation at present is far different. Modern continuously welded rails laid on concrete sleepers do not suffer from any of the above drawbacks. The structure is also so heavy that the gangmen can hardly rectify any defect with their conventional tools. The sectional gangs have, therefore, lost their relevance.

Social factors have also come up against the continuation of traditional gangs. Educated gangmen of today do not like to carry on their activities in the old hazardous manner. They would also like to be stationed near towns where they can enjoy better living conditions and send their children to schools. A new maintenance regime has been suggested taking into account the current ground realties. A three-tier system of maintenance is given in the following paragraphs for adoption.

## 4.5 Top Tier

Top tier will consist of heavy on-track machines to carry out the following track maintenance works:

- Lifting, levelling, tamping and aligning of plain track
- Lifting, levelling, tamping and aligning of turnouts
- Ballast distribution and profiling
- Track recording

***Periodical maintenance***

Periodical track maintenance will be carried out by heavy on-track machines. A group of the following six machines will form the maintenance unit to carry out tamping of track from one end to the other, attention to turnouts, picking up of the slacks, ballast profiling and monitoring of track.

- Plasser & Theurer plain line tamping machine Dumatic 09-32-CSM
- Dynamic track stabilizer
- Unimat compact multipurpose machine 08-3S, for the maintenance of turnouts and plain track
- Ballast distributing and profiling machine USP 2000 SWS
- Track recording car
- Oscillation measuring system (OMS)

The deployment of these machines will depend on the general stability of track, rainfall and other environmental conditions. The track recording and oscillation monitoring results will determine the periodicity of deployment. The Unimat track tamping machine will, in addition to the tamping of turnouts, attend to the slacks, all over the system as and when they develop. Dynamic track stabilizer will follow the tamping machines to ensure uniform settlement of track after the lifting and levelling operation. Ballast distribution may be needed in advance of the working of tamping machines and ballast profiling will have to follow the tamping operation. USP 2000 SWS will be utilized for this purpose.

Track recording/oscillation measurement will be carried out at regular intervals to determine the health of the track and for planning the track maintenance work.

## 4.6 Middle Tier

***Mobile multipurpose maintenance gangs***

Each of the mobile multipurpose maintenance gangs will be provided with a self-propelled rail-mounted gang lorry, which can carry six to seven track maintenance personnel along with the equipment for carrying out its activities.

It will have a hoist of about one tonne lifting capacity for the loading and unloading of track components and equipment. Multipurpose gang will be headed by PWI (M) and will have a jurisdiction of 70 to 80 km i.e. each Assistant Engineer will have two such multipurpose maintenance gangs (MMG). The MMG will carry out the following jobs:

- Repair to rail/weld fracture
- Reconditioning of switches and crossing
- Adjustment of SEJs
- Spot renewals of rails, sleepers and other track components
- De-stressing of LWR
- Tamping of a few sleepers if provided with off-track tampers
- Any other work incidental to track maintenance

***Equipment***

MMG will be provided with the following equipment:

- Portable generator
- Rail cutter
- Rail driller
- Lifting and aligning track jacks of five to ten tonne capacity
- One set of thermit welding equipment, including weld trimmer and rail grinder.
- Equipment for reconditioning of switches and crossings
- Certain special equipment such as:
  - Rail tensor
  - Sleeper changer
  - Rail closures
  - Rail benders, rail adjuster, track lifting and slewing equipment

On a day-to-day basis, only the equipment that would be needed will be carried to the site of work.

***Strength of the MMG and its composition***

Each MMG will have a crew of five persons excluding the PWI (M), who will be overall in-charge of the unit. The crew will consist of:

| | |
|---|---|
| – Motorman-cum-track man | 1 |
| – Motor mechanic | 1 |
| – Welder-cum-blacksmith | 1 |
| – Electrical fitter | 1 |
| – Mechanical fitter | 1 |

All the crew members as a group, will be trained to carry out the track jobs jointly. For example, while carrying out welding of rails, the welder will be assisted by the other four crew members in carrying out the welding operation. PWI (M) in charge of the gang will be trained to work as motor man to drive the gang lorry, if required.

### 4.7 Base Tier

***Inspection and monitoring units***

Base tier will be manned by the Sectional Permanent Way Inspector, who will be responsible for the safety of railway operation in his section, including the protection of track during emergencies. He will be provided with a self-propelled rail-mounted gang lorry with a capacity of carrying eight to nine workers. He will carry out detailed inspection of track. He will also be suitably trained in ultrasonic testing of rails and welds. He will be assisted by two trackmen for performing his duties. He will carry out the following inspections:

- Cover the whole section by his gang lorry once a week.
- Foot by foot inspection of all his length once in three month (1/3rd of the section to be covered every month).
- Foot plate inspection on the train locomotives once a week.
- Inspect points and crossings, bridges, level crossings, curves at intervals laid down in the maintenance manual and record his observations on the prescribed proforma.
- Supervise and record the work being executed by contract labour in his section and arrange payments. If required, he will use his gang lorry for the transport of labour engaged in the works of a seasonal nature.
- Sectional Permanent Way Inspector will be provided with proper equipment for carrying out inspection and monitoring duties. A list of such equipment is placed at Annexure 2.

### 4.8 Identification of Track Defects

Data regarding location of track defects will be obtained from the following sources:

- Output from the track recording car, which will cover the whole sections once a month. The standards for the construction and maintenance of freight lines as laid down by the British Railways are given in Tables A & B (Annexure 3), which can be taken as a guide till freight corridors establish their own standards;
- Oscillation Monitoring System (OMS) results, which will be covering the total length once a week, possibly placed on a nominated locomotive. In the case of Indian Railways all peaks above 0.20g are

taken into account. The classification/acceptable standard in terms of peaks/km for routes having a maximum speed of 110 kmph are as under:

| | Very good | Good | Average |
|---|---|---|---|
| Peaks/km | 1.5 | 1.5-3 | 3 |

Any stretch of track having more than 10 (ten) peaks/km is taken as a bad stretch requiring attention. The peaks exceeding 0.3g are specially marked for immediate attention. These norms can be used in the initial stages.

- Ultrasonic rail/weld flaw detections carried out by the sectional PWIs.
- Data collected by the sectional PWIs, Assistant Engineers and other officials during their inspection. Data loggers will be provided to the inspecting officials for recording the track defects and also for periodical inspection of points and crossings, SEJs, curves and other important locations.

### 4.9 Monthly Plan for Track Maintenance Operations

Based on the track defects data and taking into account the threshold values laid down for various track geometry parameters/track structures, a monthly work plan will be drawn for carrying out the track maintenance operations for all the three tiers.

While the heavy on-track machines will attend to long stretches requiring attention, the middle tier will mostly be engaged in the rectification of rail/weld fractures and in the maintenance/replacement of other track components, including carrying out of new thermit welds and reconditioning of switches and crossings.

### 4.10 Allotment of Working Days

In a six-day working week, generally four to five days will be allotted for carrying out the planned maintenance works, based on the track recording results/ ultrasonic rail flaw detection results, and the remaining one or two days will be utilised for attending to the bad spots needing urgent attention identified during the weekly run of the OMS, and by the inspecting officials.

### 4.11 Need for an Interactive Software

For the efficient utilization of the track maintenance men and machinery, an interactive software can be developed, which may have the following constituents:

- A data bank of the track structure and other important features of the freight corridors network.
- Periodic track geometry recording/OMS recording and ultrasonic testing and logging their output in the system. In addition, input will

also be obtained from the inspections carried out by various officials.

- Laying down threshold values to decide the track locations/track components requiring attention.
- Planning and execution of track works at the location identified as mentioned above and logging the inputs made in the system.
- Build up data for the men and material inputs entering into the maintenance of track and analyse the efficacy of the various track maintenance operations.
- Build track geometry/track component degradation models for long-term planning of track works to have a reasonable forecast for the men, material and financial input required on long-term basis.

### 4.12 Track Maintenance Manual

It will be necessary to have a separate track maintenance manual for the freight corridors, which may incorporate:

- All details about track structures and its components.
- Track maintenance standards/schedule of dimensions.
- Track inspections to be carried out at various levels. Proforma to be filled in.
- Duties and responsibilities of the trackmen at various levels.
- Action during breaches and accidents.
- Working of the various types of track machines and their upkeep and maintenance.
- Bridges and their maintenance.
- Turnouts and their inspection and maintenance.

### 4.13 Track Maintenance Equipment/Inspection Car available at the District Level

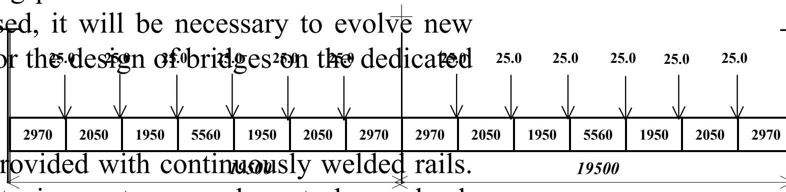
Following is the list of track maintenance equipment/inspection vehicles available in a district:

- Robel's powered gangers trolley 52.22 for four MMG gangs — 4 Nos.
- Robel's power inspection cars for accommodating 6 to 8 persons for sectional PWIs and Assistant Engineers — 6 Nos.
- Crance mounted flat BFR type rolling stock for transport distribution of rails, etc. — 1 No.
- Road trucks for transporting men and material including fuel and consumable stores for track machines, one for each Assistant Engineer and one at the district level — 3 Nos.
- Road inspection vehicles for district engineers and assistant engineers — 3 Nos.

## 5. BRIDGES AND THEIR MAINTENANCE

Indian Railways bridges have been designed to meet specific bridge loading standards. The latest among them is a modified broad guage standard (MBG) finalised in 1987. These loading standards indicate the maximum axle loads, the loading pattern of the locomotive wheels and the trailing loads. MBG 1987, prescribes an axle load of 25 tonne and a train loading density of 8.25 tonne per metre as may be seen from the following loading diagram (Figure 11).

**Figure 11: Loading standards – MBG-1987**




Obviously, these loading standards cannot be adopted for the design of the bridges on new freight corridors. Apart from the axle loads, the tractive effort of the locomotives and the braking resistance of trains, also play a significant role in the design of bridges. Once the hauling pattern of the locomotive is decided and the design of rolling stock is finalised, it will be necessary to evolve new bridge loading standards, to be adopted for the design of bridges on the dedicated freight corridors.

Track on bridges will have to be provided with continuously welded rails. In some cases, special rail to sleeper fastening system may have to be evolved. Track on long bridges may have to be isolated from the adjoining tracks by providing specially designed switch expansion joints with a longer range of expansion and contraction. Such SEJs are now commonly available in the world market. The new Yamuna bridge constructed by the Delhi Metro Rail Corporation, has a switch expansion joint with a range of over 500 mm.

### 5.1 Territorial Jurisdiction and Administrative Set-up

A section PWI will have a territorial jurisdiction of about 70 to 80 km. An Assistant Engineer will have two section PWIs under him. A District Engineer will have a jurisdiction of 300 to 400 km, exercising control and provide guidance to two Assistant Engineers.

Every District Engineer will have a track superintendent who will maintain a workshop for the upkeep and maintenance of small-track machines and also for providing local support for the working of heavy on-track equipment. He will also maintain a store of essential items of permanent way to meet emergency requirements.

### 5.2 Advantages of the New Maintenance System

Following advantages would accrue with the adoption of the new maintenance system:

- It will be cost-effective – Konkan Railway which adopted a similar maintenance system reported a saving of 30 to 40 per cent when compared with the conventional system;
- With higher level of supervision, the quality of track work will be much better. Rail welds will have a longer life. Track geometry deteriorations will reduce;
- Gangmen will be saved from hazardous back-breaking work. Qualified skilled workers will get attracted to the permanent way maintenance jobs;
- Track emergencies will reduce. All track works will be better planned and executed. In case of emergency, restoration work will be faster and of a better standard;
- With mechanical handling of track components there will be less damage to the components and they will have longer service life in tracks;
- The trackmen in general will have a better quality of life and will take pride in their profession.

## 6. CONCLUSIONS

- Heavy haul association has brought out the track structure models that can be adopted for various levels of heavy haul operation. The model best suited to Indian environment can be selected.
- For dedicated freight corridors, it should be possible to evolve a track structure similar to the one already in use on long welded rail track of Indian Railways, with suitable modifications to meet the requirement of higher axle loads.
- In finalizing the alignment of new freight corridors, it will help if the curvatures are limited to 2 degrees and the grades are not steeper than 1 in 200.
- Continuously welded rails must be adopted all along the corridor. Welding of rails must be continued through turnouts and on bridges, to the extent possible. The turnouts and the track structure on bridges need to be suitably designed to meet the LWR requirement.

- The track all along the new freight corridors should be fenced. A service road may be provided, if possible, to have an easy access to the track, at all times, without interfering with the railway operation.
- Rail grinding/rail lubrication may be carried out after proper study of the wear pattern of the rails.
- In tunnels and on viaducts, the possibility of use of ballastless track structure needs to be explored.
- For the successful implementation of an efficient cost-effective mechanized track maintenance system, it is necessary that the track locations which normally required frequent retention are given special treatment at the construction stage itself.
- For mechanized maintenance of the tracks, certain minimum requirement with respect to the quality of track, availability of windows for adequate maintenance, deployment of skilled category staff, a good level of communication network, etc. have to be met.
- All work of a seasonal nature requiring large inputs of unskilled labour may be farmed out to contractors.
- A three-tier system of maintenance has been proposed for adoption for the freight corridors. This consists of (a) top tier of heavy on-track machines; (b) middle tier of mobile multipurpose gangs; and (c) base tier of inspection and monitoring units.
- All planning for track maintenance works must be based on the results obtained from the track recording cars/oscillation monitoring system and on the inspection notes taken by officials at various levels.
- There is need for developing a software for effective implementation of track management system. Such a system will help in the proper planning of track maintenance and renewal works.
- It will be advantageous if a track maintenance manual is prepared. This should incorporate all the essential details about track structure, provide guidance for maintenance, and lay down duties and responsibilities of trackmen at various levels.
- New bridge-loading standards shall have to be evolved for the design of bridges, taking into account the higher axle loads, increased tractive effort, braking resistance and other operating characteristics. All new bridges will be designed and constructed to the newly evolved bridge loading standards.
- The new track maintenance system will be more effective, economical and will provide a better working environment to the trackmen.

*Annexure 1*

**Table 1: Traffic Mix: Dedicated HH Axle Load: 30-34**
**Terrain: <875 meter radius Traffic Density: 50+ MGT**

**Table 2: Traffic Mix: Dedicated HH Axle Load: 30-34**
**Terrain: <875 meter radius Traffic Density: 30-49 MGT**

| Traffic Density | Rail | | Crossties | Fasteners | Ballast | M/L Switch & Crossing Work | Geometry Inspection | Flaw Inspection |
|---|---|---|---|---|---|---|---|---|
| | Type | Weight | | | | | | |
| 30-40 MGT | Standard tangent Premium in curves | 136 RE or UIC 60 | Prem: Wood or concrete monobloc nominal spacing 500 mm wood 600 mm concrete | Elastic – curves Elastic or spikes – tangent | 300 mm select crushed rock + 200 mm sub-ballast 300 mm shoulders | Premium rail Fixed point premium frog | 46 months with profile monitoring | 4month intervals |

| Wheels | | Bogies | Profiles & Maintenance | | Lubrication Wheel/Rail | Wear Limits |
|---|---|---|---|---|---|---|
| Type | Profile | | Wheel | Rail | | |
| Prem HT curve Plate AAR Class C 900 mm | AAR 1B or equivalent | Improved standard 3-piece or self-steering | Limit hollow wear to 3mm | Periodic grind to remove corrugation and surface damage and to treat rail joints (material flow) | Curves: Gauge face U<0.25-0.30 Rail head U<0.35-0.40 U<0.10-0.15 B-R Tangent: rail head U>0.35 | Measure frequently to ensure optimum … |

**Table 3: Traffic Mix: Dedicated HH Axle Load: 30-34**
**Terrain: <875 meter radius Traffic Density: 20-29 MGT**

| Traffic Density | Rail | | Crossties | Fasteners | Ballast | M/L Switch & Crossing Work | Geometry Inspection |
|---|---|---|---|---|---|---|---|
| | Type | Weight | | | | | |
| >50 MGT | Standard tangent Premium in curves | 136 RE or UIC 60 | Prem: Wood or concrete monobloc nominal spacing 500 mm wood 600 mm concrete | Elastic – curves Elastic or spikes – tangent | 300 mm select crushed rock + 200 mm sub-ballast 300 mm shoulders | Premium rail Fixed point premium frog | 3-6 m… with p… monito… |

| Wheels | | Bogies | Profiles & Maintenance | | Lubrication Wheel/Rail |
|---|---|---|---|---|---|
| Type | Profile | | Wheel | Rail | |
| Prem HT curve Plate AAR Class C 900 mm | Specifically designed (see Part 2 Section 2.5) | Improved standard 3-piece or self-steering | Limit hollow wear to 2 mm | Periodic grind to remove corrugation and surface damage and to treat rail joints (material flow) | Curves: Gauge face U<0.25-0.30 Rail head U<0.35-0.40 U<0.10-0.15 L-R Tan… |

| Traffic Density | Rail | | Crossties | Fasteners | Ballast | M/L Switch & Crossing Work | Geometry Inspection |
|---|---|---|---|---|---|---|---|
| | Type | Weight | | | | | |
| 20-29 MGT | Standard tangent Premium in curves | 136 RE or UIC 60 | Prem: Wood or concrete monobloc nominal spacing 500 mm wood 600 mm concrete | Elastic – curves Elastic or spikes – tangent | 250mm select crushed rock + 100 mm sub-ballast 300 mm shoulders | Premium rail Tangential, spring point premium frog | 6 months profile monitoring |

| Wheels | | Bogies | Profiles & Maintenance | | Lubrication Wheel/Rail |
|---|---|---|---|---|---|
| Type | Profile | | Wheel | Rail | |
| Prem HT … AAR Class C … | [illegible] | Improved standard 3-piece or self-steering | Limit hollow wear to [illegible] mm | Periodic grind to remove corrugation and surface damage and to treat rail joints (material flow) | Curves: Gauge face U<0.25-0.30 Rail head U<0.35-0.40 U<0.10-0.15 L-R Tangent: rail head U>0.35 |

***Annexure 2***

1. Inspection, monitoring and protection equipment
   - Gauge cum cross level
   - Stepped feeler gauge
   - Steel scale 15 cm
   - Steel tape 3, 15 & 50 m
   - Nylon cord 25 m
   - Curve measuring equipment
   - Fleximeter 2 nos.
   - Clearance gauge for level crossing
   - Clearance gauge for points and crossings
   - Wear measuring gauge
   - Thermometer
   - Inspection hammer
   - Magnifying glass and mirror
   - Hand signal flags (two red and one green)
   - Battery operated hand signal lamps
   - Banner flag
   - Detonators 12 nos.
   - Flare signal (Fusees) 2 nos.

2. Other equipment
   - Telephone
   - Whistle
   - First Aid Box

3. Maintenance tools
   - Spanner – one
   - Hammer/Pandrol puller – one
   - Non-infringing hydraulic jacks – three
   - Beaters – three
   - Ballast fork – three
   - Basket – three

4. Emergency track material
   - Joggled fish plates
   - Rail clamp
   - Rail closures upto 30 cm long
   - Wooden blocks (8 nos.)

***Annexure 3***

**Table A: Geometrical Standards for Freight Lines**
**All measurements quoted in mm**

***Manual Standards: Construction***

| **Category** | **F1** | **F3** | **F5** |
|---|---|---|---|
| *TWIST on 3m* | | | |
| Design | 7.5 (1:400) | 7.5 (1:400) | 7.5 (1:400) |
| Acceptance | 10 (1:300) | 10 (1:300) | 10 (1:300) |
| *Gauge* | | | |
| Deviation from 1432 mm (or 1435mm) | | | |
| Acceptance | – 2, + 10 | – 2, + 10 | – 2, + 10 |
| *Top* | | | |
| Maximum variation from design position | | | |
| Acceptance | + 10, – 25 | + 10, – 25 | + 10, – 25 |

***Manual Standards: Maintenance***

| **Category** | **F1** | **F3** | **F5** |
|---|---|---|---|
| *TWIST on 3m* | | | |
| Immediate Action | 15 (1:200) | 15 (1:200) | 15 (1:200) |
| Programme Work | 12 (1:240) | 12 (1:240) | 12 (1:240) |
| *Alignment* | | | |
| Maximum offset 20m chord | | | |
| Deviation from design | | | |
| Immediate Action | 19 | 24 | 32 |
| Programme Work | 12 | 15 | 20 |
| *Top* | | | |
| Maximum offset 20m chord | | | |
| Immediate Action | 21 | 26 | 35 |
| Programme Work | 13 | 16 | 22 |

*Target response times to be achieved*

| | |
|---|---|
| Immediate Action: | 36 hours |
| Programme Work: | 7 days |

**Table B: Recording Car Standards: Maintenance**
**All measurements quoted in mm**

| Category | F1 | F3 | F5 |
|---|---|---|---|
| ***Vertical*** | | | |
| Max SD | 5.7 | 7.3 | 9.7 |
| 90% SD | 3.5 | 4.4 | 5.9 |
| 50% SD | 2.1 | 2.6 | 3.5 |
| ***Alignment*** | | | |
| Max SD | 5.5 | 6.9 | 9.2 |
| 90% SD | 3.3 | 4.2 | 5.6 |
| 50% SD | 2.0 | 2.5 | 3.3 |
| ***L1 exceedences*** | | | |
| Top | 12 | 15 | 21 |
| Alignment | 11 | 13 | 18 |
| TWIST 3m | 10 (1:300) | 10 (1:300) | 10 (1:300) |
| Crosslevel | 10 | 12 | 15 |
| Gauge | 17 | 21 | 25 |
| ***L2 exceedences*** | | | |
| TOP | 20 | 25 | 34 |
| Alignment | 17 | 22 | 28 |
| TWIST 3m | 15 (1:200) | 15 (1:200) | 15 (1:200) |
| Crosslevel | 15 | 17 | 20 |
| Gauge | 22 | 26 | 30 |

Note: F1, F3, F5 are three categories in which freight lines are divided. The maintenance at F5 category carries the highest risk and F1 the lowest.

L1 denotes tolerance beyond which a "Level 1" exceedence is reported. At this level remedial work is to be planned on a routine basis.

L2 denotes tolerance beyond which a "Level 2" exceedence is reported. At this level attention is mandatory on a basis of urgency.

# WHEEL AND RAIL PERFORMANCE

***Sergey M. Zakharov****

*This paper describes the prevalent wheel and rail defects related to rail/wheel interface on heavy haul lines, conventional and advanced materials that are used for rails and wheels, their chemical composition and mechanical properties. Mechanisms of rolling contact giving rise to wheel/rail defects are presented. Wear modes, influence of wheel and rail hardness and its ratio are described. Finally, conclusions and recommendations on stress and wear related factors, thermo mechanical damages as well as wheel materials requirements are given.*

## 1. INTRODUCTION

Experience shows that wheel and rail performance is an important issue for heavy haul railways. No wonder that this subject became one of the themes of Guidelines to Best Practices for Heavy Haul Railway Operations[1]. In particular, it is recognized that the most effective way to provide proper functioning and reliability, extend life and maintenance cycles and thus obtain cost-effective operation of wheels and rails is by treating wheel/rail interface as a system.

However, this subject is so vast that it is not possible to be covered in one paper. Besides, there are a variety of operating conditions among heavy haul railroads. There may be dedicated lines or lines with combined freight and passenger operation. They may differ in traffic level, axle loads, annual tonnage, vehicle design, etc.

In the light of the wide-spectrum conditions and complexity of the wheel/rail issues that are part of vehicle/track system, this paper addresses only the first level of mechanisms associated with contact mechanics and wheel and rail materials.

## 2. RAIL AND WHEEL DEFECTS

### 2.1 Rail Defects

Though types of defects are generally described in catalogues, field manuals of railways administrations and other publications, their distribution and range differs considerably from one heavy haul railroad to another. For instance, rail

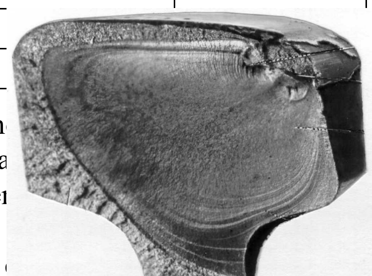
* All Russian Railway Research Institute, 10,3-d Mytishchinskaya, Moscow,129851, Russia.

defects distribution and ranging in North American railways (during 1990-1995) is the following[2]: transverse defects (25%), field and plant welds defects (25%), bolt-hole (15%), vertically split head (10%), horizontally split head (5%), side wear, engine burns, corrugation (20%).

Rail wear replacement criteria is 30-35% loss of the rail head, rail life in curves, in tangent – 1.3 MGT and in curves – from 300 to 1000 MGT. Rail defects distribution in Russian Railways (in 2000) is : RCF of all types (44%), wear and crushed head (24%), transverse cracks (16%). Average rail life in curve and in tangent is about 700 MGT. Corresponding wheel defects distribution in both railway systems is given in Table 1.

**Table 1: Main freight cars wheel defects**

| **Defects** | **North America (1999)** | **Russia (2000)** |
|---|---|---|
| RCF of all types | 24.6 | 35.5 |
| High flange + thin rim | 20.2 | |
| Thin flange | 6.8 | 24.4 |
| Slid flat | 8.3 | 21.5 |
| Thermal cracks | | |
| Build up | | |



It is necessary to comment on th… ditions of both railway systems which are average a… passenger traffic for the Russian railways, differe… systems.

Rail and wheel defects and their … atalogues and in field manuals of many publications … The defects characteristics for heavy haul lines were presented in the IHHA Guidelines to best practices[1].

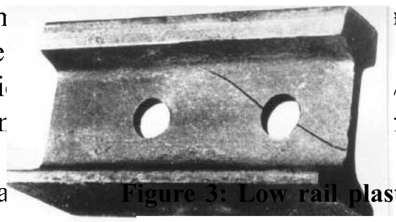
**Figure 1: Rail transverse defect resulting from gauge shelling**

Shelling is a rolling contact fatigue defect that is characteristic of heavy haul railways. It initiates under subsurface predominantly at stringers of oxide inclusions in the rail steel under action of tangential stresses. The critical metallurgical factors contributing to initiation of shells are the oxide volume fraction in percent, the stringer's length and the Brinel hardness (HB). Shells may turn to transverse defect often resulting in rail fracture (Figure 1).

Rail weld defects are becoming more and more widespread for heavy haul operation. Problems arising from rail welding may contribute to about 25% of rail failures. IHHA member countries use various combinations of welding technologies for plant and field welding. North American Railways predominantly use electrical flash-butt for plant welding, and thermite for field welding because of a much lower cost in the field compared with mobile flash-butt welding equipment. To avoid reduction of hardness of the rail in the weld zone which results in dip joint failure, thermal treatment technology is used.

The typical bolthole failure has cracks that propagate along a plane at 45 degree to the vertical plane (Figure 2). This failure is associated with web shear stress caused by battered rail joints and the stress concentration at boltholes caused by poor drilling and beveling.

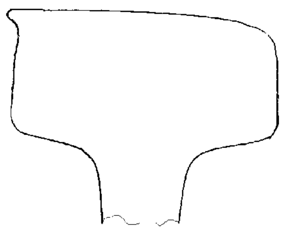
**Figure 2: Rail bolthole defect**



*Plastic flow*: There are three major regions of intensive plastic flow on the high and low rails. Sometimes under heavy cars the low railhead is crushed. The field side of the low rail can suffer fron ading of the low rail (Figure 3) and inadequate the rail loading conditions encountered in servi ves may occur because of an imbalance betweer n.

Sometimes, low rail crushing ma because of track gauge widening when the low rail is subjected to a combined high stress and lateral traction.

**Figure 3: Low rail plastic flow**



## 2.2 Wheel Defects

Rolling contact fatigue (RCF) is a predominant type of wheel defect characteristic of heavy haul railways. For heavy haul railways operating under very heavy axle load (more than 30 tonnes) hollow wheel wear is an issue. It is known that[5] wheel RCF defects are of three types: wheel spalling, tread checking and shelling. Wheel spalling is a defect of thermomechanical origin when a wheel experiences gross sliding on the rail during braking. Large frictional energy is generated instantaneously, causing the wheel surface temperature to rise above austanization limits. Heating is followed by rapid cooling resulting in martensite formation which further fractures under wheel/rail loading cycles (Figure 4).

**Figure 4: Thermo mechanical damage**

Thickness of martensite layers varied between 0.1-0.5 mm. Formation of martensite layers resulted in residual stresses in the surface layers with the maximum at the boundary of light gray spots. Wheel/rail contact stresses considering these residual stresses may be noticeably higher than the yield shear stress.

*Tread checks*: Micro cracks develop at a small angle to the surface resulting in fine angled cracks developing on the wheel thread. Fine cracks then join forming spalls on the wheel surface (Figure 5). Metallographic analysis has shown high degree of deformation in the surface layers.

**Figure 5: Thread checks on the wheel thread surface**

Deep shell-like defects with characterizing fatigue rings predominantly parallel to the tread surface with metal break out (Figure 6) are the result of the normal and shear stresses caused by the wheel rolling on the rail. Usually, c initiated predominantly at non-metallic in The shell depth is about 4-5 mm.

*Wheel/rail wear:* There are two m of wheel and rail wear. One is top of wheel tread. It should be noted tha hollowing is an issue for heavy hau especially operating under high axle loa.

**Figure 6: Wheel tread shelling**

Rail gauge side wear and flange wear is a serious issue in unlubricated conditions. Wear modes are described in the following sections.

## 3. WHEEL AND RAIL MATERIALS

### 3.1 Chemical Composition and Mechanical Properties

Rail and wheel materials should possess high wear resistance, high resistance to plastic deformation and rolling contact fatigue RCF and should be made of clean steel to avoid internal defects, obtain sufficient toughness to ensure low defect development rate, rail weldability, reduced sensitivity to martensite formation, resistance to thermal fatigue defects, favorable residual stresses distribution.

*Chemical composition of rails (weight %)*: C – 0.72-0.82; Mn – 0.80-1.10; Si – 0.10-0.60; S – 0.037 max; P-0.035; Cr – 0.25-0.50; V – 0.03 max; Ni- 0.25 max; Mo- 0.10 max. This is an example of chemical composition of general categories of rails used in North America. Standard rails are hot bed cooled, intermediate are alloyed, premium are fully heat treated, super premium – head hardened and micro-alloyed.

*Chemical composition (weight %) of class C wheels*: C – 0.67 – 0.77; Mn-0.60-0.85; P-0.05 max; S-0.05 max; 0.15 max. Wheels are heat treated - controlled cooled.

***Wheel and Rail materials' mechanical properties***

Rails and wheels are metallurgically similar. Both use high carbon steels which have pearlitic or near-pearlitic structure. The heat-treated rails are made from rail steel that contains carbon in an amount close to the eutectoid composition which leads to a microstructure of pearlite. The fine pearlitic structure is promoted by the addition of alloying elements, such as chromium, molybdenum, and vanadium, or by accelerated cooling.

The mechanical properties of rails and wheels are evaluated by yield, tensile and fatigue strength, hardness and fracture toughness. Yield strength is an indication of the material's plastic flow characteristics and work hardening. Work hardening is an increase of hardness of interacting surface layers compared with the initial hardness after multiple wheel/rail interactions in operation. Tensile and contact fatigue strength is an indication of fatigue resistance of the materials that are characterized by laboratory tests. Fracture toughness governs the ability of steel to resist propagation of brittle cracks from rolling contact fatigue and other fatigue defects.

(i) Mechanical properties of rails used for heavy haul operation:

| | |
|---|---|
| Yield strength | 640-800 MPa |
| Tensile strength | 1080-1176 MPa |
| Elongation | 9-10% |
| Hardness (surface) | HB 320-390. |

(ii) Mechanical properties of wheels:

| | |
|---|---|
| Yield strength | 696-800 MPa |
| Tensile strength | 960-1190 MPa |
| Hardness | HB 280-360 |

The material quality of rails and wheels significantly affects their resistance to wear, rolling contact fatigue, fatigue, and plastic flow. Improvement in rail/wheel material quality may significantly increase the range of allowable contact stresses.

Many material characteristics are in conflict with one another. For instance, hardness and fracture toughness are inversely related. There is a set of material property characteristics, which the material should possess to meet operating requirements A set of wheel/rail interaction simulated laboratory tests help to establish these characteristics: contact fatigue tests, wear resistance tests, static and cyclic resistance to crack propagation tests, and rail static, cyclic and impact tests. The values selected after this set of tests have to be validated in field-simulated tests. Only after validation are they used in revenue service for pilot testing

## 3.2 Role of Material Microstructure, Material Cleanliness

Contact fatigue strength of rail and wheel highly depends on steel microstructure, that is contamination of steel with oxides, dispersity and shape of carbides, austenite grain size, martensite and iron carbide microstructure, macroheterogeneity of steel microstructure. homogeneity of their structure. Structural heterogeneity, which may appear in a process of thermal treatment can be classified as the zonal macroheterogeneity and microheterogeneity. Steels with mixed structure have lower contact fatigue to compare with steels having homogeneous structure The presence of even small quantity of troostite in the steel with the structure of low-tempered martensite decreasing its contact fatigue strength[6].

Another influencing factor is steel cleanliness that is judged based on the amount and distribution of inclusions. Hard inclusions or inclusions stringers (alumina-silicate Al2 O3- Si O2) contribute to the initiation of sub-surface rolling contact fatigue. Stringers of inclusions are strongly implicated in the formation of vertical split head defects and in the development of deep-seated shells that lead to transverse defects.

There exists a variety of different types of material imperfections in wheels/rails. These are inclusions of various origin, voids, pores and material anisotropy. Defects may indicate locally poor quality of material in the vicinity of these defects which causes crack initiation. Close to defect stress may increase and local plastic deformation may occur giving rise to residual stresses. In compressive loading, these stresses may be tensile and may decrease fatigue resistance.

It is likely that only subsurface defects will affect the fatigue behavior of wheels or rails, since defects have only a minor influence on the macroscopic plastic deformation that governs surface induced fatigue, i.e in wheel material containing defects RCF defects may be initiated at the depth up to 25 mm. If there are no macroscopic defects in the wheel material, RCF defects may initiate at 3-5 mm below the surface:

*Rail weldability*: Performance of rail welds is a critical aspect of heavy haul operation. There are two approaches to rail material selection in relation to rail weld failures: developing new rail materials considering their welding ability and adjusting welding technology to developed rail materials. To provide welding quality, it is necessary to consider rail welding as mass-line production. Residual stresses resulting from welding could be decreased by improved welding technology and post welding heat treatment. Besides, it is important to provide stability of technology through technological methods and quality control (ultrasonic, radiographic).

## 3.3 Advanced Rail Materials

Advanced rail materials are produced by increasing steel purity in respect of non-metallic inclusions by means of vacuum degassing, deoxidation, treatment outside furnace. Increasing rail hardness to HB 400 is by heat treatment and alloying.

Increasing wear resistance is achieved by decreasing distances between cementite lamellas in pearlite to about 0,1ì m. Rail manufacturers have developed hypereutectoid rail steel by increasing carbon content in steel to hyper eutectoid level (C=0,85-0,90 %). The idea is to incorporate Fe3C in the pearlite lamellae thus increase the share of cementite in the pearlite structure. Mechanical properties of one of the type of hypereutectoid steel are: tensile strength 1340 MPa, 0.2 proof stress is 860 MPa and elongation 10%. Wear resistance of HE steels are improved by 20% to compare with conventional heat treated rail steel. They possess increased RCF resistance, hardness up to 400 HB. Weldability of HE steel are comparable to high strength heat treated rails.

As many rail grades are produced by rail manufacturers, guidelines are required to better utilize these grades. Rail grades are selected basing on two operational parameters – axle load, track curve radius. In a range of the axle load from 20 to 30 tonnes, the following rail grades are recommended[1,7]:

**Table 2: Strategy of rail selection**

| Axle load (tonnes) | Grades, hardness for track curve radius, | | |
|---|---|---|---|
| | ≤800 | >800 | |
| 25-30 | Head hardened, alloyed, HB370 | Head hardened, HB350 or HB 370 alloyd | Star… HB… |
| 30-35 | HE, HB400 | Head hardened, alloyed, HB370 | Hea… HB |

Work is continuing on developing rail steels with other than pearlitic structure. Among two possible ways of structural changing (martensite and bainite) the bainitic structure seems to be more preferable. Development of the new low-alloy rail steels with bainitic structure makes it possible to increase strength of the rail steel and simultaneously to decrease the carbon content, which in turn will produce positive effect on the rail resistance to thermomechanical damages.

Mechanical properties of bainitic steel rails:

| | |
|---|---|
| Ultimate strength | 1420-1480 MPa |
| Hardness | HB 410 - 430 |
| Impact strength, $KSU_{+20}$ | 0.40-0.45 $MJ/m^2$ |
| Elongation | 12-14% |

*Wheel advanced materials*: Further increasing pearlitic wheel steel cleanliness, application of rim quenching technology to create compressive residual stress in rim and eliminate thermal failures and at the same time increase hardness, use micro-alloyed wheels and use martensite resistant wheel steel.

Micro-alloyed wheels are based on chemical composition of AAR C wheels micro alloyed to produce a more even hardness distribution through the rim. The tensile strength of such wheels is 800-1200 MPa. Other directions of advanced materials are wheel hardening, depositing and cladding technologies.

## 4. MECHANISMS OF ROLLING CONTACT GIVING RISE TO WHEEL/RAIL DEFECTS

### 4.1 Contact Mechanics

During vehicle movement the position of wheelset in relation to the rails changes considerably resulting in various combinations of wheel and rail contact zones.

Though the wheel and rail profiles vary considerably, three functional zones of rail wheel contact are: contact between the central region of the rail crown and wheel tread, contact between the gauge corner of the rail and the flange, and contact between the field sides of both rail and wheel[8]. The most important are conditions of two point contact, single point contact and conformal contact of the region between wheel flange area and gauge corner of the rail head.

*Two point contact*: Because of the wheel-to-rail angle of attack, the second contact patch is moved forward, associated with gross slippage and wear if a flange force and lateral creep are present as is the case in curves. Under these conditions, wheel flange wear takes place. Contact is often so severe that material flows occur on the flange of the wheel. In this condition, the flange cuts under any lubricating film applied to the contact zone.

*Single point contact:* The high contact stresses occurring under high creep conditions result in fatigue of the gauge corner. This, in its mildest form, produces head checks, and in its worst form, breaking-out of the gauge corner of the rail.

In the conditions of single point contact, the contact domain is shared by two or more separate radii of curvature and the Hertzian assumption is not valid and a non-Hertzian solution to find the contact patch is necessary. Non-Hertzian solution is important to be applied for numerous combinations of worn wheel and rail profiles and to conformal wheel/rail contact, for instance, an ellipticized non-Hertzian geometry approach which shows good agreement with the exact solution[9].

*Conformal contact*: This type of contact is observed as the gauge-corner and flange wear to a common profile predominantly under flange contact in curves. There exist several definitions of conformability of the wheel/rail contact. For instance, these are contacts where transverse width of the contact is about 20 mm or more. Wheel and rail contact are considered as conformal where the maximum separation at defined the transverse width is between 0.1 and 0.4 mm[1]. Conformal contact in a curve decreases the maximal contact stress comparable to non-conformal and two-point contact and wheel flange and rail head wear.

*Worn profiles*: At the contact of severely worn rail with new or worn wheels, the pressure at the contact patch changes its configuration. The contact patch size decreases considerably and shifts to the field side of the high rail resulting in corresponding growth of the contact pressure which may reach the yield stress and result in rail head plastic flow.

*Wheel hollowing*: Hollow wear of the wheel-tread results in increase of the normal contact stress which may occur on either side of the hollow worn pattern of the wheel. Depending on the lateral position of the wheel relative to the rail calculated contact, stress could rise two times for a 4 mm hollow worn wheel to compare with not worn wheel profile, resulting in plastic flow or increasing probability of RCF failure.

*Influence of wheel lateral position in a gauge*: The wheel lateral shift has an influence on the normal contact stress distribution. If the left wheel comes in flange contact with the wheel and moves in incremental steps until the right wheel is in flange contact and for each position to calculate the Hertzian contact stresses and this calculation is done for typical wheel profiles, then picture of the probable contact stress distribution is obtained.

*Wheel/rail contact considering surfaces roughness:* Real wheel and rail surfaces are rough and real contact area considerably differs from nominal contact area. For the elastic conditions high peaks for the contact pressure may exceed Hertzian pressure greater than ten times. If microplasticity at asperities is considered micro-peaks of pressure about 5 time exceeds the maximal Hertzian pressure[7]. Although this stress exceeds the yield stress for rail and wheel materials, shakedown and work hardening mechanisms increases the range of durable stresses. The surface roughness decreases the initial slope of creep force -creep curve.

## 4.2 Failure of Wheel and Rail Materials under Rolling-sliding Contact

***Shakedown principles***

Shakedown principles were developed to study response of elastic-plastic bodies to repeated cyclic loading[14,15]. Generally four steady state behavior are identified: perfectly elastic, elastic shakedown, plastic shakedown and ratcheting[15]. If the loads are small for no element of the structure to reach its elastic limit, the response will be perfectly elastic. If the elastic limit is reached in the first cycles, but the steady state is entirely elastic th stic shakedown can be achieved is called th stic shakedown (or cyclic plasticity) regime t cle of plastic deformation. In the regime c tes increments of uni-directional plastic str

When sliding accompanies rolling, frictional traction is exerted. The influen of traction on shakedown limits for perfectly plastic and a kinematical hardened materials is described by tl shakedown diagram (Figure 7)[10,11].

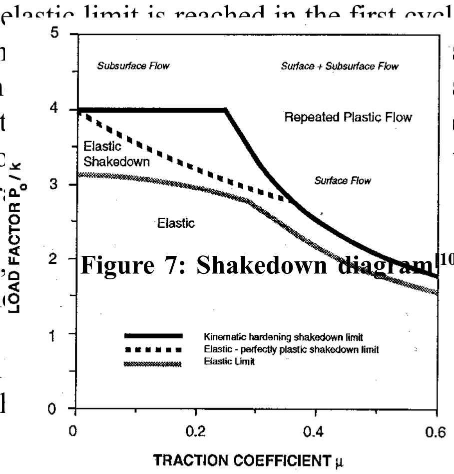



**Figure 7: Shakedown diagram[10]**

This diagram describes the limits of material behavior in terms of non-dimensional normal contact pressure $P_0$ /k as a function of non-dimensional traction coefficient ì =T/N, where $P_0$ is the normal contact pressure, *k* is the shear yield strength, *T* is the tangential (traction) force, *N* is normal load. At relatively low traction coefficient cumulative plastic flow occurs bellow the rail surface. If the traction coefficient is high (greater than about 0.3), plastic flow is greatest at the rail surface.

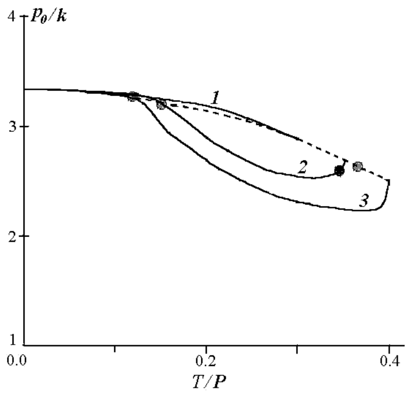
Figure 8 Dependence of the load factor *($p_o/k$)* which causes an onset of plastic deformation from the traction *T/P* for the coefficients of friction 0.3; (curve 1); 0.35 (curve 2); 0.4 (curve 3)[12].

– onset of plastic flow at the surface

– onset of plastic flow at the subsurface

**Figure 8: Shakedown Principle[11]**

For kinematically hardened materials with lower values of the coefficient of friction, plastic deformation is governed by the sub-surface stress and shakedown limit is enhanced by hardening. At higher values of the coefficient of friction (more than 0,35) plastic deformation occurs at the surface and shakedown limits is not improved by hardening[12].




The shakedown diagram gives possibility of damage modes evaluatio the axle load, operating conditions, mat used of the particular railway. A shaked luate safety of given material operation. If t (load factor) is bellow the shakedown limit, tl asure of safety of operation. If the operating , the difference is a measure of how much r

The value of k is originally definec l and rail steel. There seems to be a genera Mises criterion could be considered as the first approximation to calculate k value as $k= {}_y/v\ 3$, where ${}_y = {}_{02}$ and is taken from the tensile stress-strain diagram. However, there are several effects to be considered: cycling loading, high hydrostatic compression, strain rate and work hardening, contact temperature:

*Critical stress concept*: Critical stress concept is designed to provide values of “safe” wheel and rail operation[13]. It is considered that “safe” operation of rail could be achieved if contact stress ${}_c$ is less than critical value. As a first approximation it is assumed the critical stress is as ${}_c = k\ F_{WH}\ F_{SR}\ F_{SH}$, where $F_{WH}$ - is a factor account for work hardening, $F_{SR}$ - is a factor account for the effect of strain rate, $F_{SH}$ - is the shakedown factor.

***Rolling contact fatigue failure***

A typical rolling contact fatigue failure (as any fatigue failure) can be divided into two principal phases: micro-crack initiation and crack propagation.

There are two significant layers of material which exhibit plastic deformation. One is a very thin layer on the surface of the contact patch, and the other is the subsurface layer in the region of the maximum shear stresses. When the traction coefficient exceeds 0.3, the plastic flow is located in a thin layer at the surface.

Crack initiation takes place:

- After the accumulation of cyclic micro-plastic deformation at the subsurface layers under action of the maximal tangential stresses predominantly in the area of the defects in the material structure.
- At ratcheting mode of material response to cycle loading.
- At high tensile stresses near the boundary of the contact patch. This may promote the surface initiated cracks of tribo-fatigue origin.

*Subsurface initiated rolling surface fatigue*: After the accumulation of cyclic micro-plastic deformation at the subsurface layers under action of the maximal tangential stresses predominantly in the area of the macroscopic defects in the material structure.

In wheels or rails containing no macroscopic defects, RCF may initiate at 3-5 mm below the surface. In wheel or rail containing material defects, fatigue may initiate at defects down to a depth of 10-25 mm. Close to a defect, stress magnitude is locally increased and local plastic deformation may occur giving rise to residual stresses. In compressive loading, these stresses may be tensile and thus promote crack initiation. Defects initiated at subsurface form a shelling type of defect. Gauge face shell in rails may turn into transverse defects. Shell in multiple wear wheels may also result in wheel rim failure when the wheel rim is thin.

***Ratchetting***

Ratchetting is the fourth type of the material response to cyclic loads[11]. In this regime, the material structure accumulates increments of unidirectional plastic strain, leading to incremental collapse of the material. The process of incremental, unidirectional strain accumulation occurs when the material is loaded above the plastic shakedown limit. Though very high strains are possible, the material cannot accumulate strain indefinitely and eventually when a critical strain is reached, plastic deformation builds up with each passing wheel until the ductility of the material is exhausted and the cracks initiate on the surface, leading to *tread checking* in wheels and *head checking* in rails.

Head checks initiated by ratchetting grow perpendicular to the prevailing direction of the traction force. In mild curves longitudinal traction is dominant and cracks grow primarily perpendicular to the direction of travel. In sharp curves traction forces are primarily in the lateral direction. For mixed longitudinal traction, the cracks can grow at an angle about 45 degrees to the direction of travel. The direction of cracks follow the direction of deformed material microstructure generated by traction forces.

### 4.3 Wear Mechanisms

There are two main areas of wheel and rail wear. The first one is the top of rail and the wheel tread. The second is the gauge face and wheel flange wear. Rail and wheel wear is generally assumed to be proportional to the energy dissipated overcoming wheel and rail rolling-sliding resistance. Wheel and rail wear rates (*I*) in rolling-sliding conditions are determined by the relative slippage ($\lambda$), the normal stress (*p)* at the contact patch and on 'the third body' properties resulted from the diverse coefficients of

Basing on laboratory wear simulat
major wear modes have been identified: n
Wear modes are characterized by wear ra
size.

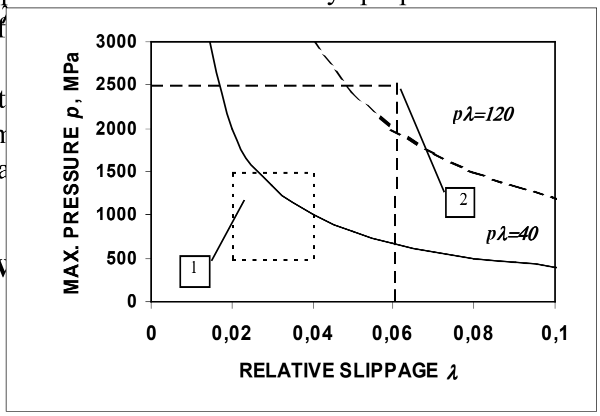



**Figure 9: V**

1 - field of normal performance,
2 - boundary of abnormal performance

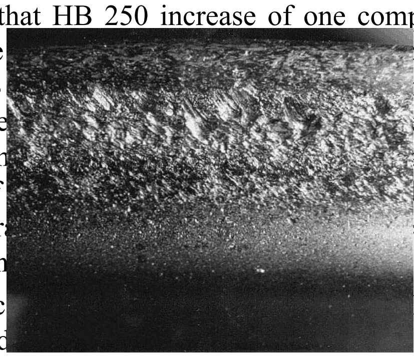
The wear diagram, that is *p* =*const* curves, represents zones with different wear modes and areas of normal and abnormal performance (Figure 9)[1,17]. This diagram was obtained for conventional rail and wheel carbon steel of initial hardness up to 300 HB. For these conditions the curve *p* =*40* is the boundary between the mild and the severe wear modes, whereas

*$p\lambda=120$* is the boundary between the severe and the catastrophic wear modes. Between severe and catastrophic wear modes a heavy wear mode was discovered [17]. For the heavy wear mode the maximum and the minimum ratio of wear may differ by one order of magnitude during a test run. The wear rate decreases with the growth of the $p$ parameter. The severe and the heavy modes can exist at the same level of $p$ and may transform into each other. It is presupposed that the heavy wear mode is closely connected with the working hardening process of wheel and rail surfaces.

**Figure 10: Wheel flange surface under catastrophic wear mode**

*Influence of wheel rail hardness and its ratio*[1]: Hardness is integrated property of the material reflecting its structural changes. There are some myths about the influence of hardness and wheel and rail hardness difference on wheel and rail wear.

– At the hardness level less that HB 250 increase of one component hardness does not influence [illegible] nents. At the hardness level HB [illegible] of one component hardness resulte[illegible] total wear rate of both componen[illegible] an HB 400 increase in hardness of [illegible] erable decrease of the total wear r[illegible] ase of wear of the second compon[illegible]



– The degree of the influenc[illegible] highly dependent on the wear mod[illegible]

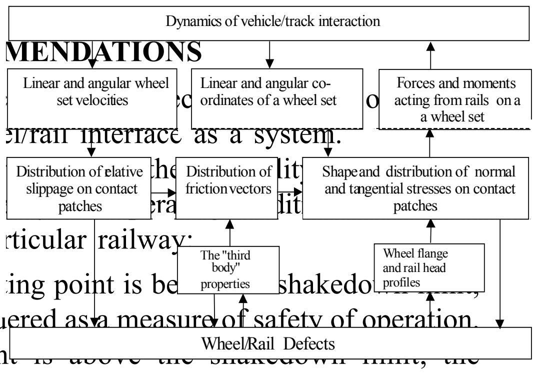
– There is no optimal rail to wheel hardness ratio providing for minimal total wear of both wheel and rail.

## 5. SYSTEM FACTORS INFLUENCING WHEEL AND RAIL PERFORMANCE

There are many other systems and issues which to a great extent determine wheel and rail performance. These factors and their interrelation which define wheel/rail defects are schematically presented in Figure 11[1].

These factors are dynamics of vehicle/track interaction, linear and angular wheelset velocity, forces and moments acting from rails to wheelset, distribution of slippage on the contact patches and friction vectors resulted from normal load, normal and tangential stresses on the contact patches, wheel flange and railhead profiles and 'third body' properties.

**Figure 11: Factors determining wheel/rail wear**




In order to provide rational (optimal) wheel and rail performance, several technologies are used. These are:

- lubrication and friction management;
- rail profile maintenance practices, which comprise rail grinding, longitudinal and transverse rail profile correction
- wheel profile maintenance.

Lubrication and wheel/rail profile management are technologies that are the subject of a separate paper.

## 6. CONCLUSIONS AND RECOMMENDATIONS

(i) The most effective way to a[illegible] o[illegible] and rails is by treating whe[illegible]l/rail interface as a system.

(ii) It is expedient to perform e[illegible] the [illegible]lity [illegible] rail damage for prospective h[illegible] era[illegible] dit[illegible] rail material used by the particular railway:

- If the wheel/rail opera[illegible]ing point is be[illegible] shakedo[illegible] the difference is considered as a measure of safety of operation. If the operating poin[illegible] the difference is a measure of how much ratchetting will occur.
- "Safe" operation of rail and wheel materials could be achieved if the contact stress is less than critical value, which depends on shear yield strength of the material and accounts for shakedown, work hardening and strain rate factors.
- When evaluating probable material damages under a particular operating condition wheel/rail contact temperature that gives rise to the thermal stresses should be taken into account. The contact thermal stresses have a significant influence on the elastic and shakedown limits, reducing shakedown threshold in traction.

(iii) The desirable contact between the rail and the wheel from stress perspective will occur under the following conditions:

– When the contact band is in a middle of wheel and rail. In the vicinity of the contact area, the rail head is supported by the rail web and the wheel rim is supported by the wheel disk. If the prevailing contact takes place at the edges of the contacting bodies then plastic flow may be expected on the field side of the wheel and the rail and thus these conditions should be avoided.

– When the radii of the surfaces of the contacting bodies are to be as large as possible to insure the largest area of the contact patch.

– When the two contacting bodies, in the regions of the rail head gauge corner and wheel flange throat, have conformal shapes thus provides for the largest possible area of contact and lowest maximal contact pressure

– When there is no stress risers from the contact or false flange hollowed wheel and rail or non-conformal worn wheel and rail area.

– When friction forces between the wheel and the rail caused by relative slippage are at minimum necessary level. The most damaging are lateral friction forces causing surface initiated rolling contact fatigue.

(iv) Wear related factors:

– The wear rate is defined by the contact pressure which depends on vertical and lateral forces, rail/wheel profile and the relative slippage, which, in turn, depends on axle load, dynamics of vehicle/track interaction, and wheel and rail profiles. Other important factors are “third body” properties and material characteristics.

– The catastrophic wear mode, that is characterized by a considerable adhesion type of wear, should be avoided as it results in the wear rate that is two orders higher than other wear modes. For a conventional wheel and rail steel with hardness level about HB300, boundaries between the severe and the catastrophic wear modes (a product of the maximal contact pressure and relative seepage pë) is equal. The catastrophic wear mode should be avoided; this is achieved by a gauge face lubrication, decreasing the angle of wheel to rail attack by improving bogie's performance, increasing material wear resistance. Among the material characteristics affecting wear resistance are: material hardness, carbon content, microstructure and material cleanliness, particularly sulfide content.

– The degree of the influence of wheel and rail hardness is highly dependent on the wear mode and assets hardness level. At the hardness level HB 250-400 increase in hardness of one component hardness results in considerable decrease of the total wear rate of both components.There is no optimal rail to wheel hardness ratio providing for minimal total wear of both wheel and rail.

– Because wear and rolling contact fatigue are major competing failure modes of material under rolling-sliding contact, there exists an optimal wear rate in which fatigue and wear are in balance. The optimal wear rate depends on traffic type density, axle load, assets metallurgy, track curvature, etc.

(v) Wheel/rail materials requirements:

– There is a set of material property characteristics, that is the constructive strength of material, which the material should possess to meet operating requirements. These are yield and tensile strength, fracture toughness, elongation. In addition to conventional mechanical properties of material, contact fatigue, wear resistance, static and cyclic resistance to crack propagation and static, cyclic and impact are required .

– Contact fatigue strength of rail and wheel steels highly depends on steel microstructure, that is contamination of steel with oxides, dispersity and shape of carbides, austenite grain size, martensite and iron carbide microstructure. Size of inclusions (voids, pores etc.) has a strong detrimental effect on the subsurface initiated contact fatigue defects. Contact fatigue strength of wheel and rail steels depends on homogeneity of steel microstructure. Structural heterogeneity results in lower contact fatigue to compare with steels having homogeneous structure.

– To decrease wheel and rail spalling because of thermomechanical damages from material perspective, it is recommended to use higher strength steels which show higher resistance to crack propagation and to use alloyed wheel steels with higher temperature of material structural transformation. However, the effective measures to decrease wheel and spalling are in the operational area (in track and yards braking, violation of lubrication technology, etc.).

(vi) Maintaining optimal wheel and rail performance require measurements of wheel/rail and vehicle track conditions and diverse characteristics of the performance, in particular assets profiles measurements, including reprofiling, lubrication effectiveness, wheel/rail tribology charachteristics, rail and wheel life, defects inspection, etc.

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# TECHNOLOGICAL ADVANCEMENTS IN ROLLING STOCK PERFORMANCE MONITORING AND MAINTENANCE

*Harry M. Tournay**

## 1. INTRODUCTION

The North American railroad industry is increasingly moving to wayside detection to reduce vehicle inspection and maintenance costs. Currently, vehicle inspection costs are about 50% of the cost of the actual maintenance of the rail vehicle (labor plus materials).

Through automated wayside detection, a significant reduction in the inspection costs would be achieved and maintenance time could be increased. Vehicle fleet maintenance can be better planned using information derived from both single vehicles and fleet performance. Maintenance could then be focused on specific components or systems directly related to the poor performance measured by the wayside detectors.

Analysis of data from wayside detectors is providing valuable information on the root causes of poor performance. This is leading to the development of component and vehicle designs that improve component life and extend vehicle performance. This paper presents the current state of deployment of wayside detectors and detector databases in North America. It describes the algorithms used to identify cars requiring maintenance attention and the correlation between detector data and car condition.

A variety of detector types are in the process of development and/or deployment in North America. These are listed in Table 1 with an indication of the state of development and deployment, the anticipated effect on track and vehicles, and the action to be taken on detecting excesses. The development/ deployment of the following detectors will be discussed:

– Hot Bearing Detectors (HBD)
– Truck Performance Detectors (TPD)
– Wheel Impact Load Detectors (WILD)
– Hot and Cold Wheel Detectors (H & CWD)

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– Overload and Imbalanced Load Detectors (OILD)
– Acoustic Bearing Detectors (ABD)
– Hunting Detectors (HD)

**Table 1**

| Basic Metric | | Detector Type | Deployment Status | Effect on Track | Effect on Equipment | Action |
|---|---|---|---|---|---|---|
| Performance Based Metrics | Force | Wheel Impact Load Detector (WILD) | Extensive deployment with appx. 86 sites in North America. Data in InteRRIS® | Track & Track Component Degradation | Damage to: Bearings Truck Components (Brake Beams) Car Components | Wheel Removal Correct Root Causes |
| | | Overload & Imbalanced Load Detector (OILD) | Closely related to WILD All WILD sites have OILD capability Data in InteRRIS® | Track Degradation Bridge Degradation Derailment Potential | Poor Steering & Wheel Wear | Correct Loading Discipline |
| | | Hunting Detector (HD) | One HD type is closely related to WILD with 66 sites with HD capability Data in InteRRIS® | Derailment Potential Gauge Widening | Lading Damage Car Component Degradation Derailment Potential | Truck Rebuild + Constant Contact Side Bearings |
| | | Truck Performance Detector (TPD) | 22 sites Data in InteRRIS® | Gauge Spread, Gauge Corner Wear, Gauge Widening Derailment & Derailment Potential | Wheel Wear Derailment potential | Focused Truck & Car Body Component Maintenance |
| | Temperature | Hot Wheel Temperature Detector (HWTD) | Limited to Canada + limited sites in USA Data to InteRRIS® pending | | Wheel Damage Early Warning of Brake problems | Focused Brake System Maintenance |
| | | Cold Wheel Temperature Detector (CWTD) | | | Wheel Damage Early Warning of Brake problems | Focused Brake System Maintenance |
| | | Hot Bearing Detector (HBD) | Extensive but negligible AEI associativity to date. No Data in InteRRIS® | | Potential Derailment | Remove Wheelset Root Cause Analysis |
| | Sound | Acoustic Bearing Detector (ABD) | 7 sites with others pending Data available in InteRRIS® | | Early Warning of Defective Bearings | Remove Wheelset Root Cause Analysis |
| Condition Based Metrics | Machine Vision | Wheel Profile Monitoring (WPM | 3 sites. More pending. InteRRIS® availability in 2006 | Contact Stress & RCF High Lateral Forces | Derailment Potential (Vertical Split Rims) Wheel Wear | Replace Wheel Correct Root Cause of Poor Performance |
| | | Brake Shoe Thickness Measurement (BSTM) | 2 sites in NA | | Brake Condition Uneven Shoe Wear | Shoe Change |
| | | Other e.g. Hand Brake on/off? | Under development | | | Repair / Replace Equipment |
| | | Safety Equipment Condition | | | Not Operable for Safety Reasons | |

A common database, InteRRIS®, has been developed to enable common access to data across railroads and detectors and integrated information between detector types. The integration of detector information will be discussed. Integration is in process as experience with wayside detection is gained and as detectors are deployed across the network.

## 2. HOT BEARING DETECTORS

Together with dragging equipment detectors, HBDs are the most established form of wayside detection equipment on railroads. Journal bearings are known to be subject to rapid temperature rise immediately prior to burn-off. Consequently, in order to be effective, HBDs are deployed at short intervals alongside the track, often at intervals of 20 miles with exceptions at intervals of 10 miles.

Historically, HBD sites have not been equipped with Automatic Equipment (Vehicle) Identification (AEI or AVI) because of the relative high cost of the equipment and a significant number of sites to be equipped. HBD sites have thus, until recently, only been coupled to local operating offices (in some cases to dispatching centers, but frequently in stand-alone warning notification by wayside indications with axle count displays or by train radio “talkers”), providing alarms associated with axle counts of the cars in the train. The use of axle counters has often led to errors in identification of the poorly performing bearing and resulting unreliability of the total system. The lack of time-based information on the performance of individual bearings has also precluded the implementation of predictive processes.

Railroads in North America are overcoming these limitations by using systems to associate data between limited numbers of immediately adjacent detectors. Algorithms are used to detect a trend in temperature rise in a bearing over a limited distance and time immediately prior to that bearing setting-off an alarm. (These temperature rises are at levels lower than the temperatures triggering an alarm.) The measured trend can be used to confirm the eventual alarm, improving the reliability of the HBD alarm system. Algorithms have been developed by Transportation Technology Center, Inc. and a number of railroads. These algorithms are currently being evaluated.

One system used to associate data is the so-called “Virtual AEI” system developed by CN Railway. With this system, vehicle information is obtained from strategically placed AEI equipment. This information is used, together with information on the topology of the railroad and where vehicles may be set-out and train configurations altered, to associate HBD information with a particular vehicle and bearing.

As HBD data availability and associatively improves, it should be expected that predictive methods should improve. In particular, the use of acoustic bearing detection (ABD), providing an extended term indication of bearing performance. The linking of HBD and ABD is expected to appreciably improve the maintenance and performance management of journal bearings on railroads into the future.

## 3. WHEEL IMPACT LOAD DETECTORS

Typically, WILD sites comprise a number of instrumented cribs (Figure 1) that measure vertical wheel loads as the car passes across the site. The cribs are spaced so as to detect the vertical impact load on wheels of differing diameter.

An evaluation is made of both the static and dynamic load imposed by each wheel passing the site. Alternative detector types have been developed based on different measurement methods. One such type uses accelerometers attached to the rail. No alternative types are currently used in North America, and the potential problem of comparison between performance and performance limits has not yet been encountered.

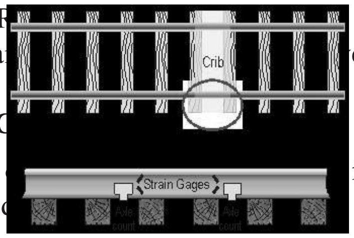
As Table 2 shows, WILD information is sent to InteRRIS® together with other relevant information:

**Table 2**

| | |
|---|---|
| - Date, Time | - Train speed |
| - Site I/D | - Wheel I/D |
| - Train I/D | - Axle I/D |
| - Car I/D | - Truck I/D |

InteRRIS® provides a WILD time history for each wheel. Vehicle owners are currently being advised when wheels on their vehicles exceed certain impact thresholds. Currently, 90 kips is the performance limit. There are now additional reported levels for “window of opportunity” and “opportunistic repair”. These are described in AAR web page <www.aar.org>. Most railroads stop tra e 140 kips.

**Figure 1: Instrumented crib**




## 4. OVERLOAD AND IMBALANC

The OILD is currently a derivative information from WILD sites is integrated to provi

- Vehicle overload
- Vehicle load imbalances:
    - Between one side of the vehicle and the other
    - Between one end of the vehicle and the other (across bogies)
    - Diagonal load imbalances

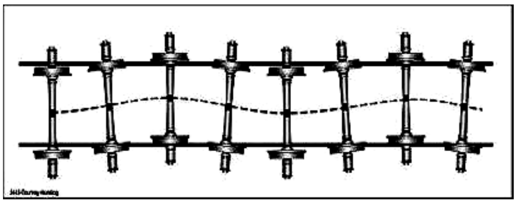
Performance limits have not yet been set for OILD. Studies are currently under way on the effect of overloads and imbalance loads on:

- Vehicles, including:
    - Vehicle stability
    - Vehicle and vehicle component life (body structural failure, suspension failure)
- Track and track structures, including:
    - Track component stresses
    - Bridge stresses

## 5. HUNTING DETECTORS

Current hunting detectors are another derivative of WILD. Cribs are instrumented to measure lateral as well as vertical loads. A vehicle that is hunting exhibits a sinusoidal motion on the track (Figure 2) and imposes regular lateral and vertical load patterns on the track.

**Figure 2**



These load patterns are detected at the series of instrumented cribs in the track. Algorithms are used to categorize each bogie in terms of a truck (bogie) hunting index (HI). In a strict sense, stability cannot be attributed to a bogie but to the vehicle associated with the bogie, as there are body dynamic modes that can (and do) contribute to hunting. It is, however, convenient to attribute a hunting index to a bogie in a wagon, particularly as there are many wagons in North America with more than two bogies.

Hunting detector types are in development/deployment that measure the position of the wheelset at different points on the track rather than forces, and thus detect the sinusoidal motion of the wheelset. These detectors will be accommodated in InteRRIS®, when they are available. When other detector types are introduced with data to InteRRIS®, it must be anticipated that they will have a different formulation of HI together with different performance levels. Means will have to be developed to relate the different developed indices to each other. The particular HI currently being used varies between 0 to in excess of 0.65.

– A HI below 0.1 indicates a stable bogie/truck
– A HI of 0.65 indicates a bogie/truck with poor stability

TTCI is currently in the process of refining these HI levels. This process has been done in two steps. Firstly, HD data for a period of one year was analyzed across all HDs currently in operation in North America. Four different hunting levels were chosen based on HI and the number of occurrences across the same or different detectors. Table 3 shows the chosen criteria, together with the number of cars that would have been identified at that level within a period of one year. The latter figure gives an indication of the workshop loading and cost

**Table 3**

| Hunting Index (HI) | Number of Passes | Approximate Number of Cars Identified |
|---|---|---|
| >=0.65 | At least 1 | 300 |
| >=0.45 | At least 2 | 1500 |
| >=0.30 | At least 3 | 4700 |
| >=0.25 | At least 3 | 5200 |

associated with fixing the wagons. In this regard, it should be remembered that the total wagon population in North America is approximately 1.6 million including Canada and Mexico.

Sample wagons from each of these levels were sent to TTCI for inspection, test, teardown, repair, and subsequent test. Findings from this exercise are as follows:

- All wagons sent to TTCI showed signs of instability between 35 and 50 mph
- All wagons showed signs of hunting:
  - Melted polymer spring elements in constant-contact side bearers (CCSBs) fitted to increase rotational friction constraint and hunting stability under-tare conditions
  - Worn coupler support plates
  - Worn uncoupling levers
  - Worn/damaged doors
- All wagons showed typical reasons for poor bogie hunting performance:
  - Low bogie warp (shear) constraint on 3-piece bogies:
    - Worn/high wedges •
    - Worn column wear liners
    - Worn pedestals
  - Low bogie rotational resistance:
    - No CCSBs fitted (fitted with roller or clearance side bearings)
    - If CCSBs were fitted, the vertical pre-load (and hence rotational friction constraint) was inadequate because of:
      - Incorrect set-up heights
      - Excessive pre-set on polymer CCSBs

Wagons were repaired as follows:

- Bogies were rebuilt:
  - Side frame and bolster castings were built-up by welding and wear plates were replaced
  - Coil springs and stabilizer wedges were replaced where necessary
- CCSBs were fitted

Subsequent tests revealed that hunting performance was improved by 15 mph by either repairing the bogies or fitting side bearers. Tests by TTCI indicate that both actions improved the hunting performance by more than 15 x 2 mph, or greater than 30 mph. Consequently, it has been recommended that both actions should be undertaken if a wagon is identified as a poor performer to ensure reliable hunting performance in excess of 50 mph.

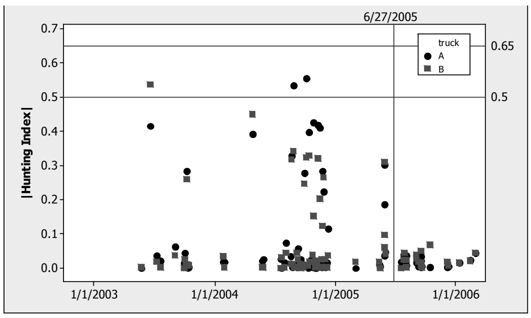
Currently, the following recommendations are in process:

(i) A wagon must be repaired when detected with:
- A single Truck Hunting Index reading above 0.65
- Two Truck Hunting Index readings above 0.50 in a 12-month period

(ii) Prescribed maintenance is as follows:
- Trucks are to be qualified and/or repaired to AAR Specification M-214 (rebuild of main truck castings).
- Condemnable friction wedges are to be replaced.
- If equipped with CCSBs, resilient or spring elements are to be replaced.
- Roller or block type side bearings are to be replaced with long-travel steel capped CCSBs.

Further investigation on wagon condition below a hunting threshold of 0.25 is currently in process. In addition, an investigation into the hunting performance history of previously repaired wagons is also in process. Typically, performance histories wagons receiving bogie rebuilds and/or CCSB fitting/repair have been examined to see if performance has been improved. Figure 3 shows a typical example. Also, performance has appreciably improved since repair on 27 June 2005.

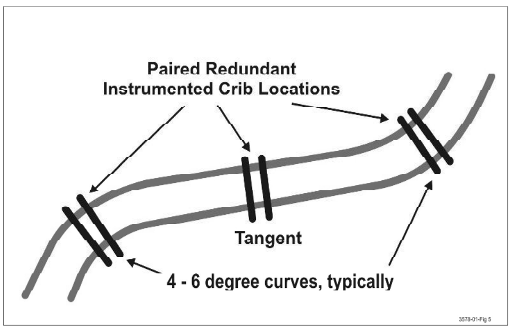
**Figure 3**




## 6. TRUCK PERFORMANCE DETECTORS

TPDs have been developed to monitor the tracking performance of vehicles, particularly on curved track. Cribs are instrumented (Figure 1), using strain gauges, to measure lateral and vertical loads. These cribs are located in two reverse curves and the inter-leading tangent track, as Figure 4 illustrates.

**Figure 4**




Vertical (V) and lateral (L) loads on each passing wheel are measured on both high and low rails in the curves and left- and right-hand rails on the tangent track. Examination of the force patterns associated with each bogie gives an indication of the condition of that bogie and, in particular, the tracking errors associated with the bogie. Tracking errors can be generalized to the following three separate tracking states, as Figure 5 illustrates.

– Bogie rotational tracking error (rotational misalignment between bogie and body)
– Bogie warp (or shear) tracking error (the shear of two axles relative to one another and associated with three-piece bogies)
– Bogie radial tracking error (radial misalignment between two wheelsets within the truck and normally associated with a mismatch in side frame length on three-piece bogies)

**Figure 5**

Many performance metrics have been developed to detect these misalignments. TTCI has recently reviewed these metrics and established that the following metrics are appropriate:

– The ratio of L/V load of the lead wheel of a bogie on the high rail in a curve (Figure 6)
– The truck (bogie) gauge spr
the bogie pushing the two ra
particularly high when a bo
– The truck (bogie) warp index
is an indication of the degr
the wheelsets are sheared relative to one another (Figure 5).

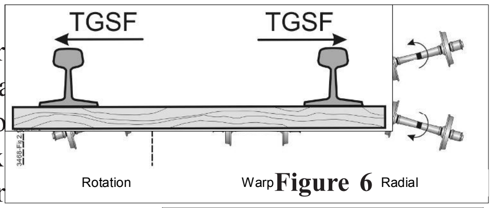



**Figure 6**

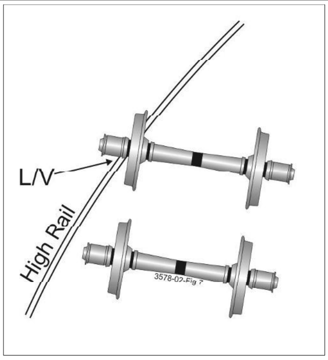



**Figure 7**

Wagons exhibiting high L/V ratios or high gauge spread forces have been identified and inspected, torn down, and tested. Typically, the bogies exerting these high forces have been found to have either:

– Radially misaligned wheels: mismatched side frames
– Low warp (shear) restraint: missing main or wedge springs, worn wedges or column wear liners
– Mismatched wheel diameters on the same axle

Inspections, however, have also found wagons with trucks in good condition with no obvious signs of poor wagon condition. Further investigation has revealed that poor performance is associated with high rotational resistance at the bogie/body interface. This high resistance is associated with:

- High friction coefficients at the bogie center bowl
- High rotational resistance caused by:
    - Tight center plates
    - Body twist (causing high side bearer loads)
    - Twisted center plates across a wagon body
    - Non-flat center bowls and center plates

Investigation and test have revealed that lateral off-center vertical loading on the bogie/body interface can shift the center of rotation of the bogie laterally relative to the bogie (Figure 8).

This causes sidewall contact in the center bowl which appreciably increases the rotational resistance between bogie and body. Rotating a bogie under the body of a loaded coal car using an air table has simulated this effect. Figure 9 shows results of a typical test. Here, a hysteresis of truck rotation versus rotational resistance is plotted as well as the relative lateral and longitudinal motion of the center plate in the center bowl. Sidewall

**Figure 8**

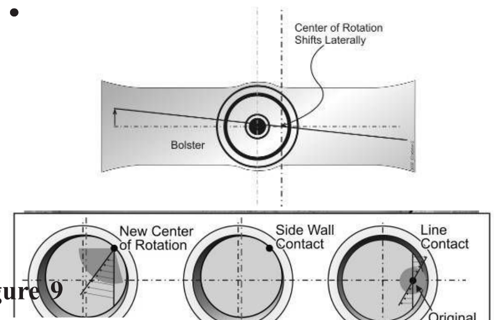
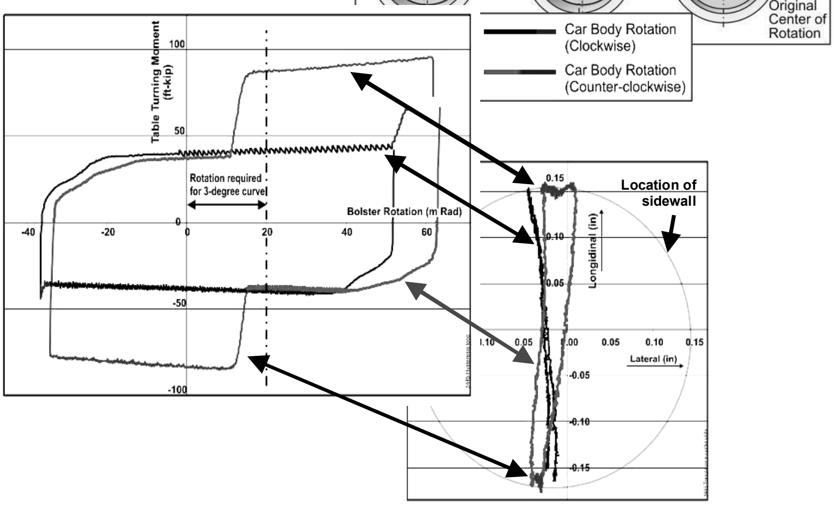



**Figure 9**

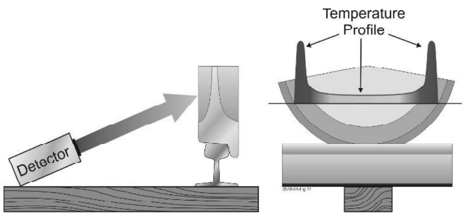


contact is indicated and related to a step-function increase in rotational resistance. It may be seen that sidewall contact can double the bogie/body rotational resistance.

## 7. HOT AND COLD WHEEL DETECTORS

Current wheel temperature detectors are direct derivatives of HBDs. They are infra-red devices that are focused on the level of the wheel rim and measure the temperature profile of both the rim and a part of the dish as the wheel passes (Figure 10). The wheel rim temperature is deduced from this profile.

**Figure 10**




These wheel temperature detectors are termed either cold or hot wheel detectors (CWDs or HWDs), depending on their placement on the track:

– CWDs are placed towards the bottom of an extended downgrade on which trains normally experience extended braking. All wheels (except, normally, the locomotive wheels) should be hot. Wagons with inoperative brakes will have cold wheels (hence the name); however, wagons with valves that have leaked-on above to a pressure above that for the rest of the train (possibly brake pipe pressure) will indicate higher than average wheel temperatures. Uneven braking of individual shoes in the car due to poor rigging performance may also be seen.

– HWDs are placed beyond the end of the downgrade at a point at which the wheels are expected to have cooled after a brake release. Wagons, bogies, and wheels in which the brakes have “stuck-on”, for whatever reason, may be seen as having hot wheels (hence the name).

Figure 11 is an example of train temperature data. This data can be processed to indicate poorly performing valves, as Figure 12 shows. Figure 13 shows the average temperatures of the eight wheels associated with a particular air brake valve. Those wagons with average wheel temperatures per valve that are lower than this temperature are not shown but are considered to have inoperative valves.

**Figure 11**

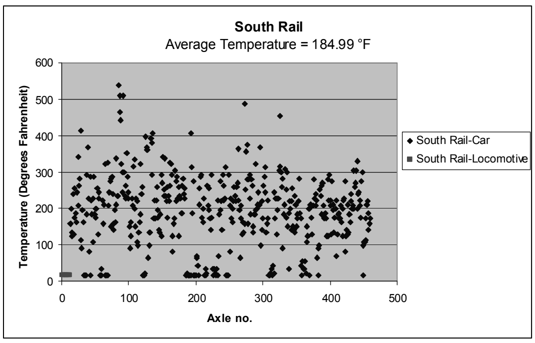
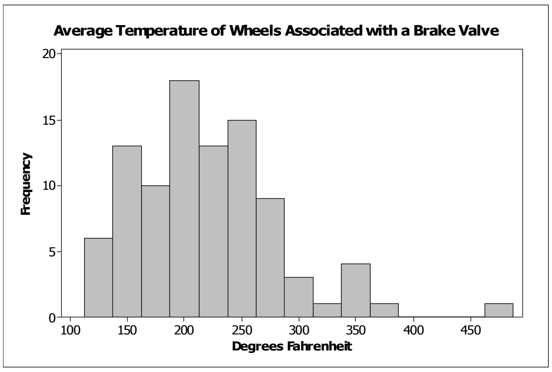


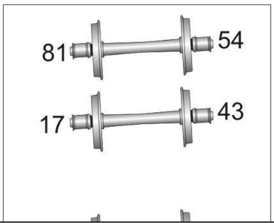
**Figure 12**




The train data can be further processed to reveal uneven temperature patterns within a wagon that are indicative of poorly performing brake rigging. Various different patterns can be detected. Figure 12 shows inoperative rigging in one bogie. Wheel temperatures are indicated alongside each wheel in degrees Fahrenheit above ambient.

## 8. ACOUSTIC BEARING DETECTORS

**Figure 13**




The acoustic bearing detector allows railroad operators to detect defects long before they cause overheating and before plan bearing maintenance based on performance. The minimization of service disruption is a major economic driver for the acoustic detector as well as the prevention of catastrophic failures that can occur despite a network of HBDs. Due to capability of this detector, a large nu detectors are not required provided that in are monitored over a reasonable time or

Acoustic bearing detectors compr are positioned alongside the track to detect the characteristic sounds emanating from bearings with defects on their rolling surfaces.

Frequency and amplitude measurements are processed, together with the speed of the vehicle, to determine the defective components (cup, cone, or roller) and the magnitude of the defect. Recent developments also enable analysis of high risk bearings with severe defects on components – so-called “growler” bearings. This type of bearing is most likely to be a bearing in a relatively advanced stage of degradation. The detection of “growler” bearings thus selects a limited number of bearings closest to failure, refining the selection of poor performers. InteRRIS® is structured to provide TADS performance indices.

**Figure 14: TTCI’s acoustic detector called TADS™**

## 9. INTEGRATED DETECTORS

Currently, detector information on each car and for each detector is reported separately in InteRRIS®. This information is used to identify poorly performing cars and/or components when they exceed acceptable performance norms, as well as relating wayside performance information to physical conditions in order to validate developing detection metrics and algorithms.

It is envisioned that, ultimately, car and component performance histories across all detectors and detector types will be matched with operational and maintenance history to provide complete information in support of car and fleet maintenance planning.

Increasingly, however, the demand is for integrated information, both across detectors of the same type, as well as across differing detector types; information is also sought relating to fleet characteristics and not just individual cars. Integration presents a new set of challenges as there are many different bases on which information may, or indeed should, be integrated and interpreted.

### 9.1 Data integration can be introduced on a number of levels

On the most simplistic level, all c be expressed in a number of appropriat line together with a number of pre-detern (Figure 15). Current development is at survey all metrics for a chosen time interval and to draw conclusions from any associations found.

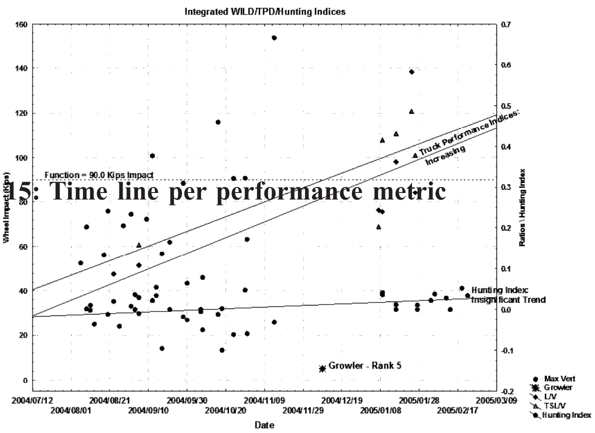



**Figure 15: Time line per performance metric**

Table 4 shows the current recommended performance metrics used or envisioned, specific to the detector type.

Table 4 also shows that there is commonality in the basic measurements made at the WILD, OILD, and HD sites. TPD sites also measure vertical loads. This commonality is not reflected in Figure 15 in order to highlight metrics specific to each detector.

**Table 4: Recommended performance metrics per detector type**

| Detector Type | Recommended Basic Performance Metric |
|---|---|
| WILD | Vertical Wheel Load, Impact Load (kip), Dynamic Ratio |
| OILD | Vertical Wheel Load, Axle Load, Truck Load, Truck Side Load, Truck Diagonal Load, Car (or Platform) Load, Car (Platform) Side Load, Car (Platform) Diagonal Load |
| HD | Vertical Wheel Loads, Hunting Index, Maximum L/V |
| TPD | Lead Truck Lead Axle High Rail L/V, Truck Gauge Spread Force, Truck Warp Factor |
| HWTD | Wheel Temperature, Train Mean Wheel Temperature, Left and Right-hand Train Mean Temperature, Mean of wheels associated with a brake valve, Mean of wheels on a truck, Mean of wheels on an axle, Differences between the metrics |
| CWTD | Wheel Temperature, Train Mean Wheel Temperature, Left and Right-hand Train Mean Temperature, Mean of wheels associated with a brake valve, Mean of wheels on a truck, Mean of wheels on an axle, Differences between the metrics |
| HBD | Bearing Temperature |
| ABD | Acoustic Level, Bearing Defect Type |
| WPM | Wheel Diameter, Rim Thickness, Flange Height, Flange Thickness, Hollow Tread, Differences between the metrics across an axle, diagonally across axles in a truck, back-to-back distance between flanges |

Wheel Impact Load Detectors (WILD), Overload and Imbalanced Load Detectors (OILD), Hunting Detectors (HD), Truck Performance Detectors (TPD), Hot Wheel Temperature Detectors (HWTD), Cold Wheel Temperature Detectors (CWTD), Hot Bearing Detectors (HBD), Acoustic Bearing Detectors (ABD), Wheel Profile Monitoring (WPM)

Also associated with each detector type are the following measurements of operating conditions:

- Date, time
- Site I/D
- Train I/D
- Car I/D
- Train speed
- Direction of travel
- Vehicle end leading

- Where applicable:
- Wheel I/D
- Axle I/D
- Truck I/D

At this level, integration between detectors of the same type is required. This assumes that measurements taken at different sites are comparable within a required degree of accuracy or that some form of normalization can be applied. This matter is being addressed as detector types are introduced.

The more simplistic detectors such as WILD and OILD require static calibration. They are, however, subject to variations associated with the dynamics of the car. WILD, for instance, can be subject to variations that are functions of:

- Direction of travel (wheel surface damage is rarely circumferentially symmetric)
- Lateral displacement of the wheel on the rail (a wheel never runs at a fixed lateral displacement)

Despite these variations, a properly calibrated WILD will measure wheel impacts accurately under each noted condition. The more complex detectors (e.g., HD and TPD) are subject to other parametric variations. For example:

- HDs are subject to variances in track condition (e.g., rail profile, gauge, cross level).
- TPD data varies according to curvature and car direction.

Variance between detector sites does not mean that comparisons cannot be made. Experience shows that detectors have the relative accuracy required, that is, to identify high impact wheels, hunting trucks, and poor performers at TPDs.

Table 5 below may be interpreted as follows:

- All defects that can give rise to high-impact wheel loads are listed in the central column of Table 5.
- All related causes are listed in the left-hand column together with detectors or other measurements that might give information or clues as to the possible cause.
- The impact of defective wheels on the equipment is listed in the right-hand column together with detectors that might sense the same consequences.

**Table 5: Cause and effect relationship for WILD**

| **DIRECT CAUSES OF DEFECT** ***(& RELATED DETECTOR TYPE)*** | **DETECTOR & DEFECT DETECTED** | **EFFECT OF DEFECT ON VEHICLE SYSTEM** ***(& RELATED DETECTOR TYPE)*** |
|---|---|---|
| | | |
| **WILD**<br>**Minimum unit of measurement: Specific Wheel independent of static load**<br>**Impact loads as a result of:** | | |
| High contact stresses ***(WPMS, WRTOL et al)***<br>High wheel loads ***(OILD)***<br>Poor curving performance ***(TPD)***<br>High wheel temperatures (excessive braking / defective brakes) ***(Hot, cold wheel detectors, locomotive event recorders, hand brake on/off)*** | Shelling | Defective bearings ***(HBD, ABD)***<br>Damaged safety equipment (steps / handles) ***(Machine Vision)***<br>Defective brakes ***(HWTD, CWTD)*** |
| Unreleased handbrakes ***(hand brake on/off)***<br>Defective brakes ***(HWTD, CWTD)***<br>Poor curving performance ***(TPD)*** | Spalling | |
| Unreleased handbrakes ***(hand brake on/off)***<br>Defective brakes ***(Hot, cold wheel detectors)***<br>Poor curving performance ***(TPD)*** | Slid Flat | |
| Out-of-Round Machining ***(WILD)***<br>Unknown ***(but probably all of above)*** | Out-of-Round Wheels<br>Polyagonalized Wheels | |

Hence, vehicle operators/maintainers looking at the WILD history of a particular car may want to access related information from other detection systems;

e.g., wheel profile monitoring (WPM), hot wheel temperature detectors (HWTD), cold wheel temperature detectors (CWTD), OILDs, and TPDs. Other performance measures are also listed: Machine Vision refers to some form of visual detection (i.e., wheel profile, hand brake position). Table 6 shows a similar relationship for OILD.

**Table 6: Cause and effect relationship for OILD**

| OILD<br>Minimum unit of measurement: Specific Wheel but more likely groups of wheels per truck<br>Overload / imbalanced loads in the form of: | | |
|---|---|---|
| Overload ***(OILD and/or load profile measurement)*** | Overload | |
| Poor lateral loading ***(OILD and/or load profile measurement)*** | Lateral load imbalance | Spring Bottoming / E |
| Poor longitudinal loading ***(OILD and/or load profile measurement)*** | Longitudinal (truck-to-truck) load imbalance | ***(Machine Vision, TI*** |
| Car body twist ***(OILD and/or TPD)*** | | Poor curving perform |
| Incorrectly set side bearings ***(TPD)*** | | Poor Hunting Perform |
| Broken springs ***(Machine Vision,.TPD)*** | Diagonal load mismatch | High contact stresses |
| Poor diagonal loading ***(OILD and/or load profile measurement)*** | | |

In determining what information to present, or to have available to the operator/maintainer on exploring the Inte*RRIS*® database, care is being taken to determine whether information should be presented on a wheel, axle, truck, or car basis. Detector information is on one or more of these bases, whereas cause and effect information may be on either a broader or a more focused basis.

For example, WILD data is prima[illegible] an individual wheel. When developing [illegible] maintainer may well want information on the other wheel on the axle, the other wheels in the associated truck, and the other wheels in the car as well as the other wheels in, for example, a unit train. When looking at associated detector data, owners will want to look at yet other levels. For example, if they suspect that the WILD impact on a particular car was associated with defective brakes, they might want to search both hot and cold wheel detector databases on a wheel, axle, truck, and valve or train level.

Ultimately, on a fleet maintenance management level, fleet performance must be assessed across cars in different services. It is envisioned that certain fleets would be grouped based on a number of similar attributes:

– Car and component design similarity
– Car and component service history
– Future service intensity

Fleet performance across each detector type would be studied for variance between fleets and within a fleet in order to decide the priority and nature of the required maintenance interventions.

The integration of detector data is complex. Therefore, TTCI is addressing development as follows:

- Identifying appropriate performance metrics
- Anticipating the groupings of different metrics at different detector types that will be attractive to car owners/maintainers so that appropriate "pages" can be introduced to the InteRRIS® database
- Identifying cause and effect relationships between poor performance at the detector and associated metrics at other detectors
- Anticipating the development of fleet groupings according to particular car designs and operational metrics

### 9.2 Integration of Wayside Detector Data is Complex and Wide Ranging

Wayside data integration is dependent on many factors, including:

- Rate and stage of development of individual detectors
- Ability to deal with inter-site variance for more complex detectors
- Interim experience gained from using individual detectors and/or detector types as lessons are learned and the full utility of the detector is explored
- Experience gained as car owners/maintainers utilize detector data
- Correlation of data, indices, performance attributes, etc. from the various manufacturers systems and approaches to measurements/sensors used, e.g. TADS and competing ABDs may not have readily comparable severity ranking criteria

TTCI is assembling the basic building blocks for integration. Time histories for individual cars from each detector type will be available to car owners through Inte*RRIS*® in prototype form in the first half of 2006. The ability to "page" through related data on the basis of "cause and effect" defined in this article will be available by the end of 2006.

Automated wayside detection is proving an invaluable aid in reducing maintenance costs by the timely focus of attention on specific cars and car components requiring repair/replacement and enabling planned maintenance.

## 10. CONCLUSIONS

North American railroads are increasingly moving to automated wayside detection to identify poorly performing cars and support planned maintenance. Detectors are being deployed throughout North America, and the information is linked through a continent-wide database called InteRRIS®. As detectors are deployed and experience with measurement is gained, maintenance rules are being developed based on the measured performance to enable maintenance actions.

Data from different detector sites and types is increasing our understanding of actual vehicle performance in service under differing service and maintenance conditions. This knowledge is enabling an understanding of the root cause of poor performance and providing a sound basis for improved design and maintenance.

# THE USE OF AUTOMATION AND TECHNOLOGY IN IMPROVING MAINTENANCE PRACTICES IN A HEAVY HAUL RAILROAD

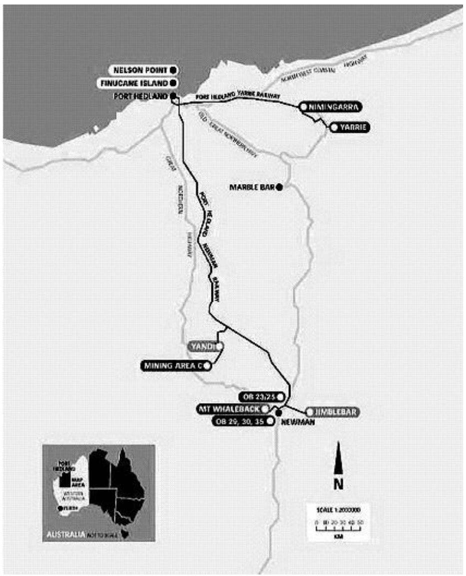
*Russell Donnelly*, Murray Lynch & Mike Darby**

*BHP Billiton operates amongst the most efficient heavy haul railroads in the world. This has been achieved through continual improvement, research and development and innovation. Currently, in the wake of the booming Chinese economy, the railroad is being pushed to the limit and increasing demands are being made on equipment and maintenance personnel. Through the use of automation and technology, the ore car fleet maintains consistently high levels of availability and reliability despite a significantly increased fleet size from two years ago. The article describes some of the innovations and production improvements which have been introduced and which contribute to the safety and reliability of the railroad.*

## 1. INTRODUCTION

BHP Billiton operates the longest and heaviest scheduled trains in the world from mine sites near Newman and Yandi to the port of Port Hedland in northwest Western Australia (Figure 1) The current railings for the year ending June 2005 is in excess of 105 million tonnes compared with approx 80 million tonnes two years ago.

**Figure 1: BHP Billiton operation**




In order to sustain this growth, the ore car fleet size increased from 2210 to a current level of 3051 in December 2004. The forecast growth in ore car fleet size is shown in Figure 2. If forecast market demand is realised, additional growth of

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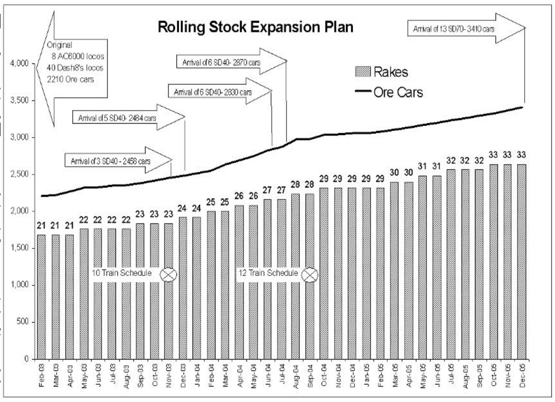
a further 1000 ore cars is expected. In addition to ore cars, rebuilt SD40-2 locomotives have been imported from the US and new SD70 ACe Locomotives have been ordered from EDI/EMD.

**Figure 2: Ore car fleet growth**

Along with the increase in demand, axle loads have also increased by 22 percent over the last 30 years to a current weighted average of 35 tonnes. Over the same period, the average life of a wheel has increased from 340,000 km to 1,800,000 km. The increase in both life and axle load has been due to a history of innovation and research over the life of the project to achieve the performance we see today.

## 2. THE ORE CAR REPAIR SHOP




The primary function of the Ore (
the rolling stock fleet consisting primar
ballast cars, flat cars and miscellaneou
locomotives are machined on a newly i

The maintenance of ore cars predo
and wheel and bogie maintenance. Re(
incurred to reduce manual handling and
been complemented by proactively enco
to improve processes and ensuring f
improvements and change to work proc

Much of the equipment within the workshop has been purpose-built to OCRS specification, and is not commercially available equipment. In recent times, after visiting the OCRS, both international and domestic rail maintenance operators have placed orders for identical equipment to that designed to OCRS specifications.

In conjunction with the research programme, it has been through the use of specialist machines operating at high efficiency and production levels and the collection and analysis of data that the availability and reliability of the ore car fleet has achieved and sustained the current levels.

## 2.1 Packaged Bearing Mounting Machine

The original axle bearing mounting machine was manufactured in 1971. Recently, it was upgraded to include a self-loading and positioning system designed to BHP Billiton's specifications. Prior to the upgrade, two operators were required full time to manually lift each bearing into position in a stooped position. One bearing weighs 50kg and up to 60 bearings can be mounted in one eight-hour shift. Following the modifications, one operator slides the bearing from a pallet at waist level onto the loading system and does not touch the bearing again. The reduced weight required to be lifted by the operator has reduced by over 600 tonnes in one calendar year.

The bearing mounting press has a unique pressing and centering cylinder consisting of a combination of three cylinders combined on both left and right sides of the machine:

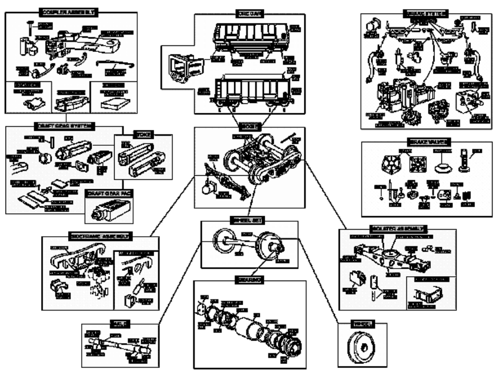
- Cylinder 1 is the centering cylinder, which passes through the package bearing locating in the axle centre.
- Cylinder 2 is the spacer ring centering cylinder, which expands radially from inside the centering cylinder. This device keeps the spacer ring in exact alignment with the axle centre line during the bearing mounting process.
- Cylinder 3 is the lateral pressing cylinder, which moves over cylinders 1 & 2 pressing the bearing onto the axle.

Once the bearing is loaded, the process becomes fully automatic with no further operator intervention required. A PLC control system records the bearing mounting pressure and seating force and records this against the unique wheelset identification number.

## 2.2 Component Tracking System

In 1986, a custom-built rolling stock component tracking system was developed to meet BHP Billiton's requirements. The tracking system required all major components to have their manufacturers year of manufacture and unique serial number entered into the system (Figure 3). The system is used for the every day management of rolling stock maintenance and is invaluable for locating and effective management of defective batches of components.

**Figure 3: Ore car trackable components**



With changes in software operating systems, the original package became obsolete and the component tracking system now runs on a purpose-built variant of a SAP package. Whenever an ore car is brought in for maintenance, the car is physically stripped of necessary components e.g. wheelsets, bogies, etc but in so doing, the components are stripped from the virtual car in the component tracking system. The car cannot be released from service until valid components have been physically and virtually rebuilt onto the car.

Each wagon is fitted with a passive ID tag and readers throughout the system record which mine site a particular wagon has been loaded at and the time. This data is stored against the car ID number so it is possible to determine not only where and on what car an individual component is but also the kilometres travelled by each car and hence component. This information has been invaluable in determining optimum life cycles for critical components such as wheels, axles and bearings. One of the drawbacks to this system is that long wheel and axle ID numbers need to be transposed from components and entered into the component tracking system. This sometimes leads to incorrect or duplicate data being entered.

Over the past 15 years, many methods of component identification have been trialed on ore car components with limited success. The failure of systems, such as bar coding was in the main attributed to the harsh operating conditions. Recently, modern day RF tags were selected for trial as they exhibited the characteristics necessary for reliability in a harsh environment.

### 2.3 Radio Frequency Tagging of Ore Car Components

Following an extensive evaluation of systems in the market, unit cost, ease of fixing, life expectancy, software and backup, a system was finally chosen for evaluation. Tags were fixed to wheels in various locations and subjected to harsh braking and thermal cycles. Tags were glued to the drive plates of wheel machining centers and quickly accumulated several million rotational cycles in an environment of swarf, coolant and vibrations. The tags could be read with 100% reliability at the end of the trial.

Prior to fitting the tags software needed to be developed to ensure that the introduction of the tags would meet production requirements and not introduce delays in component repair/qualification. Software was successfully developed to link the unique tag identification number to the manufacture's component ID number. When the wheelset component ID numbers are created in the component tracking system the newly attached RF tag is scanned linking the unique RF tag ID to the wheelset for the life of the wheel.

Initially, wheelsets were targeted for fitting of the tags due to the more frequent change-out period. Currently, over 5,000 tags have been fitted to wheelsets, they are attached using a heat resistant industrial adhesive in the wheel hub area on the axle bearing side. Off the shelf tag scanners are being used to read RF tags attached to wheelsets. The scanners are linked by cable to a PC in workstations. Further hardware and software has now been developed to cater for workstations where a cable-linked scanner is not suitable. For example, when four wheelsets are rolled out from under an ore car at service, a cable-less remote scanning unit is used to gather the unique serial ID from each wheelset. As it is important for the remote scanning unit to know the position in which the wheelset was located under the ore car, the operator who follows a screen prompt enters this into the unit. The remote unit is then placed in a cradle allowing the serial numbers, in sequence, to be downloaded into the component tracking system. The process is repeated when replacement wheelsets, drawn from a buffer float, are placed under the ore car.

Software has also been developed to allow permanent aerials to be fitted to the machines. The aerials automatically pick up the RF tag ID and communicate to the component tracking system. This is currently executed transparently while each wheelset is being ultrasonically tested in the wheel-qualifying machine. This enables the orientation of the wheels on the axle to be determined in turn ensuring the ultrasonic testing results of each are allocated against the correct wheel ID.

The justifications for introducing the RF tagging system are:

- Increase in component tracking system database accuracy.
- Reduction in man-hours maintaining component tracking system (Correcting incorrect data input).
- Reduction in man-hours manually recording component serial numbers.
- In-field confirmation of component location (When a component serial number cannot be read i.e. bearing ID under adapter).
- Automatic process time confirmation at component level.
- Ability to accurately confirm wayside detection equipment results.

### 2.4 The Wheel Qualifying Machine

The Wheelset Qualifying Machine (WQM) plays an integral part in the scheduled maintenance of the Ore Car fleet. Wheelsets are changed out on a scheduled basis on all 3,000 plus ore cars. As the wheelsets are processed through the Ore Car Workshop qualification and inspection workstations, they pass through the wheel qualifying machine.

The wheel qualifying machine, purpose-built for BHP Billiton, automatically picks up and centers each individual wheelset after which the wheelset is rotated. While rotating a set of electronically controlled water baths which house specially made ultrasonic probes position themselves at critical points across the wheel profile. The critical positions located in the wheel-tread have been determined over 20 years of research into premature wheel failure while in service, manufacturer's wheel making techniques and metallurgical cleanliness/makeup of wheel steels.

WQM is a most critical piece of condition-monitoring equipment. The machine has identified numerous heats (batches) of wheels which have been found by the machine to contain both service induced and manufacturing subsurface induced defects within the wheel. Had these wheels been left to run undetected in service they would have failed resulting in at least delayed train railings and at worst catastrophic derailment.

The RF ID tag fitted to the wheelset is used not only to identify the wheels and axle but also to act as a reference point to identify circumferentially where a defect is located. Once the machine has completed its cycle, the result of the scan is an ultrasonic record in two dimensions of each wheel. This data is stored against each wheelset ID as read from the unique RF ID tag. Defects in any wheel can be retrieved at any time and the previous history of a defect can be recalled and compared to the current scan to monitor defect initiation and propagation. Each defect is assigned a severity rating which ranges from immediate machining or scrapping to no action required. When the wheelset is next identified in the workshop for maintenance, the defect history is automatically flagged for attention and review.

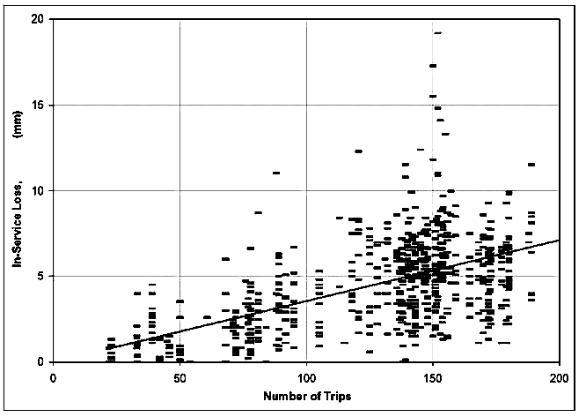
### 2.5 High Capacity Underfloor Lathe

At the inception of the Mt. Newman Mining project in the late 1960s, two Hegenscheidt 105 hydraulic copying underfloor lathes were installed to machine wheels on ore cars and locomotives. The machines had a rated capacity of 28 tonne axle-load and would typically take, depending on severity of wheel wear, between 10 to 12 hours to machine a locomotive. Each wheel had to be individually measured for diameter and flange thickness and manual calculations carried out to determine minimum metal removal to ensure tolerances were matched between wheelsets, bogies and within the locomotive.

As these machines were reaching the end of their life-cycle, tenders were called for a machine that would offer enhancements in safety, production and reliability. The specification called for an automatic vehicle indexing system which would pick up a locomotive from outside the lathe, automatically gauge all wheels, compute optimum machining cycles, machine all wheels and transfer the finished locomotive to the other side of the lathe on completion. BHP Billiton worked with the successful tenderer, Hegenscheidt, to develop this system, which had never been combined with this type of machine before. When the lathe and progression system was commissioned in Jan 2004, it was able to meet the specified requirements of gauging and machining two 200 tonne locomotives in 8.5 hours and 12 ore cars in 9 hours. The machine productivity has since more that doubled whilst at the same time the quality of finish and dimensional tolerances has also improved.

During the machining cycle, the lathe measures the profile of each wheel prior to machining and again at finish and compares this to a master profile. The amount of metal removed during the machining cycle is calculated from the profiles and this is used as an assessment of the performance of locomotive wheels. If the (metal removed) x (number of trips) increases, it could be symptomatic of changed track conditions or altered driving practices.

**Figure 4: Wheel in service loss**




The data collated, typical of that shown in Figure 4 is used to determine projected annual wheel usages for budgeting purposes as well as comparing performance of wheels from different manufacturers.

## 2.6 High Capacity Portal Lathe

In 1990, a Hegenscheidt PN180 p this was the only one of its type available in the world. Presently, it is believed there is only one other machine in operation. The machine features:

- Two ten tool indexing tool turrets
- Full automatic operation mode
- Self-loading wheelset device

When commissioned, the machine had a specified capacity of 40 wheelsets in an 8-hour shift and as it was then, is still the central and most important machine for the maintenance of the ore cars.

Ore cars are scheduled in for maintenance based on the number of trips they have undertaken as recorded by passive ID tags. The number of trips is determined based on the degree of wheel hollowing. If hollowing is allowed to develop, hunting and subsequent flange wear can result as well as field side hollowing giving rise to high rail stresses as well as high wheel stresses in worn wheels.

As all cars scheduled for maintenance require, by default, a wheel turn, the productivity of this machine is crucial to the throughput of the workshop.

In order to improve the throughput, the following projects have been undertaken recently to reduce the cycle time. All these projects have been undertaken using in-house expertise and local contractors:

– Automatic tool monitoring to retract the tool post in the event of a tool breakage.
– Separate wheel profile measuring station. The profile measuring machine is now located outside of the wheel-turning machine. The profile is measured prior to the wheelset entering the lathe and measured co-ordinates are passed to the CNC controller. This process eliminates the need to measure the profile inside the turning machine, hence significantly reducing overall turning machine cycle time.
– Automatic data transfer to GSAP (improved accuracy of data).
– Automatic tool setting device.

The net result of this is that the overall cycle time to machine a wheelset has improved by xx %

## 2.7 Coupler Life Extension

***Prevention***

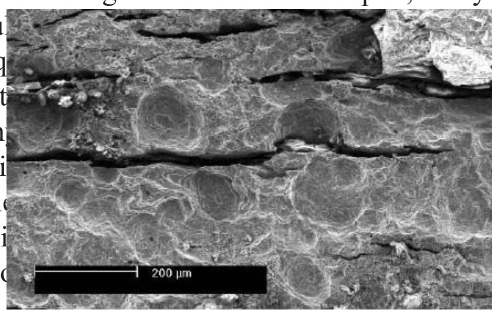
BHP Billiton operates a locally manufactured ultra capacity coupler in all ore cars. Over the years, BHP Billiton has worked with the manufacturer to improve the impact resistance and overall life of couplers. Several modifications have been made to the patterns to reduce cracking and ultimate failure.

In an effort to increase overall production rates, the standard train leaving Port Hedland is now between 300 and 330 cars long compared with 220 a couple of years ago. This increase in train length, combined with an unfamiliarity in driving trains of this length, gave rise to a considerable increase in broken couplers as well as an increase in workshop scrapping rates.

Based on work carried out by Monash Institute for Rail Technology using BHP Billiton's instrumented ore car, it was found that coupler fatigue indices were increased by up to a factor of 1.8 when comparing 200 car trains to 300 car trains over the same sections of track. This corresponds to a reduction in coupler life of up to 25%. Considerable work has gone into improving the quality of the coupler, reducing the in-train forces and detecting faults in couplers.

Based on work carried out by Monash IRT, corrosion pitting and minor fatigue cracking was evident on the coupler surface from an early time (<1 year) (Figure 5). Based on this research, the surface treatment methodology has been revised and early indications are that coupler life could be extended by one to two years.

**Figure 5: Coupler surface corrosion**




***Detection***

Owing to the complex nature of the casting at the head of a coupler, many conventional NDT techniques are difficu
Over the years, numerous NDT techniq
proved successful. For the last 12 mont
been working with a US-based compan
Scan, utilising non-linear vibro-modulati
to analyse complex shapes. The principl
whose frequencies are modulated by i
provides a high degree of discriminati
material inhomogeneities.

"N-Scanâ 1000 consists of a PC-based Data Acquisition and Processing station, Digital Synthesizer, High and Low Frequency Amplifiers, two ultrasonic sensors, and magnetorestrictive shaker. One of the ultrasonic sensors and the shaker continuously transmit high, $f_m$, and low, $f_n$, frequency signals, respectively. Another sensor receives the modulated signal and forwards it to the acquisition and processing station. The modulation appears as two side band spectral components (left, $f_m$-$f_n$ , and right, ,$f_m$+$f_n$ , of the transmitted ultrasonic frequency, $f_m$ ,). The result of the test is a Modulation Index (the ratio of the sideband amplitudes to the amplitude of the transmitted ultrasonic signal) normalized and averaged across the selected ultrasonic frequency range."[2]

In order to test the effectiveness of the N-Scan unit on couplers, two couplers were sent to the US for instrumentation and testing in January 2003.

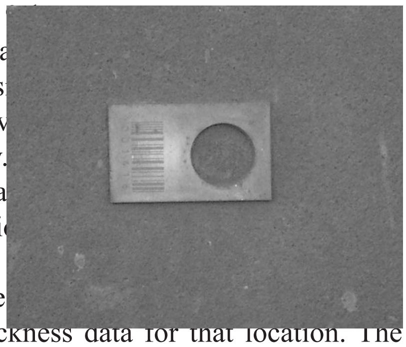
One of the couplers was free of cracks and used as a reference whilst the other had a 30 mm crack in the lower pulling lug area. The initial results of these tests showed the technique could detect the crack and had the potential to be used as a tool for the in-field determination of coupler cracks.

In order to validate these tests, two additional couplers were sent to the US in 2004 for further evaluation. The results of these tests were again positive and clearly showed the technique and instrumentation could identify cracks in couplers. This technique shows considerable promise as a workshop tool for the inspection and qualification of couplers, in particular in areas which are not visible and without the need to remove the couplers from the car. A unit is currently being purchased to carry out evaluations in a workshop environment and calibrate against further known defects.

### 2.8 Car Care

Car care is a system developed for BHP Billiton by a local Australian consultant for the determination and assessment of ore car structural integrity and remaining life.

**Figure 6: Sidewall bar code**



On each ore car body, there are coded templates placed at the same stra locations (Figure 6). Each bar code is ass to the unique car ID as well as the indiv location of the template on the body. template has a hole in it to allow an ultra probe to be placed in the same locati measure the side wall, end wall or thickness. A hand held reader simultane reads the bar code and collects the thickness data for that location. The reader then uploads the collected data to the car care system. The number of trips each car completes as well as axle load data from a weigh bridge is also fed into this system. This reasonably accurate loading spectrum and fatigue cycle history, along with the ore car thickness measurements is then used as inputs for a finite element analysis (FEA) of the body.

The system outputs are the remaining fatigue life for individual walls and floor, residual thickness, annual corrosion and wear rates and a recommended repair date. The system also has the ability to input the type, size and location of various defects, which are taken into account in the FEA analysis.

In a large fleet of ore cars with a high percentage of ageing bodies, it is not possible to visually and structurally inspect every car on a regular basis. The use of this system provides a first pass ranking of the worst cars in the fleet that can then be targeted for a more thorough inspection as well as an overall indication of the structural integrity of the fleet.

### 2.9 Instrumented Ore Cars

The BHP Billiton ore car fleet contains three instrumented ore cars which are used for the continuous collection of information regarding track condition and vehicle response. The ore cars are standard revenue wagons that have been fitted with accelerometers, strain gauges, displacement transducers and a GPS systems. A digital data recorder powered by batteries supplemented by solar chargers, collects the data in real time and stores onto solid state memory. As the car approaches the port, the data is automatically downloaded via radio to a web server for post processing and analysis.

Information recorded by the cars includes:

- Vertical suspension travel (ride quality)
- In-train forces
- Longitudinal accelerations
- Sidewall strains
- Wheel accelerations (track conditions)
- Lateral stability
- Draft pocket strains

In addition, there are several spare
for specific project work. The informatio
department to determine specific areas
give adverse vehicular responses or high
for maintenance before there is a delete

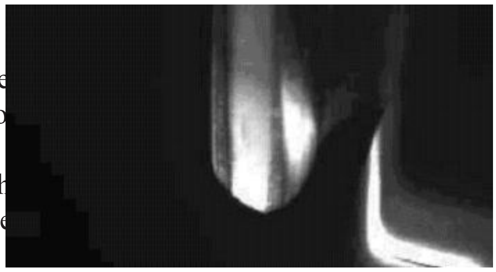


Figure 7: Worn flange

### 2.10 Video Imaging

As trains enter or leave the Port, they pass by an array or cameras mounted at track and axle level. Using high speed digital photography, images are taken of a number of components of each car. These images are processed and an exception report is produced of problems with the car. In particular, the areas that are photographed include:

- Car number
- Wheel tread - looks for hollow tread
- Wheel flange - looks for thin flanges (Figure 7)
- Wheel diameter - measures wheel diameter

- Sideframe damage (Figure 8)
- Bogie springs - looks for missing or broken springs (Figure 9)
- Brake shoes - looks for missing shoes and calculates the thickness of each shoe
- Handbrake - looks for handbrakes that are applied
- Coupler to body clearance - looks for collapsed draft packs.
- Bearing end cap bolts - looks for missing bolts (Figure 10)

The video imaging system uses high speed processing and digital image recognition to analyse each photograph and compare the image to a standard outline and from that determine any anomalies. The images represent some of the exception reports that are produced.

The system has been particularly beneficial in picking up cars with relatively newly machined wheels which may be showing signs of premature flange or tread-wear due to problems with bogies. Once a wheel of this type is detected, the exception report will indicate the severity of the fault and the car can either be cut out or a visual assessment made.

**Figure 8: Bent pedestal**

**Figure 9: Incorrectly seated springs**

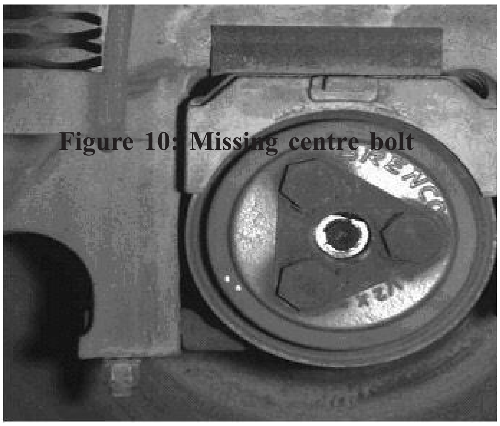


**Figure 10: Missing centre bolt**

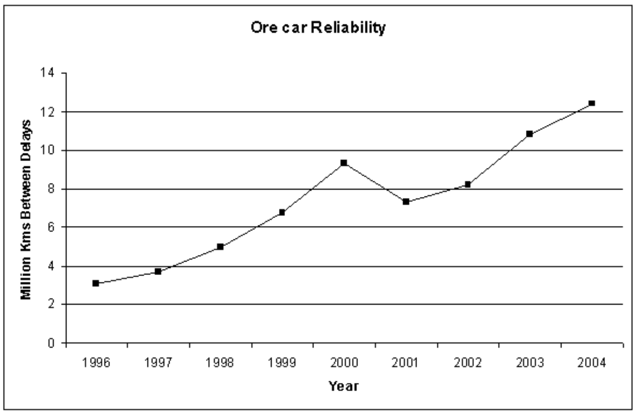
**2.11 Bearing Acoustic Monitoring**

In early 2004, a bearing acoustic monitoring system was installed on the mainline. This system listens to all ore car bearings on loaded cars and captures every bearing approximately every 30 hours. The system can detect a variety of faults in inner and outer cones, cups, rollers and cages as well as loose backing rings. Each acoustic signature is post processed at the wayside site and exception reports are sent to a server via a radio link. Faults are ranked according to severity and the acoustic signature can be played back for reference. Exception reports are available approximately 30 minutes after the train has passed enabling severe defects to be cut out before the next trip.

Although the system is still being customised to suit BHP Billiton's unique operating environment, to date, every bearing that has been flagged as having a fault, when stripped has been found to have that nominated defect.

## 3. ORE CAR RELIABILITY

Ore car reliability is tracked by measuring the mainline delays caused by ore car failures against the kms travelled for a particular month. Owing to the single line operation of the railroad, a relatively minor fault or failure on an ore car can cause significant delays and train cancellations resulting in lost tonnes that, in this business environment, cannot be recovered. It is, therefore, a prime focus on the workshop's management to ensure that ore car reliability is maintained at high levels. Figure 11 shows the reliability, measured in millions of kms between delays from 1996.




As can be seen from the graph, the reliability has improved significantly when compared to the situation nine years ago. The decrease in 2001 was due to several heats of wheels that were put into service and subsequently developed flat spots due to uneven heat treatment of the wheel. These flat spots were picked up on the wheel impact monitor and the train stopped for inspection.

By using the component tracking system, workshop staff were able to identify every wheel from the affected batches and which car and position they were on. This significantly reduced the time taken to remove the affected wheels from service and reduced the risk of a broken weld due to high impact loadings. Without this system, manual inspections would have been required for every wheel in the fleet with associated delays and risk of error.

## 4. SUMMARY

BHP Billiton's iron ore railroad is currently one of the safest and most efficient railroads in the world. Productivity figures for rolling stock, labour and asset utilisation are equal to, or in most cases, an order of magnitude, greater than other recognised heavy haul railroads in Australia or overseas.

This current position has been achieved by pushing the boundaries of commonly accepted best practice and challenging views of what can be achieved. In close cooperation with BHP Billiton's research partners, small but continual, incremental steps have been taken over the last 30 years. Some things have produced significant benefits whilst others have been discarded after trial and evaluation.

Where equipment did not exist that was felt beneficial to the improvement process, it was purpose-designed and built for our system. High production machinery has been justified and purchased to improve the quality and throughput of workshops and highly automated processes have, most importantly, improved the safety and work environment of maintenance personnel.

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# RESEARCH PRIORITIES FOR FREIGHT RAILROADS IN NORTH AMERICA

*Roy A. Allen,*[1] *Scott B. Harvey*[2] *& Semih Kalay*[3]

## 1. INTRODUCTION

It is clear that North American freight railroads face a new series of challenges that are quite different from those the industry faced just a few years ago. The industry has gone from seeking to shed capacity to attempting to manage growth and historically unprecedented levels of traffic. While increasing demand has enabled railroads to sustain price increases and to improve earnings and profit levels, it has also created capacity and service issues for an industry that is already highly capital intensive and struggles to earn the cost of capital. Where in the past the emphasis was on cost reduction, the emphasis now is on increasing the utilization of existing capacity, improving service to help justify increased prices and yield, and ensuring returns on investments to justify capital investments to maintain and increase capacity.

This paper details the new challenges and describes some of the research initiatives in North America designed to meet these challenges. Most of the projects are associated with safer and more efficient operation of heavier axle loads to better use of existing capacity.

Transportation Technology Center, Inc. (TTCI)[4], a subsidiary of the Association of American Railroads (AAR), is responsible for the executing the industry's collective research program, commonly referred to as the Strategic Research Initiatives (SRIs). The content and extent of the research program is determined by a series of railroad committees, based upon the threats to and needs of the freight railroad industry. The final program and budget is approved on an annual basis by the railroad chief executive officers acting as the AAR's Board of Directors.

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4. TTCI has its headquarters in Pueblo, Colorado at the Transportation Technology Center, a unique railway testing center owned by the US Department of Transportation (DOT). TTCI operates the center under a care, custody & control contract with US DOT.

## 2. CURRENT BUSINESS CONDITIONS

Before we begin to describe the more important research projects, we will examine the general business conditions prevalent in North America and in the United States in particular. Through the year 2005, the U.S. enjoyed positive GDP growth for 17 consecutive quarters (Figure 1). Since freight transportation demand is largely derived from economic activity in business sectors like mining, manufacturing, agriculture, and international trade, the general economic trends have been favorable. The overall demand for freight traffic in the U.S. has increased with general economic growth. Railroads have participated in that growth with tons originated and freight revenue increasing (Figure 2).

**Figure 1**

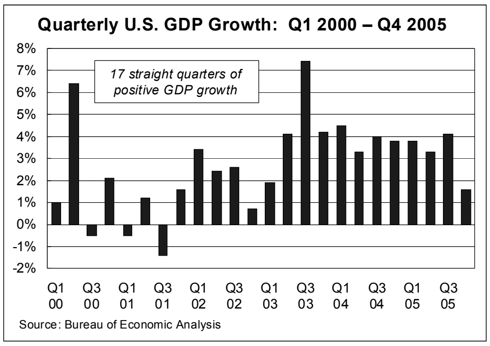
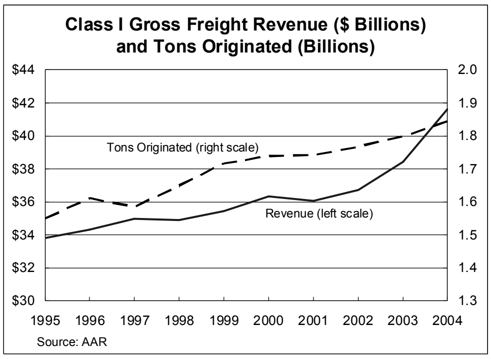
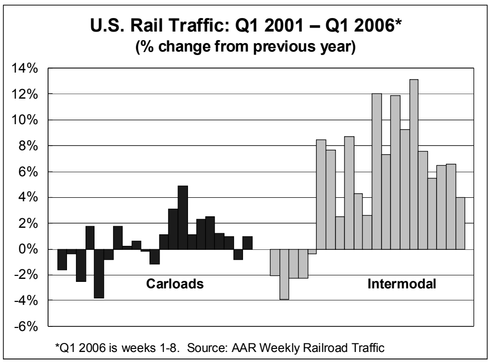



**Figure 2**




Increasing volume is the major driving force in the industry. Over the last 10 years (1995 to 2004), carloads originated have increased 27 percent, tons originated 19 percent, and ton miles 27 percent. Growth in volume continued in 2005, with U.S. railroads reaching record levels of ton-miles and intermodal loads.

**Figure 3**

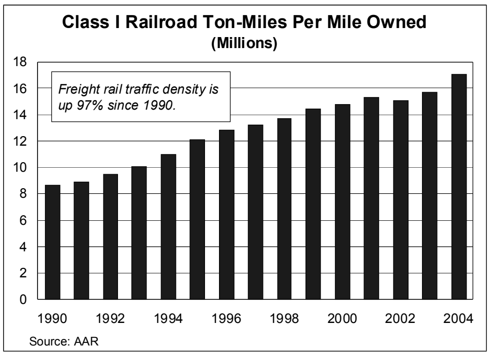



The growth rate accelerated in 2004 and 2005, particularly in intermodal traffic (Figure 3). Through the first quarter of 2006, intermodal traffic has increased for 15consecutive quarters. Growth has been enhanced by an overall tight freight transportation supply, in particular, limitations on truck and highway capacity. Increasing fuel prices have also acted in the railroads' favor giving them inherent energy efficiency advantage over highway trucks.

The growth in railroad traffic has increased density in the rail network (Figure 4) and has led to capacity constraints in parts of the rail network.

Railroads have been able to translate the overall tight market conditions into increased prices and yields. For the first time in many years, railroads have been able to exert pricing power.

**Figure 4**

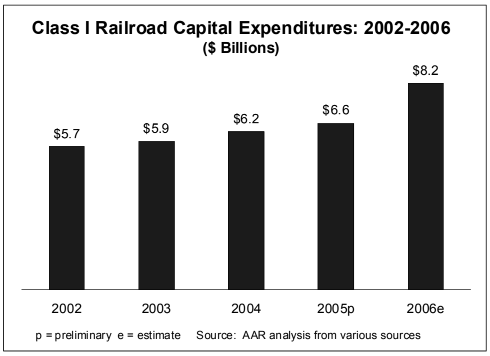



The combination of increased volume and increased pricing power has enabled railroads to increase revenues to a level higher than that of cost increases and to increase total profits and capital investment. Net railway operating income increased by 3.1 percent in 2004 and by 4.4 percent in 2005. (*Railroad Revenues Expenses and Income. U.S. Class I Railroad,* 4th Quarter 2005, AAR Policy and Economics Department.)

The increase in demand has led to a significant increase in capital investment. The AAR's Department of Policy and Economics notes that, based on an analysis of recent railroad financial presentations, press releases, and other sources, it appears that Class I capital expenditures are set to rise sharply in 2006 to around $8.2 billion — up from around $5.7 billion just 4 years earlier. This huge increase demonstrates the diligence with which railroads are responding to the capacity issue (Figure 5).

Despite favorable trends, significant issues continue to face the industry. While profitability has increased, most railroads still do not earn the cost of capital. In 2004, one railroad earned the cost of capital as measured by the Surface Transportation Board (STB). Analysts expect that three of the seven Class I railroads will earn the cost of capital in 2005.

**Figure 5**




## 3. ECONOMIC OUTLOOK

Most economic forecasts, including from the U.S. Congressional Budget Office and Global Insight, call for continuing economic growth and increasing freight demand, with railroad intermodal traffic growing 5.9 percent per year from 2005 to 2010 and non-intermodal traffic growing 2.0 percent per year (Figure 6).

**Figure 6: Economic growth**

| | '05 | '06 | '07 | '08 | '09 | '10 |
|---|---|---|---|---|---|---|
| CBO | 3.8% | 3.6% | 3.4% | 3.1% | 3.1% | 3.1% |
| Global Insight | 3.7% | 3.0% | 2.8% | 3.1% | 3.1% | 3.1% |

- Freight 04-16 2.4% per year
- Railroads
  - Nonintermodal 05-10 2.0% per year
  - Intermodal 05-10 5.9% per year

AAR Department of Policy and Economics

The rail outlook is influenced by the fact that there will be continuing constraints on highway capacity. The American Association of State Highway and Transportation Officials (AASHTO) draws a direct connection between the ability of railroads to increase capacity and capital investment, and the demands for highway capacity. This suggests a need for public support for freight capacity enhancement (Figure 7). Note that AASHTO's rail ton-mile estimates vary with the level of railroad investment. Increasing investment from $8.2 billion (the estimate for 2006) to $10-$11 billion v rail-ton miles by 48 percent by 2020*.

**Figure 7: ASHTO study**

| Scenario | Annual Railroad Investment (Billions) | 2020 Rail Ton Miles (Millions) |
|---|---|---|
| No Growth | 5.3 – 6.3 | 1,239 |
| Constrained investment | 7.3 – 8.3 | 1,531 |
| Aggressive investment | 10.2 – 11.2 | 2,265 |
| Base Case | 8.8 – 9.8 | 1,821 |

## 4. THREATS/CONSTRAINTS/RIS

Several threats, constraints, and ri is to be able to take advantage of these favorable demand trends and projections. Industry profitability needs to increase to enable railroads to generate the funds necessary for capacity expansion.

There is concern over railroad safety and security, particularly involving hazardous materials transportation and the need to prevent and efficiently respond to hazardous materials accidents and incidents. The industry's record in hazardous material transportation is excellent – 99.998 percent of hazardous materials carloads arrive at their destination without a release caused by a train accident. Hazmat accident rates are down 90 percent since 1990. And rail transport of hazardous materials is 16 times safer than trucks (AAR). However, some recent high profile accidents and concerns over security have led to the threat of government action at all levels, which would increase the cost of hazardous materials movements and impair efficient movement.

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* *Freight Rail Bottom Line Report*. AASHTO. 2002, p. 64.

Environmental regulations for both emissions and general environmental issues are increasing railroad costs. Increased density has led to many communities initiating plans to reduce noise and traffic delays, placing further demands on scarce railroad funds.

There are indications that the rate of increase in railroad productivity – which has been particularly impressive since deregulation – has begun to slow down, placing greater emphasis on finding new ways to increase productivity and efficiency in order to increase railroad profits and enable railroads to respond to demands for capacity increases. The technology exists to operate trains safely with one-person crews, but labor is resisting this effort, a source of significant potential productivity growth in the future.

Increased demand and its impact on congestion and density have led to service problems in some areas and resistance by some shippers. This, in turn, has contributed to efforts to re-regulate the industry, which would severely hamper the industry's ability to address capacity requirements.

Increasing density is having an impact on the railroad cost structure. One way railroads have addressed increasing demand and capacity constraints has been to increase axle loads, which has in led to the industry's desire to acceler development and implementation efforts

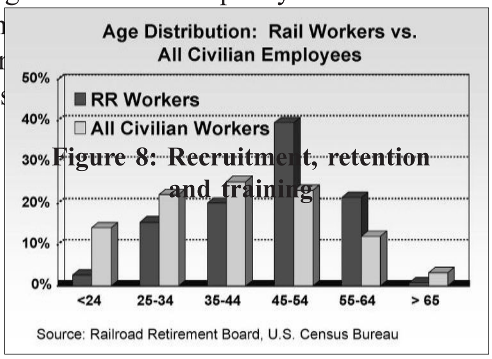



**Figure 8: Recruitment, retention and training**

The railroad workforce is aging and skilled workers represent a constraint on capacity (Figure 8). Large numbers of new workers will need to be recruited and trained (at considerable expense) in future years. This generates a challenge to researchers to, on the one hand, develop technologies that will reduce the replacement requirement and, on the other, develop techniques to efficiently train the new workers required.

## 5. IMPLICATIONS FOR RESEARCH

The industry's SRI program has been designed to address four primary industry business objectives:

– Safety
– Efficiency

– Reliability
– Effective and efficient regulatory and legislative policies

Clearly the outlook for the industry and the threats to that outlook support and increase the need to address these issues. The need to contribute to these objectives is enhanced by:

– The recent slowdown in safety improvement and productivity growth.
– The continuing need to improve railroad profitability, generate capacity investments, and to increase asset utilization to reduce pressures on capital spending.
– The increasing importance of avoiding line-of-road failures due to accident or equipment or track failure, and to maintain the "fluidity" of the network.
– Legislative and regulatory threats in areas of safety, security, and environment.
– The immediacy of the need to address profitability and capacity issues.

At the same time, competition for scarce railroad funds makes it increasingly important that research projects demonstrate timely, significant potential industry improvements that can be instituted with minimal implementation costs while not ignoring longer term, more sweeping pot

In the sections that follow, each of th RI program (safety, efficiency, reliability, and l he program is compared with current safety s nd legislative and regulatory conditions. Gaps

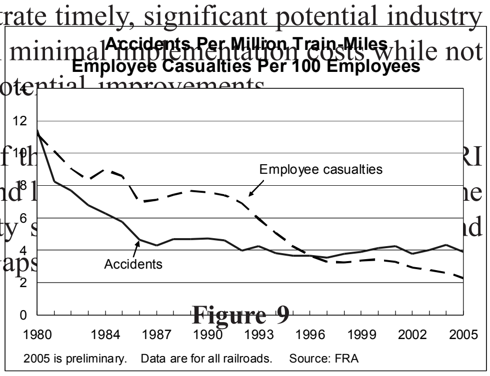



**Figure 9**

### 5.1 Safety

Railroad safety has shown marked improvement over the last two decades – especially since deregulation. Many factors contributed to this gain, including new technology. Improvement seems to have slowed since the late 1990s. Accidents per million train-miles rose in 2004, but declined sharply in 2005 (Figure 9).

The current research program has a strong emphasis on safety improvement. Statistics addressing accident causes show that 40 percent of reportable (Federal

Railroad Administration) accidents were attributable to human factor causes, 31 percent to track causes, and 13 percent to equipment defects.

The cause categories tallying the highest track and equipment damage costs in 2004 were:

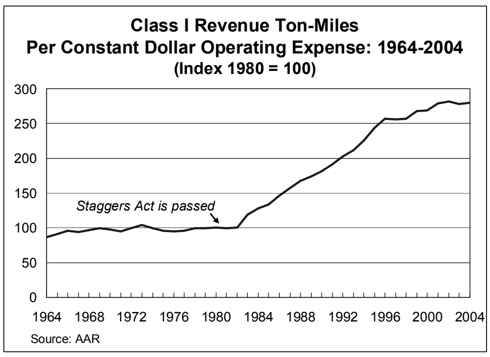
| Cause | Damage Costs ($ Millions) | Number of Accidents |
|---|---|---|
| Rail, joint bar and anchors | 70 | 318 |
| Track geometry | 35 | 376 |
| Axles and journal bearings | 21 | 78 |
| Misc. (esp. vandalism, interference) | 20 | 119 |
| Switching rules | 20 | 477 |
| Frogs and switches | 17 | 207 |
| Truck components | 11 | 71 |
| Wheels | 11 | 79 |

*Source: AAR Policy and Economics Department from FRA data.*

The current SRI program is highly focused on reducing track and equipment caused derailments. All of the major causes of derailments mentioned above (with the exception of those relating to switching rules and miscellaneous, both of which involve differing forms of human factors) are addressed in the current program. The current program includes several special trackwork projects that address the reduction in accidents due to frogs and switches.

The most obvious gaps in the current program, in terms of railroad safety, are grade crossings, human factors, and employee injuries and fatalities that do not result from accidents and derailments. Other government and individual railroad efforts address these issues; for instance, Positive Train Control, in the human factors area.

**Figure 10**




## 5.2 Efficiency

Railroads have made significant productivity improvements and efficiency improvements, especially since deregulation (Figure 10). There are indications, however, that the rate of increase has slowed, and that the low hanging fruit, so to speak, has been picked.

Recent gains in traffic and profitability do not lessen the need for productivity and efficiency improvements. The industry has yet to earn the cost of capital. Meeting the cost of capital on a sustained basis is essential to meeting demand requirements.

Between 2000 and 2004, Class I railway expenses increased from $30.2 billion to $36.4 billion, or 21 percent. The theme of recent strategic plans has been to match SRI programs and spending to major areas of railroad costs, both operating and capital expense, in particular with regard to equipment and infrastructure. After depreciation, railroads typically spend $15 billion to $17 billion each year to provide the high quality assets needed to operate safely and efficiently.

The evidence is that SRI programs have contributed significantly to railroad efficiency improvements and cost reduction. For instance, post-audits of past SRI programs show results such as:

- Annual savings of $250 million in rail wear, fuel usage, and wheel wear from locomotive mounted lubrication.
- Annual savings of $100 million in reduced rail installation costs from the introduction of harder, cleaner rail steel.
- Annual savings (when extrapolated to the industry) of $31 to $61 million in bridge maintenance and renewal costs (railroad engineering departments' estimate).

All SRIs are designed to reduce railroad costs, particularly in the track and structures and equipment repair and maintenance.

**Figure 11: Road spending trends**
(Total spending = 37.7 billion)

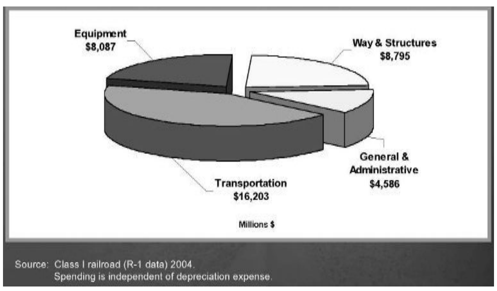



Figure 11 shows the current distribution of railroad operating expense: transportation = 43 percent, equipment = 22 percent, and maintenance of way = 23 percent. The major transportation cost centers are fuel and labor.

Recently, there has been a sharp increase in fuel costs. In 2004, costs were 27 percent greater than in 2003, and 59 percent greater than in 2002.

Although fuel surcharges and hedging have limited the impact of fuel price increases (and railroad fuel efficiency in comparison with trucks actually gives railroads a competitive advantage), minimizing fuel costs continues to be a major railroad goal for economic and environmental reasons.

Figure 12 shows maintenance of way expenditure breakdowns. The major cost areas are rail and track material (including special trackwork), ties, signals and interlockers, ballast, and bridges.

Three current projects address overall track and structures costs, five address rail, four address ties, and six address bridge costs. However, the SRI initiatives do not address signals and interlockers and grade crossings.

Maintenance of equipment expenditures and capital expenditures for railroad equipment were $7.2 billion divided almost evenly between locomotives and freight cars (Figure 13).

Figure 14 shows the major cost categories of freight car repair and maintenance. These categories are wheels, brake systems and components, couplers, yokes, and draft gears, and general repairs. Wheelsets are the major cost area (44 percent), followed by brake system components (27 percent).

**Figure 12: Railroad spending trends**
Roadway (MOW) track related spending

**Figure 13: Railroad spending trends**
Equipment spending = $7.2 billion (2004)

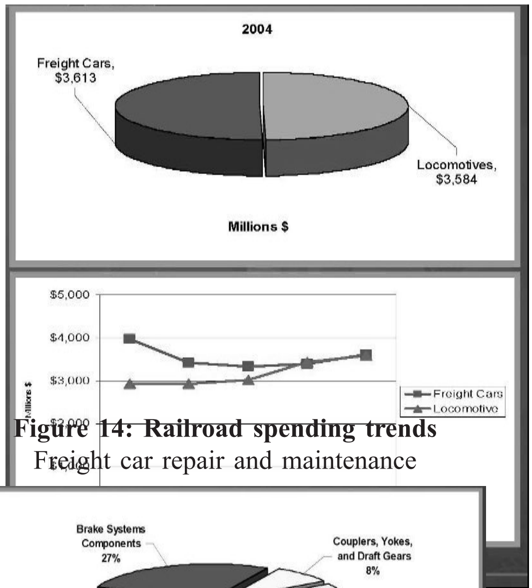
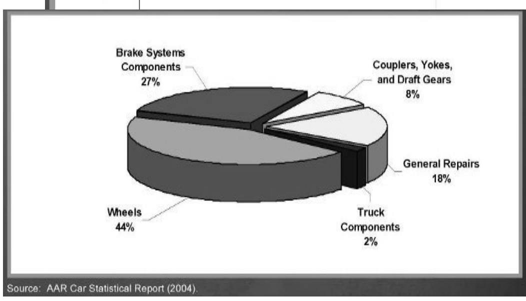



**Figure 14: Railroad spending trends**
Freight car repair and maintenance



Material costs per wheelset increased 11 percent in 2005 and are increasing again in 2006. Extending wheel life is a major research priority. However, it should be noted than 50 percent of the freight car fleet is owned and maintained by private car owners.

In terms of efficiency and cost reduction, the current direction of the program appears to address major cost areas. The major gaps – locomotives and fuel, labor costs, and signal and communications – are addressed in other industry

Another issue is the demand for capital investment to meet capacity needs. Research spending and capital investments are closely related. Both are designed to generate a stream of future benefits and indirectly compete for available funds. And research can both reduce demands for capital (by increasing the utilization and life of existing assets) and increase the demand for capital by generating implementation costs.

### 5.3 Reliability

The major change that has taken place in the last few years has been the emergence of capacity constraints as a major issue. The current railroad network has capacity constraints in several key areas. The cost of in-service failures has increased dramatically, as has the time required to recover from service disruptions. A prime objective is to eliminate line-of-road failures.

One-half of the projects in the current plan include among their benefits reductions in line-of-road failures and train delays. A major focus of the SRI program (and of TTCI's internal research and development efforts) has been to support predictive maintenance, facilitated by wayside detectors and information systems to prevent line-of-road failures and to improve asset life.

In 2006, TTCI plans to conduct a survey of the causes of line-of-road failures to determine whether the causes are adequately addressed by the SRI program or by other industry or individual railroad efforts.

## 6. RESEARCH PRIORITIES IN 2005

Research priorities for 2005 were clear: improve the safety and efficiency of operating heavy axle load cars and reduce the stress state of the railroad. Doing this, reduces the capital intensity of the industry and improves its service reliability.

As the research budget for 2005 was being prepared and discussed with the relevant committees, the chief operating officers of the AAR member railroads provided a challenge to TTCI and the Railway Technology Working Committee (RTWC) – the industry committee that provides guidance and oversight to the SRIs. That challenge was to develop a plan for the research program to bring certain technologies to fruition quickly in order to help mitigate problems that were being experienced due to increased axle loads and increased tonnage on many lines.

Under the guidance of the RTWC and other committees, TTCI developed a plan to accelerate seven research initiatives. If the funding were made available, the plan called for certain technologies to be brought to market in 2 years. As a result, the AAR Board was asked to approve a research budget for 2005 that was significantly higher than the previous year. This was the first time in more than 10 years that the Board approved an increase in the expenditure on research.

With very active and knowledgeable technology partners, TTCI is close to finalizing state-of-the-art inspection technologies to improve rail flaw inspection (of the whole rail) and, for the first time, develop the ability to detect wheel and axle cracks under a moving train. (The axle crack detection technology is being developed using TTCI internally generated funding.) And we are close to helping to solve a big industry problem by increasing the life of insulated rail joints primarily through improved designs and support structures. Major advances have also been made in understanding axle fatigue lives under heavy axle load cars, and the reasons why some freight cars perform so poorly – the so-called “bad actors.”

While working hard on the North American railroad research program, we were successful in serving our other customers, both at home and abroad. A notable highlight was the installation of a very large order of acoustic bearing detectors (known as TADSä, in our terminology) to the Ministry of Railways in China. With the help of our partners in China, 24 units were installed in about 4 months – another accelerated program successfully executed.

The following subsections briefly describe the accelerated efforts:

### 6.1 Improved Rail Flaw Inspection

The design, assembly, and laboratory checkout tests of a prototype of the world’s first laser-based rail inspection system was completed in 2005 under the supervision of engineers from TTCI and Tecnogamma of Italy.

The lasers and the associated electronic equipment were shipped to the U.S. and installed on a hi-rail vehicle donated by Union Pacific Railroad

(Figure 15). The single-rail inspection system was put through checkout tests at the Transportation Technology Center's (TTC) Rail Defect Test Facility, where known defects are installed in track for rail inspection car evaluation tests.

TTCI and Tecnogamma are testing the system to inspect the entire rail cross–section, including the rail base and rail web. Unlike conventional probes that must contact the rail top in existing inspection systems, the laser-based system is not affected by rail surface defects and contamination, as the lasers inspect the rail from side to side. It is a non-contacting system.

The capabilities of a single-rail pre-prototype system are being demonstrated at TTC, and in 2006 will be demonstrated in revenue service. Evaluation includes verification of the laser-based inspection system's reliability, repeatability, and ability to inspect the entire rail cross-section at speeds up to 20 mph. Current plans include the development of a j
ultrasonics as an additional feature.

**Figure 15: Laser-based rail inspection system**


## 6.2 Cracked Wheel Detection

Laboratory tests conducted in ea
inspect railroad wheels for internal defe
designed ultrasonic probes and detectio
for railroads has been to inspect wheels f
intensive, nondestructive inspection techniques. However, there are indications that running heavier axle loads increases the propensity for wheel failures to occur in service. On many routes and services, removing freight cars from service for inspection on a regular basis is not a viable option, but neither is having derailments (albeit, relatively few) due to broken wheels. Hopefully, the new detection system will enable wheels to be inspected without removing them from service.

In 2005, TTCI partnered with DAPCO, a Connecticut-based ultrasonic inspection company, to develop a detection system capable of inspecting internal wheel defects, such as shattered rims and wheel tread defects. The prototype system is capable of inspecting one side of a railcar at speeds up to 5 mph. The design includes servo-driven, tandem inspection heads guided by a rack-and-pinion system capable of tracking car wheels at speeds of 8 feet per second. At the prototype installation at TTC (Figure 16), there are four stations, each with the probes and tracking systems to measure all four wheels of one side of a freight car.

**Figure 16: Cracked wheel detection system**

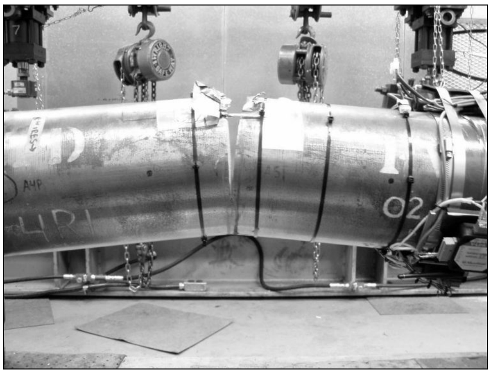
## 6.3 Cracked Axle Detection

In the case of wheels also, there are indications that axle failures might be on a slight increase due to heavier axle load operations; as with wheels, there is a need to inspect axles for cracks without removing the cars from service. TTCI's internal research and development efforts in 2005 resulted in the successful completion of the proof of concept demonstration for the application of a laser-based ultrasonic detection system. The concept is similar to that employed for the rail inspection system and is completely non-contacting. The prototype system is capable of detecting axle defects in the axle body and journal bearing area at speeds up to 20 mph. The system, also installed at TTC, has been developed in conjunction with an industry expert

## 6.4 Axle Stress Environment

As stated earlier, axle fatigue iss bigger and gross weight is increasing. In understand the load environment and fati Off-site tests were completed to identify service. This information, along with f progress at TTC, is the basis for finite ele suggests that 286,000-pound axles have close to infinite life as long as there are no defects. However, surface imperfections, such as those that can occur when handling axles in repair shops or other locations, can cause stress risers that tend to limit the useful life to time periods below acceptable levels. In addition to the FEM studies, laboratory tests are being conducted to help corroborate the analytical predictions of life (Figure 17). In other studies, crack growth rates are being

**Figure 17: Broken axle after laboratory fatigue test**



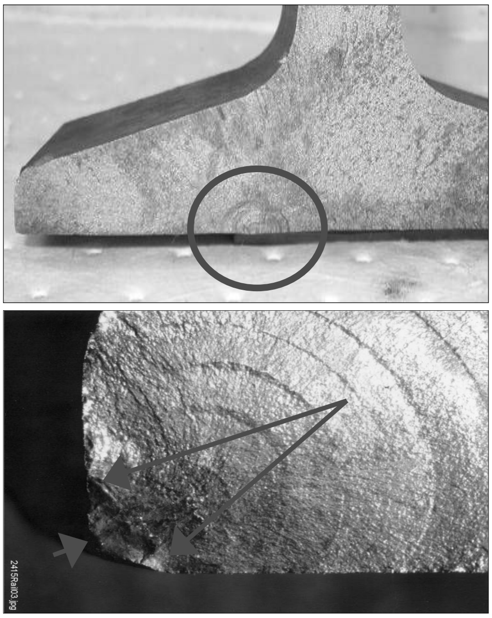
determined for full-scale axles along with crack initiation resulting from a variety of defects.

## 6.5 Facility for Accelerated Service Testing

The Heavy Axle Load (HAL) Program at TTC's Facility for Accelerated Service Testing (FAST) was another AAR accelerated program for 2005. All the projects in this program were focused on the challenges of operating heavier axle loads. Under the program's increased budget, 149 million gross tons (MGT) was accumulated – a new annual record for the HAL program.

TTCI researchers evaluated premium rails from six manufactures after 478 MGT. These rails exhibited lower wear than the rail previously tested at FAST. However, more rail breaks had initiated in the base of the rail than in previous tests (Figure 18). This may be related to the hardness and fracture toughness of these rails. Rail manufacturers and railroads are giving careful consideration to the tradeoffs between wear resistance and fracture toughness associated with increasing rail hardness.

**Figure 18: Crack initiation in base of high hardness rail**



Tonnage on the steel bridge at FAST passed 1,000 MGT. Crack growth and repair, strains in lateral bracing, and performance of an advanced design bridge joint were evaluated. The new bridge joint provided nearly four times the service life of a standard design joint. The two concrete bridges have now accumulated 253 MGT. Two types of ties were installed on the bridges to mitigate the effects of wheel impacts and heavy axle loads.

Improving rail welding procedures and practices continue to be an important part of the FAST program. Additional robotic slot welds and low consumption electric flash butt welds were installed. Information gained from testing at FAST has allowed suppliers to begin installing both types of welds in revenue service.

The FAST program, jointly funded by the FRA and AAR and generously supported by donations from the industry, focuses on investigating the effects of heavy axle loads on structures, track components, and mechanical components. The information is used to help railroads mitigate negative effects of HAL.

## 6.6 Predictive Car Maintenance

Another problem threatening service reliability and efficiency is that a relatively small percentage of freight cars, so-called “bad actors,” can cause a high percentage of track damage and derailment propensity. Poorly performing cars are identified as they pass across truck performance detectors (TPDs) and hunting detectors located around the North American network. TTCI’s study of TPD data is helping to significantly improve the understanding of the design, in-service performance, and degradation modes of current car and car component designs; in particular, the influence of the truck to carbody interface on truck curving performance.

For example, we now know that the turning mechanism at the center plate can result in a “binding” of truck rotation that is stochastic in nature. The root causes of this behavior have been established and replicated in test. Remedial action and component design initiatives are being devised.

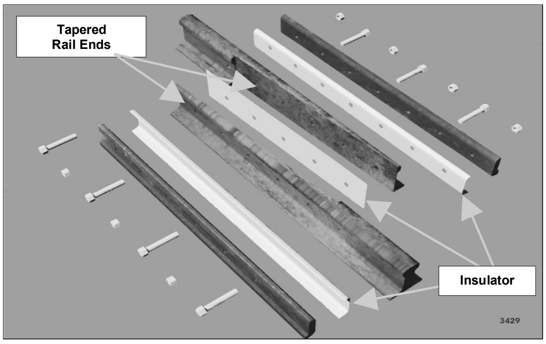
Hunting detectors are clearly identifying poor hunting performance. Cars identified during testing at TTC show hunting speeds between 35 and 50 mph. Poor performance has been shown to be primarily a function of the inherent low warp characteristic associated with a particular truck design. The application of constant-contact side bearings to poorly performing cars will improve performance by approximately 10 mph, but is not always sufficient to provide adequate stability above 50 mph. Preliminary results suggest that satisfactory performance will be obtained from a combination of an increasing warp resistance and the application of constant-contact side bearings.

## 6.7 Bonded Insulated Joints

One of the weakest links in the track structure under heavier axle loads is the bonded insulated joints, which in some cases must be replaced on an annual basis on very high tonnage lines. Significant progress is being made in understanding the effects of heavy axle load environments on the insulated joints (IJ). Having identified the parameters responsible for IJ problems, TTCI is assisting the industry in developing economical, long-lived designs. The improved IJs are expected to reduce significant direct and indirect costs for maintaining railroad track and signal systems.

Measurement of the service environment was conducted with dynamic vertical and longitudinal forces being collected. The results show that the service environment is more severe than the design loading used and that improvements in service life could be made by reducing joint deflection and impacts generated by the joint running surface.

**Figure 19: Conceptual design of improved insulated joint**

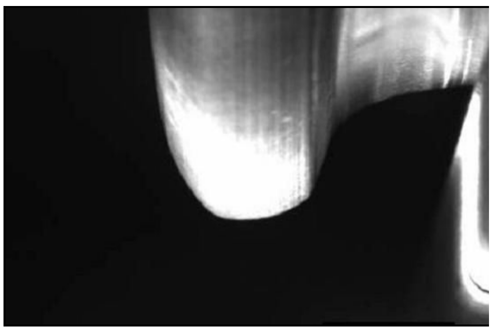



A reduced impact joint designed in concept by TTCI (Figure 19) is being developed into two prototypes by two track component supply firms. A number of thick web and section joints (American Railway Engineering and Maintenance of Way Association) are being tested at FAST and in service, and a series of foundation prototypes are being tested at FAST. These foundations have been proven effective at reducing vertical deflections and can be used with conventional bonded IJs.

### 6.8 Technology-Driven Train Inspection

A new industry undertaking began in 2005 called the Technology Driven Train Inspection Initiative (TDTI). The initiative builds on the industry's implementation of wayside detectors to improve the safety and reliability of rail service by developing advanced technology systems to enhance train inspection functions. Its present focus is to evaluate and implement various combinations of automated equipment to achieve a full complement of pre-departure train inspection requirements, including use of machine vision technology; an example of which is the Fully Automated Car and Train Inspections System (FactISä).

**Figure 20: FactISä image of wheel**



At its initial level, FactISä, jointly developed by Lynxrail and TTCI, uses "machine vision" (high-speed video image capture and analysis equipment and software) to report quantitative measurements of critical component dimensions from moving trains. To improve pre-departure inspection efficiency and accuracy while building interpretive databases, TDTI is currently focused on approximately 40 of the key inspections required by Federal law. Current modules of the FactISä system gather dimensional data on wheel profiles (Figure 20) and brake shoe condition, providing measurements on flange height, flange thickness, rim thickness, tread hollow, back-to-back spacing, and brake shoe thickness. Three FactISä units are in service with a fourth scheduled for 2006 operation. At present, additional modules are available to assess bearing adapter position, spring nest height, and draft gear position.

### 6.9 Advanced Technology Safety Initiative

Introduced in 2004, the AAR's Advanced Technology Safety Initiative is an ongoing activity using inspection technologies to reduce the stress state of the railroad.

The industry's existing array of wheel impact load detectors provided the opportunity for rapid implementation of new rules for identification and removal of high-impact wheels. Dividing impacts into degrees of severity led to the establishment of corresponding removal criteria. The lowest level, opportunistic repair, allows for offending wheels to be removed when a car is at a repair facility for other maintenance. This window of opportunity allows car owners to efficiently schedule repairs and avoid service interruptions. The AAR condemnable level allows railroads to route a car to a repair facility for action. And a final alert level calls for more immediate action, either setting an offending car out on line of road or reducing train speed until a suitable repair location is reached.

TTCI's internally developed *Inte*RRIS® system plays a key role in ATSI implementation. *Inte*RRIS® gathers detector data over the Internet and feeds actionable readings to Railinc's Equipment Health Management System for dissemination to railroads and other car owners.

### 6.10 Acoustic Bearing Detectors

The Trackside Acoustic Detection System (TADSä) detection capability in North America has expanded to include a family of roller bearing defects (called "growlers") that are of a much higher risk of service failure (Figure 21).

**Figure 21: High risk bearing defects**


Previously, this family of defects was detectable in its early stages, but is now being detected and identified when closer to failure. This new feature, as well as many upgrades, is making TADSä more useful to the railroads in preventing service failures. Hopefully, this development will lead to the AAR's member railroads and industry committees defining an appropriate industry-wide bearing removal criteria for use with acoustic detection technology.

Another exciting development occurred in 2005 when the Chinese Ministry of Railways acquired a large number of acoustic bearing detection products based on TADSä technology.

After an extensive two-year evaluation period, 24 roller bearing acoustic detection systems (TTCI's TADS™) were installed within four months on the busiest major trunk rail lines in China (Figure 22). Many of the TADSä sites are currently seeing more than 100 trains in one direction per day.

**Figure 22. TADS® unit installed on Daqin line, China**

The bearing condition data from the installed TADSä are reporting to a systemwide database in real time and is shared among all related Ministry of Railways groups. The Tibet rail line, just completed in late 2005, received two units. This rail line has one of the highest altitudes in the world with track at over 13,000 feet.

The TADSä units were assembled and tested in China prior to shipping to the installation sites. This involved an incredible amount of work by TTCI and the Chinese companies in the construction and installation of the units as they worked to accomplish a major task in a short of time.

## 7. OTHER RESEARCH PROJECTS

While the 10 research projects and industry initiatives highlighted above are clearly of the highest priority, the industry research program is much broader. Four of the other ongoing projects are described below.

### 7.1 Automated Train Operations

Development of a system to automate the operation of the train at FAST, without an operator onboard the locomotive, has been in process for several years. Originally conceptualized as a demonstration of technology integration into the locomotive cab, the project has grown to include unmanned operations.

### 7.2 Service Load Environment

Heavy axle load issues, including axle fatigue, suspension fatigue, top chord stresses, loads imparted to the track structure, brake beam stresses, and vehicle acceleration performance, were investigated by TTCI, Union Pacific Railroad, and CSX Transportation in 2005.

Car performance data was compared to measured track geometry and track features to establish relationships for railcars in 286,000-pound coal service, resulting in the following key conclusions:

- Measured axle strains do not indicate early fatigue failure in the absence of prior handling abuse.
- Bolster and side frame fatigue certification tests scaled up from existing requirements are still conservative for 286,000-pound service.
- Cars experienced frequent bounce motions at speeds near 50 mph.
- Top chord strains exceeding 90 percent of the calculated buckling limit were measured during bounce mode.
- Brake beam stresses were moderate.

### 7.3 Revenue Service Track Research Sites

A technical advisory group (TAG) comprising representatives from TTCI, member railroads, and the FRA was formed in August 2003 to determine future FAST and revenue service test needs. One of the main concepts derived from the group was to create a “mega test site” that would consolidate a wide variety of tests within two specific segments of track 10 to 30 miles long. The consolidation of the experiments would improve experiment design and capabilities, foster cost efficiency, and simplify the coordination and communication between the host railroad and TTCI.

Two mega sites were established in 2004-2005: one in the east on the Norfolk Southern mainline and the other in the west on the Union Pacific mainline. The experiments being carried out at these mega sites are testing and monitoring new technologies and track materials/components intended to mitigate the adverse effects of heavy axle load on track degradation (stress state).

### 7.4 Performance-Based Track Geometry

Working with Union Pacific and Plasser American Cooperation in 2005, TTCI implemented a performance-based track geometry (PBTG) inspection technology on Union Pacific’s new $8.5 million state-of-the-art track inspection vehicle, the EC-5. Built in Austria by Plasser & Theurer, this vehicle has several computer systems that gather data from various types of lasers measuring track and rail conditions. The onboard computers use global positioning satellite systems to accurately record and report the location of variances for accurate repairs. As part of the new technologies implemented on this vehicle, the PBTG identifies track segments that may produce poor vehicle response leading to derailment potential and recommends maintenance actions to correct track geometry. The PBTG results, as part of the real-time data recorded by the EC-5, are used in scheduling track maintenance as well as track improvement projects.

## 8. SUMMARY

The current industry research program (the SRI program) is sharply focused on current industry problems associated with safety, efficiency and reliability. It is contributing significantly to industry objectives in the area of operating heavier axle loads, and, in particular, the effects on freight cars, track, and their interaction.

It must be noted that the SRI program is not just about research. In the past few years, the industry's focus has increasingly moved the SRI program deeper into the innovation process in the areas of cars, track, and vehicle/track interaction. The program now involves itself more in product and process development (whenever supplier activity is viewed as insufficient or inappropriate) and implementation.

# TRACK CONSTRUCTION AND MAINTENANCE MACHINES AND TECHNOLOGY FOR HEAVY HAUL LINES

*Ing. Rainer Wenty**

## 1. INTRODUCTION

Whenever the capacity, axle load or speed of a line is increased or a new line is built, the application of appropriate track maintenance and upgrading procedures is very important to enable optimal and efficient use of the lines. In addition to that on heavy haul lines a low level of dynamic wheel/rail forces has to be maintained to minimize strain on track and rolling stock.

The track maintenance technologies are developed continuously in order to meet the demands of high performance railway traffic. Investment in high-tech machines with high-tech units is worthwhile. The output of the machines for track laying and maintenance is far greater than before and intelligent control circuits are being used increasingly. This has decisive effects on the work result and on the cost-effective performance of the jobs. The focus is always on the long-term effect of a maintenance operation and at the same time optimisation of the costs. Cheap methods, which do not fulfil these demands, cause resulting costs not only for the operating department but also for the maintenance department which far exceed the original savings.

## 2. HEAVY HAUL TRAFFIC

### 2.1 Characteristics of Heavy Haul Lines

According to the International Heavy Haul Association[1], a heavy haul railway should meet at least two of the following criteria:

– Regularly operates or is contemplating the operation of unit or combined trains of at least 5,000 tonnes gross mass.
– Hauls or is contemplating the hauling of revenue freight of at least 20 million gross tonnes per year over a given line haul segment comprising at least 150 km in length.
– Regularly operates or is contemplating the operation of equipment with axle loadings of 25 tonnes or more.

* General Manager, Marketing and Technical Sales, Plasser & Theurer, Austria, Vienna.

Despite the fact, that very often heavy haul lines are dedicated to freight traffic only, train blocks for track maintenance and construction have become more and more scarce.

The permanent way for such routes must have a precise geometry, very narrow tolerances must be kept in track and rail geometry. In spite of the high demands on the track, it must be constructed and maintained in a low-cost way to safeguard its competitiveness with other traffic carriers. The construction and maintenance methods for such tracks were optimized since years, so very economical solutions also with regard to the life-cycle costs are available.

## 2.2 Track Maintenance – The Cost Conflict

The need to keep track maintenance effort and costs to a minimum is acknowledged by both the engineers and the financial controllers. But the way how to achieve this is the basis for lengthy disputes. Cost cutting by reducing expenditure regardless of the long-term effect became customary during the re-organisation of European railways in the early 1990s. The effect is now evident: railways have to spend a multiple of the "savings" to bring the infrastructure back into a reasonable condition, allowing railway traffic without excessive slow orders.

For example: The income from the auction of UMTS mobile telephone licences enabled the German government to establish a •6 billion fund for the upgrading of the infrastructure of German railways. The fund was made available for the years 2001 to 2003 and a substantial part had to be spent to catch up with deferred maintenance. As the cost cutting programme also included massive reductions in engineering capacity, there are not enough planning resources available today to fully utilise the money for track rehabilitation within the anticipated time-frame. Another example for the catastrophic effect of deferred maintenance is Railtrack of Great Britain, which needs no further comment.

In a recent workshop in Budapest, organised by UIC and co-sponsored by EU, cost-effective track maintenance was a special subject reviewed. Basic papers analysing the long-term cost effects of different track maintenance strategies were discussed. This highlights the fact that now-a-days, there is a growing awareness amongst railway managers of long-term strategies for track maintenance.

For an engineer it comes as no surprise that comprehensive costs analyses have revealed that the basis for cost optimisation is the application of sound engineering principles.

### *Model for track cost calculation*

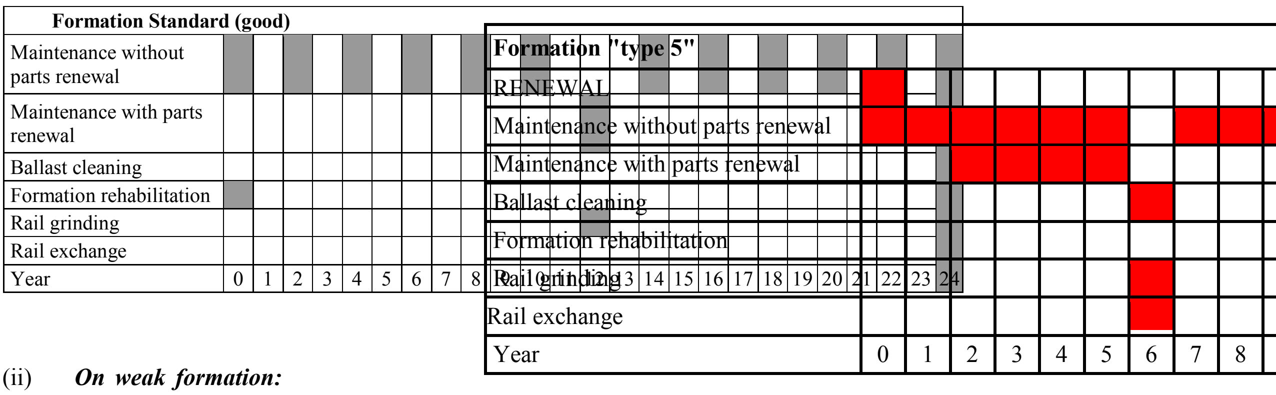
In 1998, the track management of Austrian Railways together with the University of Graz started an investigation into different options for all track maintenance strategies with regard to their long-term cost effects .

The investment and maintenance costs of different strategies are summarized for the life cycle of a track and the difference in annuities is calculated. If the new strategy shows a positive cash flow compared to the existing one, then it can be concluded that it is more cost effective. In addition, a present net value calculation is made and the internal rate of return is calculated. Generally speaking, it can be said that financial institutes regard projects with an internal rate of return of 10% as feasible and those with more than 15% as highly efficient.

A comparison of frequent maintenance versus formation rehabilitation is demonstrated as an example in the following illustrations:

**Figure 1: Service life and maintenance frequency after renewal**

(i) ***On good formation:***




(ii) ***On weak formation:***

The calculation of the average costs per year (including additional traffic costs due to slow orders) shows that the annual track cost can be eight times more due to poor subgrade conditions.

## 3. TYPE OF FORMATION

**Figure 2: Average cost per year for different types of formation on heavily loaded tracks**

| Type of formation | Average costs per year | Percentage of standard |
|---|---|---|
| Standard (good) | US$ 38.750 | 100 % |
| Formation "type 3" | US$ 70.156 | 181 % |
| Formation "type 4" | US$ 85.703 | 221 % |
| Formation "type 5" | US$ 313.359 | 809 % |

The different classes are derived from the necessary additional maintenance effort and the reduced service life of the track.

Type 3: increased maintenance but no reduction in service life

Type 4: intensive maintenance but no reduced service life

Type 5: intensive maintenance and reduced service life of the track, two months of slow orders every year.

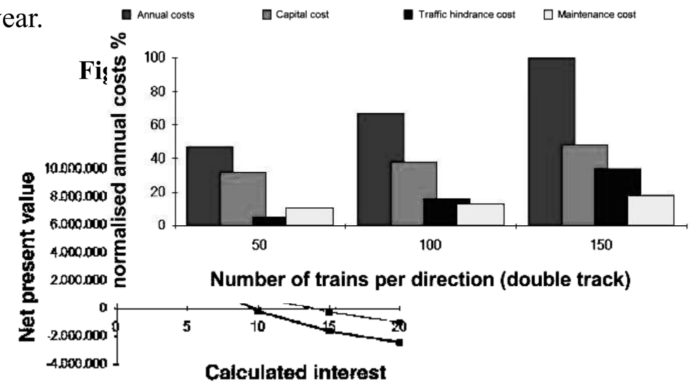



**Figure 4: Distribution of annual track costs**

The calculation of the internal rate of return (IRR), results in 10 to 15 % even for type 3, if subgrade rehabilitation is carried out within the next scheduled track relaying (beginning of the service life).

On formation "Type 5", the IRR is so high, that it pays off to carry out formation rehabilitation at any time during the lifetime of the track concerned.

From left to right the first column represents the entire rated annual costs, the second shows the depreciation of the new track, the third indicates the cost of the traffic hindrances caused by construction and maintenance activities and the last column gives the cost of the maintenance itself.

The illustration shows how dominant the depreciation of the investment is – in absolute terms as well as in comparison with the costs of the maintenance – under all investigated traffic loads. From that the strategic approach must be a prolongation of the service life. A shortening of the track service life caused by reduction of maintenance, cannot be successful because of the relatively small importance of the costs of maintenance.

These considerations are confirmed by corresponding calculations. Further calculations show that already a small service life prolongation results in appreciable saving potentials. Simultaneously, the analysis shows that the traffic hindrance costs – although surely under-estimated by the Austrian Railway model – rise on dense traffic routes up to a third of the total costs. Traffic hindrance costs reach and exceed the cost of maintenance and therefore are crucial.

### 3.1 Interaction of Track and Rolling Stock

Investigations in rail/wheel probl
failures are considering the dynamic for
speaking, vertical, lateral and creep forc
Knothe , the vertical and the creep force
are the main inputs to calculate the cont
overstress in the rail and wheel surface
on the static axle load, the travelling sp
are also influenced to quite an extent b

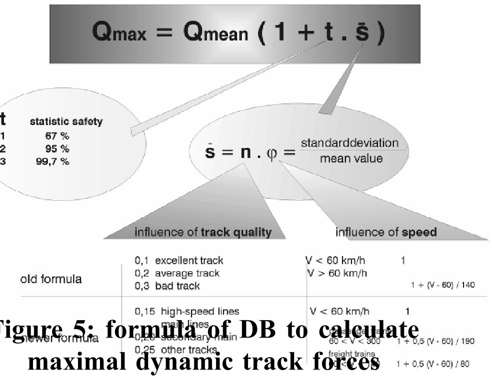



**Figure 5: formula of DB to calculate maximal dynamic track forces**

Dynamic models for track dimensioning as developed by Eisenmann and applied by DB (German Rail) prove the relationship between vertical forces (axle load) and track quality. Peak force values are identified as the decisive loads for the track structure. They are derived from measurements and statistic evaluation by the use of speed factors and track quality factors (Figure 5).

The maximum acting force Qmax is calculated by multiplying the mean force (quasi static axle load, for instance) Qmean with an amplifying factor which is basically determined by the elements speed and track quality. The formula presented in 1993 had been refined in the meantime. As shown in Figure 1, there is no influence of speed up to 60 km/hr but bad track quality increases the maximal force. For better understanding, the terms "excellent", "average" and "bad" had been replaced by "main lines", "secondary main lines" and "other tracks", based on the statistical mean standard deviations on such lines in Germany.

Excellent track geometry permits to raise the mean load without increase of the maximal forces. This allows the reciprocal conclusion that the increase of average track quality (lowering of average standard deviation) reduces the dynamic loads and reaction forces on the track

On the basis of the German Railways calculation model, Indian Railways carried out a field study about their track maintenance practice which was presented at the International Heavy Haul conference 1997. The correlation between the theoretical calculations and track measurements was shown and it was concluded that mainly the following two areas have to be tackled to keep track reaction forces low:

- Excellent track maintenance methods have to be applied to maintain low standard deviations; and
- And a high and homogenous track modulus has to be created by ballast and subgrade maintenance – for instance, by systematic ballast cleaning.

The correlation between track forces and track quality was also considered when designing the first high speed lines for the TGV in France. Alias developed a formula, showing the factors which cause the increase of the dynamic vertical forces. The standard deviation of the additional dynamic forces sDq (t) is calculated as follows:

$$\sigma_{\Delta q} = kV\sqrt{2;mh}$$

where:

k = coefficient for geometrical track quality
V = travelling speed (km/hr)
m = unsuspended mass (t)
h = track stiffness (t/mm)

Again, the proportional influence of track quality on the rail/wheel contact forces is shown. In addition, the input of unsuspended masses is also remarkable.

In summary, the aim must be to keep the vertical dynamic forces at a minimum by maintaining an excellent level of track quality and thereby also to reduce rail/wheel contact forces and rail/wheel wear.

A further factor which has to be considered is the correct support of the sleepers by the ballast bed underneath. Voids or soft spots under the sleepers also raise the dynamic forces as shown by G. Cope in "British Railway Track" . Under British Rail conditions for soft spots the increment to be added to the steady state wheel/rail contact force can be up to 1.75, which means the maximum force will be 2.75 times of the normal force (Figure 6).

**Figure 6: Dimensionless dynamic increment for a dipped weld and a soft spot**

M =
V =
K =
L =

*Source: "British Railway Track", p. 523.*

The shape of the curve reflects, that above a certain ratio of V/L the values drop down as the wheels start to "fly" over the depression. In reverse, one can conclude that at the relatively low speeds of heavy haul operations the amplification effect of depressions is quite severe.

Another aspect of wheel/rail interaction is the lateral movement of the wheelsets. Also, in this respect the question is, whether the lateral forces caused by track irregularities should not be considered to a larger extent in rail/ wheel interaction investigation and modelling? The AAR Report R-797 , for instance, shows the difference between the calculated and the acting lateral forces. These differences result from one single alignment error at the beginning of the turnout (Figure 7).

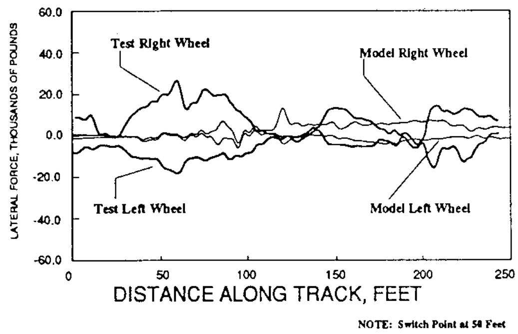



**Figure 7: Excerpt from AAR report R-797**

The train speed was 80 km/ hr and the lateral force rose from the calculated 50 kN to 150 kN measured. In other test sections without such geometrical track errors a good correlation between calculations and measurements was observed. Measurements of Austrian Federal Railways with their track recording car show the same tendency .

### 3.2 Lowering of Rolling Stock Costs by Improvement of Track Quality

The main influence to the wear of rolling stock by track quality certainly occurs in:

(a) Wear of undercarriage components by increased dynamic reaction forces

(b) Wheel wear due to disturbance of the smooth rail – wheel interaction

Whereas (a) is self-explanatory, for (b) the discussion is focused on wheel and rail shape as well as surface conditions. But one should not forget that every geometrical fault, every loose sleeper, every weak spot in ballast or formation causes additional movements of the bogies and thereby additional wheel/rail bumps and friction which cause additional wheel wear.

## 4. TRACK MAINTENANCE

The above considerations show very clearly, that not only for high speed passenger traffic, but also for high capacity freight traffic it is essential to keep the infrastructure in top condition. Deferred maintenance will not only cause increased costs later on, but if track faults are allowed to develop, the increase of the high axle loads by dynamic influences may lead to complete failure of the system.

On heavy haul tracks, the necessary maintenance must be ensured, as for any other production plant. Production breaks for maintenance of catenary, signalling installations, rails and fastenings and the track geometry should be scheduled so that the customer does not change to other traffic carriers due to unexpected production breakdowns or delays. In these production breaks, it is of course advisable to bundle the various maintenance jobs to be performed.

New tracks must be serviced accordingly from the outset. Neglect of the maintenance in the initial phase of service life will cause inherent failures that cannot be compensated later.

### 4.1 New Technologies

Track maintenance technologies are further developed continually in order to meet the requirements of high-capacity rail traffic. It is worthwhile investing in high-tech machines with sophisticated work units. Machines for track maintenance have been made more efficient and are increasingly equipped with intelligent controls. This has decisive effects on the work results and on the cost-efficient performance of the tasks. The long-term effect of a maintenance measure together with optimisation of costs stands at the forefront. Some of the latest developments and trends are:

***Track survey***

Before any efficient and precise track maintenance work can be carried out, a track survey of the actual geometry measuring the level and the alignment of the track has to be done. In the past, extensive manual track survey with sighting instruments was involved for this job. If the track should be restored to design geometry or new design the data of the database must be made available in the track.

The EM-SAT (Figure 8) track survey car enables fully mechanised measurement of the actual track geometry using a laser reference chord. It consists of a main machine with the computer system and the laser receiver and an auxiliary trolley ("satellite") which carries the laser transmitter. Measurements are taken in a cyclic sequence: the mach and deviations from the target geometry 150 metres it has to stop at a fixed point and then the laser satellite trolley is moved forward again. The working speed of the machine is 8 km/h. While the average measuring speed (including all stops) is 2.5 km/hr and besides the displacement and lifting values, superelevation and gauge faults can also be measured.

**Figu**

The recorded data and the calculated correction values are displayed on the computer screen in a similar manner as on the ALC screen of the Tamping machine computer and can be reprocessed on-board or off-board, if necessary. Electronic transmission of data to a tamping machine equipped with the ALC automatic guiding computer guarantees highest precision and at the same time prevents any transmission faults which can occur in manual measuring.

The experience of DB-AG (German Railway) is: accuracy of 1 mm, measuring speed of 1.5 to 2.6 km/hr, and cost reduction of EURO 3.- per metre of measured track.

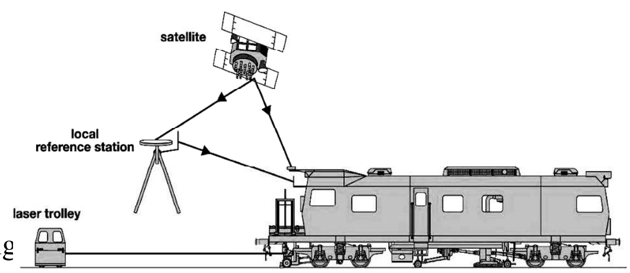
The EM-SAT is not only used for track geometry survey when preparing for tamping of the track, it is also used on track relaying and rehabilitation sites and for the acceptance of newly built tracks. It can also be used to establish a track geometry data base where these data are unknown.

*Satellite-supported track surveying*

Maintaining the fixed points is labour-intensive and, therefore, quite costly. Furthermore, when checking their position it is often found that their position has changed in the range of some centimetres. The manual measurement of the track position in relation to the reference points slows down the measuring speed and is also a source of inaccuracy and further costs.

For building new lines and for the survey of existing lines with regard to their general layout, the application of the satellite-supported Global Positioning System is already standard technology. The latest development now is the combined use of EM-SAT and GPS (Fig

**Figure 9: Application of GPS on EM-SAT**



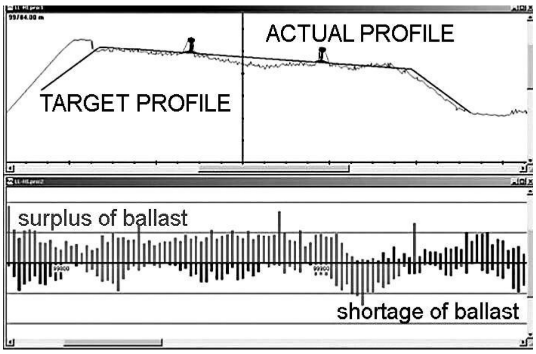

*Incorporation of ballast profile measurement*

Additionally, the EM-SAT can be equipped with a non-contact ballast profile measuring system. In the course of track surveying the system determines the ballast situation accurately together with the lifting values.

The system records the ballast profile by means of a laser scanner. When the laser pulse hits the ballast profile, it is reflected and the distance and measuring angle are registered in the receiver of the laser scanner.

The contour of the ballast profile is computed from the sequence of received pulses and stored at every 2m (max. speed 15 km/h). On the computer display the measured profile is superimposed by the image of the target profile which is selected by the operator at the start of work appropriate to the line. A surplus (green bars) or a lack of ballast (red bars) is separately indicated for the right and left side of the track (Figure 10). This allows the ballast profile to be checked immediately during the measuring run. The recording results, which can be exported onto a floppy-disk or ZIP for an in-depth office evaluation, enable decisions to be made about the lifts to be performed and ballast requirements.

**Figure 10: Ballast profile measuring device**




***09-4X Dynamic Tamping Express***

The maintenance of a track requires a range of work processes which must be coordinated as efficiently as possible. The better the work technologies act together, the higher will be the achievable work output, the quality of work and ultimately the cost-efficiency.

One of the latest machine concepts is the 09-4X Dynamic (Figure 11). It in tamping unit paired with two stabilizing for the duty on High Speed Lines the 09-4X Dynamic is an interesting and cost effective alternative to the use of 2 separate machines. Due to a further increase in overall performance the time of track possession and thus the cost can be reduced.

**Figu**

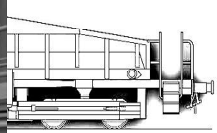
***Ballast management***

Considering that a single kilometer of a conventional double-track line has between 3000 and 5000 m³ of ballast (depending on the type of permanent way and track spacing) the absolute necessity for an economical handling and management of this valuable asset becomes obvious. The detailed knowledge of the quantities of ballast in the track (see EM-SAT ballast profile measuring) is the first step towards an efficient ballast management. Some sections of a track lack ballast while others have a surplus. So, the goal has to be to regain the surplus ballast and add it where it is needed.

The combination of this task with the ballast profiling and distribution work is at hand. The big advantage of this incorporation compared to the previous method of loading, transportation, distribution, reclaiming and returning the excess ballast is the saving of time, personnel and equipment, thus achieving a much higher cost efficiency. Two proven machine concepts could be used for this task.

The USP 2010 SWS combines high performance ballast distributing and profiling with a ballast storage capacity of 10 $m^3$. By using an additional trailer the integration of a second sweeper brush unit would be possible (Figure 12).

**Figure 12: USP 2010 SWS**



The other alternative is the BDS – Ballast Distribution System, successfully in operation in the USA on AMTRAK's and Union Pacific's track as well as Latvi (Figure 13) and Lithuania. One of th unique features of the BDS is that th ballast storing capacity can be enlarge as required by adding material conveyo and hopper units.

**Figure 13: Ballast distribution system, operating in Latvia**

The BDS was introduced in Ma 1991. As a result AMTRAK was able t reduce its purchase of new ballast by 71 percent during the remainder of that year, a saving of around US$ 36.000, equivalent to approx. 34.000 t of ballast. Amtrak estimated that the system paid for itself within 2 years.

***Ballast cleaning***

A clean, elastic and homogenous ballast bed is an absolute necessity for problem-free functioning of the wheel on rail system. Above all, on high capacity sections of track, this is gaining additional importance. Due to the impact of traffic, the ballast breaks down under the sleepers so that track correction work cannot be carried out effectively any more (Figure 14). It is clearly visible, that the ballast on top and in the cribs looks good, due to the frequent supply of fresh ballast. Nevertheless, shoulder cleaning or tamping could not improve the situation any more, it is necessary to undercut and clean the ballast to prevent further damage.

*High performance ballast cleaning machines*

In order to minimize track occupancy times on major worksites, the use of high-capacity ballast cleaning machines is required.

This trend started with the RM 800, successfully proven in operation for numerous years, and was then followed by other machines of the RM 800 series and the machines of the RM 900 series achieving cleaning outputs ranging from 800 to 1,000 m³/h. These machines are capable of keeping up with the performances of track renewal trains, thus accomplishing major worksites in shorter track possession times.

**Figure 14: caked ballast under the sleeper on a high axle load heavy haul line**

As a further improvement machines were developed capable of taking ballast from MFS material conveyor an... cleaned track under the machine.

*RM 800 3S*

The RM 800 3S (Figure 15) is a... machine with increased output due to the use of ... hr. The undercutting system has a cardan... ability of infinitely variable adjustment of the cu...

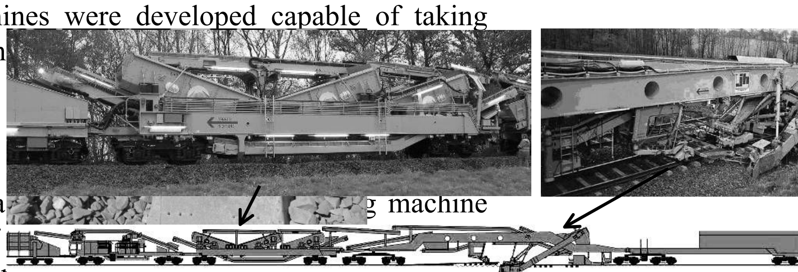


**Figure 15: RM 800 3S**

*Ballast cleaning and track relaying machine*

The complete renewal of a section of track requires both the cleaning of the ballast bed and the exchange of the skeleton track. According to UIC recommendations, this must be performed exactly in the following order: in the first working operation the track ballast is cleaned using a ballast cleaning machine and then the skeleton track is exchanged using a track renewal machine.

Since these two operations can practically never be performed in the same track possession, the track has to be made ready for traffic again after the ballast cleaning using tamping machines or an MDZ mechanised maintenance train to ensure unhindered passage of trains between the two phases of construction. Track renewal is later performed in a second track possession, after which the MDZ will also have to produce the correct final track geometry.

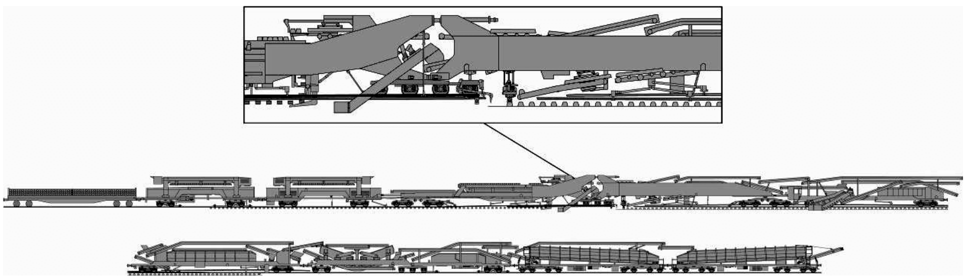
The economic costs associated with renewal work on this scale are correspondingly high. In addition to the costs for planning, machines and staff, worksite security, etc., there are the respective operational hindrance costs for two complete track possessions to be considered. Nevertheless, this a generally accepted technology today which has been in use around the world for many years - not the least for lack of realistic alternatives.

The combination of ballast cleaning and track renewal in one machine has already been discussed. Above all, the railway administrations want such a technology because the associated saving potentials would be enormous.

*RU 800 S - A machine revolutionizes line renewal*

Now, the answer is here: Plasser & Theurer has designed the RU 800 S, a continuous action ballast bed cleaning and track renewal train. This machine combines the two working operations of ballast bed cleaning and track renewal in one single machine. This makes it possible to perform the renewal of sections of track in only one track possession, with all the associated technological, logistic and above all economic advantages (Figure 16).

**Figure 16: Combined ballast cleaning and relaying machine RU 800S**



## 5. CONCLUSION

The continuous development and improvement of track maintenance machines has led to a series of designs for all applications, that not only fulfil the high demands of heavy haul railways but also provide cost-effective solutions. Either by increasing the working speed or by implementing technologies that save precious raw materials new high technology machines contribute to the sustainability of the investments in heavy haul lines as they enable to keep a high maintenance level.

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# QUADRUPLING HEAVY HAUL CAPACITY BY USING DISTRIBUTED POWER

*David Peltz**

## 1. INTRODUCTION

Continued improvements in Distributed Power (DP) functionality, ever-increasing operational experience, and the resulting recognition of return on investment has resulted in a tremendous increase in the application of Distributed Power around the world. The number of DP equipped locomotives is now over 6,500 units that are located in 10 countries, on 6 continents, for 24 different heavy haul railroads.

In continuation of this trend, analysis and demonstration testing of revenue trains in late 2004 proved that it is possible to quadruple the conventional capacity of a heavy haul rail line by simply adding DP capability. In the particular test case, the normal conventional operation is to run 5,000-ton trains consisting of one locomotive and approximately 50 wagons to maintain simple train handling and easily fit within train blocking requirements. Unique conventional trains of 10,000 tons with two locomotives pulling 100 wagons were sometimes run. However, this configuration was close to the limit of the lead coupler force capability and train blocking limits.

By installing LOCOTROL Electronic Brake (LEB) DP equipment in four locomotives, four of the normal 5,000 ton trains could be easily assembled into one 20,000 ton train configured as: 1 lead x 50 wagons x 1$^{st}$ remote x 50 wagons x 2$^{nd}$ remote x 50 wagons x 3$^{rd}$ remote x 50 wagons (1x50x1x50x1x50x1x50). Comparison revenue testing proved that the 20,000-ton LEB train had the same stopping performance, acceleration and "lifting" capability, and in-train force performance as the conventional 5,000-ton train. Additionally, certain areas of track were instrumented to determine if such a large train caused excessive track forces – the 20,000-ton train exhibited the same track force as the 5,000-ton trains.

This testing proved that with no change in the blocking or track infrastructure, this heavy haul railroad could quadruple its capacity in the time

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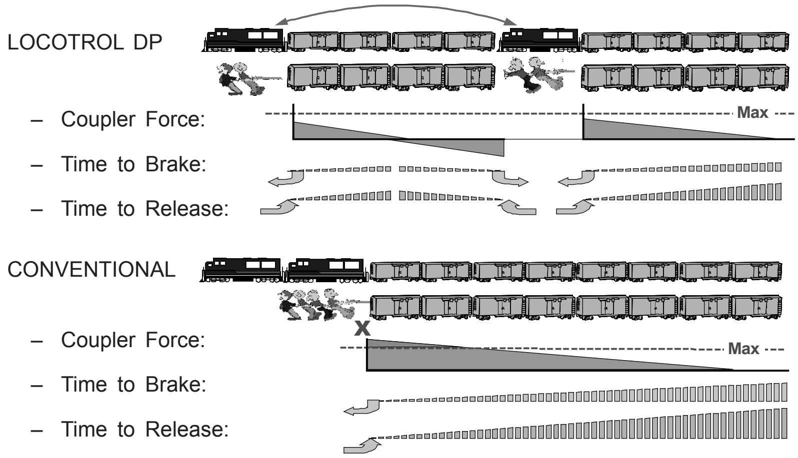
it takes to install the Distributed Power equipment. Additionally, once Distributed Power is in use, a railroad will also begin enjoying the fuel savings, reduced cycle times, reduced crew needs, and reduction in train damage, such as break-in-twos that have convinced 24 other railroads to install over 6,500 Distributed Power systems.

## 2. LOCOTROL DP CONCEPT

The basic concept of LOCOTROL DP uses a Radio Link to provide remote control of up to four remote locomotives. LOCOTROL DP senses the state of the lead locomotive and transmits that information to the remote for control of those locomotives. The remote LOCOTROL systems transmit their locomotive's status to the lead, so the driver is always aware of the state of the train. In the rare case of loss of radio communication, the Brake Pipe is used as a back-up communication link to allow the remote locomotives to idle down and allow the train brakes to stop the train. LOCOTROL DP controls all the key functions of the remote locomotives – train air brakes, locomotive air brakes, throttle, and dynamic brakes and a host of auxiliary functions. Apart from the DP functionality, safe operation through extensive interlocks, safety checks, and special processing is the most important feature of LOCOTROL DP.

Figure 1 below graphically shows the difference between a Distributed Power train and a conventional train:

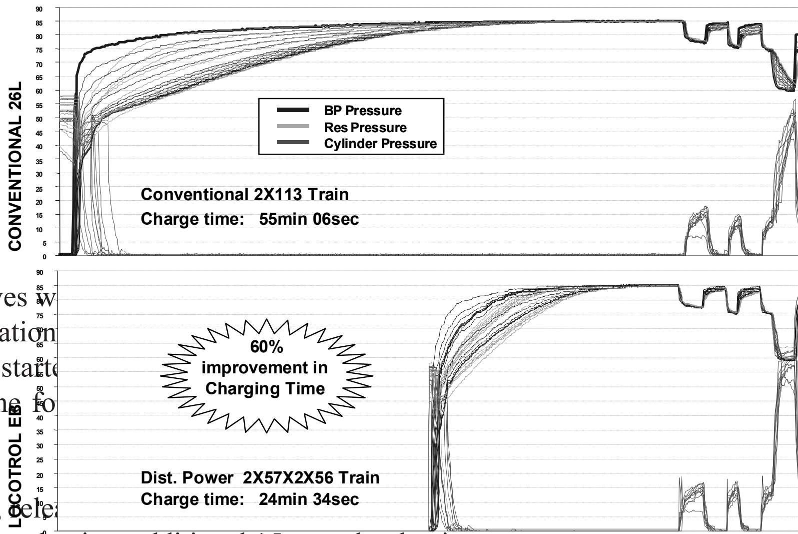
**Figure 1**




Because the remote locomotive is both pushing the wagons in front of it and pulling the wagons behind it, the draw bar forces are significantly reduced as shown. Because the remote locomotives also control the airflow at their location in the train, a DP train provides a huge improvement in braking and release/re-charge performance.

The improvements in braking and release/re-charge can be seen in the plotted pressure data in figure 2 below. The data was taken on the single 150 wagon train in conventional mode, and then in DP mode with a single remote consist in the middle of the train. Brake pipe, wagon reservoir, and wagon brake cylinder pressure sensors were placed on every 15$^{th}$ wagon of this train to capture the data shown.

**Figure 2: Improvements in braking and release/re-charge**



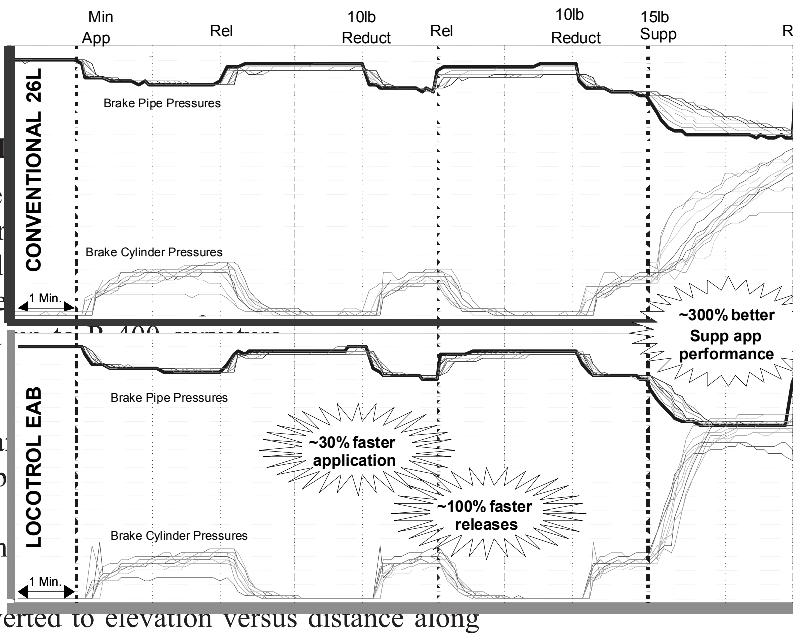

For this test, the remote locomotives w
like a wagon. Three emergency applicatio
reservoirs, and then data recording was start
the train was fully charged to 85 psi, the fo
made:

Minimum application, wait 2 min, rele
wait 1 min, release, wait 2 min, 10 pound reduction, additional 15 pound reduction, wait 2 min, release, wait 2 min, emergency.

Then two more emergency applications were made to put the train in the same original depleted wagon reservoir state, and the remote locomotives were set to DP mode. The exact same application release sequence was then run again to produce the lower graph. Note the significantly short train charge time by adding just one other locomotive in the train.

Looking even more closely at the same data, by zooming into the application/ release portion of the graphs, the improvement in air brake application and release can be seen in figure 3 below:

**Figure 3: Improvement in air brake application and release**



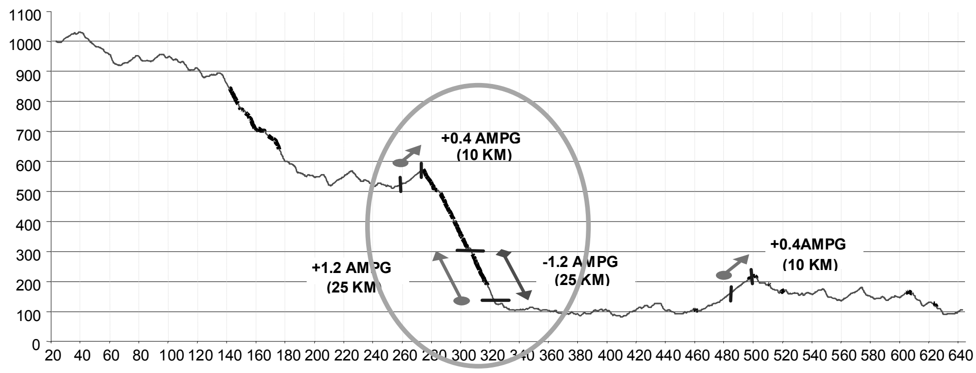

## 3. QUADRUPLING THE CAPAC

The first step in investigating the railroad's capacity is to analyze the cur railroad that was tested in 2004 normall locomotive with around 50 wagons. The a maximum 1.2 percent downgrade and

GETS used detailed track grade locomotive performance characteristics a complete the analysis and create a train p to evaluate the performance of various forces for potential locations of the rem

The track topology data was converted to elevation versus distance along the length of the rail line. This data is shown in Figure 4. The bold black portions of the line indicate locations where there are tunnels. The vertical axis is meters of elevation with a scale of 100 meters per gridline. The horizontal axis is Kilometer Posts with a scale of 20 kilometers per gridline. The graph also shows the “Adjusted Maximum Percent Grades” (AMPG) for both the downhill (1.2%) and uphill (0.4%) grades.

**Figure 4**




These are the locations along the line that have the most affect on train dynamics. The AMPG was determined in the following manner: A simulated train of 3.0 kilometers was then run over the length of the line and the average percent grade under the train at any given location was determined. The *maximum* average percent grade under the train anywhere on the run was determined and identified as the AMPG. The distance that the AMPG was in effect was also determined. The worst-case dynamics for any given train occur where the AMPG is in effect for the longest distance that creates. These AMPG locations were then modeled for various train lengths and configurations.

- The train modeling for the Da-qin line was done in three parts:
- Train energy and performance modeling
- Draw bar stretch and compression forces
- Operational comparison.

Since both the AMPG for uphill and downhill can be found between Kilometer Posts 240 and 320, we focused the simulation there. Twenty-eight different train configurations from 5,000 tons to 20,000 tons were modeled. For the first step of the modeling, we analyzed the chosen train at the uphill and downhill AMPGs. The weight of the loaded wagons and locomotives determines the total train weight. The horsepower of the locomotives is then inspected to determine if there is enough power to pull the train up the various grades. Given the nearly 9,000 horsepower for the railroad’s locomotives, there was never too little raw power.

The composite grades are the various grades under the train at a given time with a consideration for the curvature of the track under the train. Curvature acts as a retarding force just as an uphill grade.

The Tractive Effort (TE) is the amount of pull the locomotive must exert to hold the train on the given grade. To be conservative, this number is considered to be the force needed to start moving the train on the given grade. This means that static friction and bearing "sticktion" is considered. If the train is already moving, rolling friction is less than static friction and bearing "sticktion" is not a factor. We use this conservatism assuming that if a train must stop on a grade, then the train should have enough tractive effort to get moving again without the aid of another locomotive.

The 'Dispatch Adhesion' is the amount of rotational force the wheels of the locomotive can exert on the rails before they begin to slip. This number takes into account the normal force of the locomotive on the rails due to gravity, the coefficient of friction of the rails and wheels, and traction characteristic of the locomotive. The chosen value of 27% adhesion is fairly high on a locomotive with very little reduction in track coefficient of friction because of the locomotive sanding system. The Adhesion/TE column is simply the ratio of dispatch adhesion to holding tractive effort. A value of one or less here means the locomotive cannot lift the given weight of train on the given grade and could therefore be stuck if it must ever come to a stop. This ratio is also important for Dynamic Braking. If the ratio is less than one, then the dynamic brake system cannot hold the train on a downgrade and car train brakes will be required to slow the accelerating train.

All these values are computed for the various train configurations for the various grades. That particular train configuration performance is then determined at the AMPG.

Figure 5 below is a summary of the downhill and uphill modeling of 9 different train configurations using the present 60-ton cars.

**Figure 5: Summary of downhill and uphill modeling of trains**

| Configuration | Downhill Tractive Effort /Adhesion needed | 1st Car Downhill Buff Force needed | Brakepipe Recharge time | Uphill Speed MPH | Uphill Return with Empties Speed MPH | Car to loco ratio | Comments |
|---|---|---|---|---|---|---|---|
| 1 x 60 | 1.28 | 78 | Good | 67 | 61 | 30 | OK |
| 1 x 120 | 0.65 | 152 | Marginal | 34 | 32 | 60 | Marginal Handling |
| 2 x 120 | 1.28 | 152 | Marginal | 67 | 61 | 30 | OK |
| 2 x 180 | 0.87 | 230 | Poor | 45 | 42 | 45 | Poor BP recharge |
| 1 x 80 x1 x 40 | 1.28 | 76 | Good | 67 | 61 | 30 | OK |
| 1 x 120 x1 x 60 | 0.87 | 115 | Good | 45 | 42 | 45 | 2nd Best Choice |
| 1 x 133 x 1 x 67 | 0.78 | 127 | Marginal | 41 | 38 | 50 | 3rd Best Choice |
| 1 x 160 x 1 x 80 | 0.65 | 152 | Marginal | 34 | 32 | 60 | Marginal Handling |
| 1x80x1x80x1x80 | 0.97 | 152 | Good | 45 | 42 | 40 | Best Choice |

To deliver the maximum amount of load per train the three configurations indicated were recommended. This recommendation is based solely on train performance. This performance is gained by using LOCOTROL Distributed Power.

Figure 6 below shows the downhill and uphill modeling summary for 11 various heavy, large trains using 100-ton wagons. The key columns are the Adhesion to TE ratio, Uphill speed columns Kilotons per train column. As discussed earlier, an adhesion to TE ratio of less than 0.5 is shown in black because of the potential of an unsafe condition. This is especially important on trains of this size and weight. Anywhere the uphill speed indicates a “0”, this train configuration would not be able to lift off the 0.4% uphill AMPG.

**Figure 6**

| Configuration | Downhill Tractive Effort /Adhesion needed | 1st Car Downhill Buff Force needed | Brakepipe Recharge time | Uphill Speed MPH | Uphill Return with Empties Speed MPH | Car to loco ratio | Comments |
|---|---|---|---|---|---|---|---|
| 1 x 60 | 0.76 | 131 | Good | 41 | 61 | 30 | OK |
| 1 x 120 | 0.38 | 259 | Marginal | 0 | 32 | 60 | Can't go Uphill / slow downhill |
| 2 x 120 | 0.76 | 259 | Marginal | 40 | 61 | 30 | OK |
| 2 x 240 | 0.38 | 518 | Poor | 0 | 32 | 60 | Can't go Uphill / slow downhill |
| 1 x 80 x 1 x 40 | 0.76 | 130 | Good | 40 | 61 | 30 | 2nd Best Choice |
| 1 x 120 x 1 x 60 | 0.51 | 195 | Good | 0 | 42 | 45 | Can't go Uphill / slow downhill |
| 1x81x1x60x1x39 | 0.76 | 130 | Good | 40 | 61 | 30 | Best Choice |
| 1 x 133 x 1 x 67 | 0.46 | 217 | Good | 0 | 38 | 50 | Can't go Uphill / slow downhill |
| 1x89x1x67x1x44 | 0.68 | 144 | Good | 36 | 55 | 33 | 3rd Best Choice |
| 1 x 160 x 1 x 80 | 0.38 | 259 | Good | 0 | 32 | 60 | Can't go Uphill / slow downhill |
| 1x107x1x80x1x53 | 0.57 | 173 | Good | 45 | 47 | 40 | OK |

## 4. TEST TRAIN

The LOCOTROL Installation was completed by early November. Experience and installation techniques were noted during the installation process with the goal of optimizing production installation. All locomotive builders were involved with all phases on the installation to provide common understanding of the effort.

The Back-to-Back Software verification testing began on 7 November 2004. It served the dual purpose of verifying all of the locomotive to LOCOTROL interfaces were connected, and to verify all of the LOCOROL Software was functioning properly. Throughout the testing some incorrect connections and other items were found and corrected. This process went generally better than most first time installations due in large part to the excellent support and cooperation of all involved.

There were no outstanding issues from back-to-back verification testing that will have an impact on production and the installation process with the goal of optimizing production installation. All locomotive builders were involved with all phases on the installation to provide common understanding of the effort.

The primary objective of the Static Train test is to verify operation of all Distributed Power functions that depend and/or interact with the train brake pipe. The test train used for this testing consisted of a common set of wagons and the four LOCOTROL equipped locomotives. The final train configuration of 1x51x1x51x1x51x1x51 was tested as prescribed in the Static Train Test Plan.

Various train configurations were tested for many different performance measurements. Two types of testing were performed, signal strength measurements performed by the customer radio group, and actual LOCOTROL message transmission and reception performed by GETS. The signal strength testing found that under the current test conditions, if the attenuation of antenna cable was 10dB and the space interval between the locomotives was 51 wagons, there was no blind area for the field strength of 800MHz on rail Line and the total weak segment length was 750 meters. When multiple repeat and diversity receiving is used, 800MHz radio can meet the requirement of LOCOTROL when the trains are organized at 51 wagons space interval.

For the actual LOCOTROL message transmission and reception testing, the communication test results were divided into 5 categories:

(i) Comm Flashes (CF) comm flash is seen by the operator as a short yellow flash on the remote status screen. These are from a single missed status message from a remote locomotive and have no detrimental affect on the Distributed Power system.

(ii) Momentary Comm Loss of less than 5 Seconds MCLs are consecutive missed status messages for less than five seconds from any given remote locomotive. This duration of missed status messages are also not a problem for the LOCOTROL system as the re-try logic will gather the correct information and deliver the correct commands without any operator action.

(iii) Momentary Comm Loss of between 5 and 10 Seconds MCLs are a concern only if the operator needs to make changes in brake application. If a change in brake application occurs, during a comm loss the remote locomotive will perform a Comm Loss Idle down. If this occurs, the operator will need to make a brake application and then release to bring that remote’s brake system back to Distributed Power operation. This is generally not a problem, but may have the driver operate the train differently than the way he would operate normally.

(iv) Momentary Comm Loss of 10 to 45 seconds.

(v) Sustained Communication Loss (SCL) of greater than 45 seconds SCLs results from missing the status from any given locomotive for more than 45 seconds. As with other comm losses, this is an issue if the operator must make command inputs to control the train. Areas with this kind of comm loss should be investigated.

Figure 7 below summarizes the results of the Pilot Program Train Run Communication Testing:

**Figure 7**

| Train | Date | Comm Flash | MCL<5 | MCL 5-10 | MCL 10-45 | SCL |
|---|---|---|---|---|---|---|
| 19.8 Kton[1] | 04/12/04 | *120* | *21* | **1** | **0** | **0** |
| 19.7 Kton | 08/12/04 | *252* | *49* | **26** | **8** | **2** **(Max 52 sec)** |
| 20 Kton | 12/12/04 | *231* | *91* | **16** | **19** | **1** **(Max 85 sec)** |
| 20 Kton[2] | 15/12/04 | *129* | *5* | **1** | **1** | **0** |
| 20 Kton[2] | 19/12/04 | *89* | *1* | **0** | **1** **(12 sec/2 red)** | **0** |
| 20 Kton[2] | 20/12/04 | *115* | *4* | **0** | **0** | **0** |

## 5. TEST RESULTS

The comments from the customers are as follows:

– The main performance of the LOCOTROL Electronic Brake portion meets the requirements in test specification.

– LOCOTROL EB efficiently speeds up the air signal transmission, shortens the charge time, and shortens the brake time of very long trains. The 20k ton train made of four 5k-ton trains has almost the same air brake performance as a single 5k tons train.

– LEB system can work well with the type of brake valves mounted in the wagons.

– In case of locotrol system in Comm Loss, it has the feature to convert the Locotrol train into a conventional train, and ensures that the train safely stops by using air brake of the single lead locomotive.

– The locomotives in DP mode can lift the train from stopped and accelerate up the gradient of 0.4%.

- The 20k ton DP trains has almost the same stopping distance as that of a 5k-ton train for full service brake and emergency application on down grades up to 1.2%. The 20k ton DP train's stop distance was only 101m longer than that of 5k tons train for an emergency application on level grade.
- The 20k ton DP trains made from four 5k-ton trains by using Locotrol technology meets the cycle braking requirement of keeping 50-kpa reductions for 1.5 minutes and release for 2 minutes, back and forth.
- Coupler force and longitudinal acceleration of the 20k ton LOCOTROL DP trains meets the requirement specified in test plan.
- The dynamic performance of the nine instrumented wagons in the 20k ton LOCOTROL DP trains meet the requirement specified in test plan.

# Asian Institute of Transport Development

Economic and social development of communities has meant physical expansion and inevitably the movement of people and goods with technological and energy resources at their command at any given time and place in history. But it has also meant at the same time, thoughtless exploitation of nature, inequality of development, a rural-urban and a rich-poor divide, and barriers to trade and movement among nation-states.

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