MONITORING INSTRUMENTS MOUNTED ON SCHEDULED RUNNING COMMERCIAL TRAINS (INSTRUMENTED REVENUE VEHICLES, IRV) MAKE USE OF NEWTON’S LAWS OF MECHANICS FOR TRAIN BASED AND IN-SERVICE TRACK-CONDITION MONITORING IN TARGET PLANING OF MAINTENANCE

DYNAMICS OF TRACK-TRAIN INTERACTIONS

By F.A. Wingler, April 2018

Japan Railways Kyushu 800 High Speed Train fitted to Car Body and Bogies with Equipments providing Data on Track Conditions

Automatic in-service track-condition monitoring through data acquisition by means of Instrumented scheduled running commercial Revenue Vehicles (IRV), making use of NEWTON’S LAWS OF MECHANICS, drive track maintenance efficiency; see Ravi Ravitharan, Director, Institute of Railway Technology Monash University, Australia; paper presented on the Permanent Way Institution NSW Annual Convention 27th Oct. 2017 at Sydney, Australia (see ANNEXURE I); Railway Gazette International, March 2018, page 34.
Newton`s **FIRST LAW** suggests that any change of velocity of a body under consideration must be associated with the counter-action of a resultant force, which acts on his body. This in turn suggests a relationship between the resultant force and the acceleration of the body.

Newton assumed by his **SECOND LAW** the very simple relation that the resultant force, which acts on the body and causes acceleration, is linear related.

The **THIRD LAW** is the "**LAW OF ACTION AND REACTION**": “For every **ACTION** there is an equal and opposite **REACTION**”. This is probably the most famous law of motion. This means that if one object 1 acts a force out on another object 2 then object 2 will act the same size force in the opposite direction on object 1; $F_{21} = F_{12}$. Here are diagrammes to visually show this:
Newton’s Laws of Motion

1. Newton’s First Law of Motion
   - Every object will continue in a state of rest or with constant speed in a straight line unless acted upon by an external force.

2. Newton’s Second Law of Motion
   - When a net force act on an object, the object accelerates in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the mass. Thus, \( a \sim F/m \) or, \( a \propto F/m \)

3. Newton’s Third Law of Motion
   - Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

In other words, when a body (rail-track) exerts a force on a second body (rail-vehicle), in consequence the second body (rail-vehicle) exerts a numerically equal but opposite force on the first body (rail-track).

The force acted on the rail-vehicle causes acceleration in vertical and/or lateral direction and/or causes rotation movements. The extend of the acceleration and rotation is linear related to the force acted by the rail-track on the rail-vehicle and can be used to detect and measure rail-track defects by means of instruments/devices on board of the rail-vehicle (Instrumented Revenue Vehicle; IRV). The “IRV” can be a commercial and scheduled running Locomotive, Passenger Coach or Freight Wagon.

The Railway is a system, where steel-wheels run on steel-rails, with a non-elastic contact area of less than 3 cm². This means that track and train interact over a contact area of less than 3 cm², and exert the forces over this small contact area following Newton’s Laws of Mechanics.

Wheel-on-Rail Contact Area of new Wheel-Treat and Rail-Head Profile on straight Run
When running on a straight rail-track, on a perfect aligned and smooth rail-table without any roughness and with only little rail-deflection under the wheel load (optimum in the range of 1.5 mm), there are only little additional vertical and lateral inter-acting forces causing acceleration, deceleration and rotation on the rail-vehicle with equal corresponding forces acting on the rails. That is, why a high quality rail-track experience only little additional corresponding forces of the running rail-vehicles acting on the rails. Therefore, a high quality rail-track keeps its properties under given traffic load, volume and velocity over a long period and loses its properties over the time with a slow deterioration rate. The deterioration rate under given traffic load and train speed is an index for track quality.

On poor quality rail-tracks of bad alignment and poor bearing capacity with tract defects like, kinks, dips, undulations, twists, high rail-deflections under wheel load (related to deteriorated track components/constituents, poor bearing sub-structure components and poor drainage), rail-table defects and roughness (corrugation, rail-head-burns, RCF), running vehicles experience high additional vertical, lateral and rotation forces exerting equal opposite forces on the rail-track damaging the track components. With increased accumulation of traffic, through this mutual “SELF-DESTROYING SYSTEM” the situation can deteriorate rapidly.

Oscillating rail-vehicle movements, self-exited or exited by track alignment defects, like Shuttling, Lurching, Bouncing, Rolling, Pitching, Nosing and Hunting, increase further the deterioration rate of an already deteriorated track.

At misaligned and un-straight rail-joints and rail-welds as well by wheels running with flat spots, high impacts are caused. Latter produce high rail and rail-weld bending stress, causing degradation of rail-welds, rail-fastening systems, sleepers, ballast and track sub-structure components.

The geometrically perfect production of welded rail-joints and the correct alignment and rail-surface profiling of the jointed rails are therefore essential parameters for the durability of the welded joints. Rail-straightness and even rail-surfaces of welded joints are decisive factors for the durability of welds. A passenger travelling in a coach on Indian Railway’s tracks can detect nearly each and every rail-weld by the “tack-tack” sound, caused by the response of the wheels, when running over un-straight and/or uneven rail-welds. In countries of advanced railways with perfected welded rail-joints, such sound is not audible.

There is a clear correlation between weld-shape and the corresponding vehicle dynamics, which can be monitored by IRV.

In-service rail-weld failures are in India frequent and have caused many derailment-disasters with high mortality rates:
Poor quality tracks deteriorate faster, the service life is shorter, and more frequent monitoring and maintenance is needed, and in consequence the expenditures or overall life-cycle costs keeping a train service on a poor quality track can be 8-fold higher than on a high quality track.

The Newton’s Laws Mechanic is useful to analyse mutual track-vehicle/wheel-rail interactions and to determine track irregularities and track defects by vehicle mounted Instruments: **Accelerometer Sensors and Gyroscope Devices for Rotation Measurements**. This means, by measuring accelerations and rotations through instruments mounted on rail-vehicles, the cause in form of track irregularities can be determined. And by continuous track monitoring with repeated runs over the same track, the development of track-defects and track-irregularities, the development over the time of such defects and irregularities, in other words, the **Track-Deterioration Rates or Velocity of Deteriorations**, can be
measured, and the threshold for necessary interaction by repair, maintenance or renewal can be forecasted.

II. IRV`s FOR THE AUTOMATIC COLLECTION OF DYNAMIC VEHICLE PERFORMANCE DATA AND FOR IDENTIFICATION OF HIGH RISK RELATED RAIL-TRACK DEFECTS

Railway networks globally are steadily growing with significant capital investments in infrastructure and modernisation. The railway operators are demanding higher productivity and throughput to meet increasing patronage and changing needs. These coupled with shrinking maintenance windows and tightening of available asset repair budgets necessitate responsive strategies to ensure continued safe operations, service reliability, whilst at the same time looking at ways to create greater efficiencies.

Increasingly, technology and system approaches are being utilised by leading railway organizations to overcome these challenges and to improve their operations. The Instrumented Revenue Vehicle (IRV) Technology and associated sophisticated automatic data processing system are key technological innovations providing significant benefit to these railway organisations. The IRV is an intelligent automated condition monitoring tool, which is integrated into normal commercial and revenue service railway operations, and which is operating day-in and day-out without disturbing the time table of scheduled trains.

IRV automatically collects dynamic vehicle performance data and identifies high risk track related defects and the precise locations of the defects, capable of sending remote data, that can be analysed in real time. It prompts appropriate operational responses, such as the application of temporary speed restrictions and rescheduling of maintenance activities, thus limiting risk associated with catastrophic consequences such as derailment and any further damage to rail assets. The IRV technology is also used to measure the effectiveness of maintenance activities and to identify track deterioration trends and any irregular operational movements.

IRV platform has the following measurement capabilities:

- GPS Positioning,
- Altitude,
- Vehicle dynamic Response to Track, Roll, Pitch, Bounce and Hunting,
- Vehicle in-Train Forces,
- Ride Index and Ride Safety,
- Vehicle Loading and Wheel/Axle Loads,
- Rail running Surface Accelerations,
- Track Surface/Alignment Conditions,
- Track Super-Elevation and Cant,
The above cited papers of R. Ravitharan; see ANNEXURE I, outline the IRV technology, and how the shift from reactive to proactive maintenance and operation using new technological innovations are providing significant benefits to the railway industry. Through the integration of the IRV intelligent automated condition monitoring tool into normal everyday operations, the railway industry has an opportunity to create greater efficiencies, reduce maintenance costs and to ensure safer operations, whilst at the same time extending asset life.

The IRV concept had been developed by the Monash University Institute of Railways, Australia, which provides both the measuring systems and the data processing services to a growing number of railway operators around the globe. In July 2007, Monash University Institute of Railway Technology, Australia, signed a collaboration agreement with the Hong Kong Mass Transit Railway, MTR Corporation, to installed the most advanced IRV condition monitoring technologies on the Hong Kong metro network. Further customers are V-Line of Rio Tinto, Australia Rail-Track Corporation, Fortescue Metals Group, Roy Hill Aurizon, Vale and Pt Kereta Api in Indonesia.

The basic concept is fairly straight forward: Rather than using dedicated inspection cars, the measurement platform is mounted on daily running commercial standard revenue vehicles during the normal daily operating cycle, both loaded or empty. To learn more about IRV, read the paper of R. Ravintharan in the ANNEXURE I.

Federal German Railway (DB) equipped the Locomotive of one of its Intercity Express Trains with acceleration and rotation-gyroscope sensors mounted on the axle-box for transmitting during scheduled train runs in-service monitoring data of vertical and lateral alignment defects as so-called “TRAIN BASED IN SERVICE MONITORING FOR TARGET PLANING OF MAINTENANCE”. This IC transmits daily the acceleration and rotation rates cum position on its route. The computer evaluates a history diagram from which a forecast for the further deterioration rate can be estimated. Through the wheel/bogie acceleration/rotation rate values, measured by axle-box mounted accelerometers and gyroscopic measurement sensors, the running trains will transmit in future to the Permanent Way Engineer the telemetric data of developing track defects with their exact location in his jurisdiction, how the defects develop with the time and with what rates (dynamic of deterioration) under given traffic load, volume and speed. The Track Engineer will get alarm, when he will have to interfere by repair or maintenance. This method includes also the monitoring of turnouts.
The prerequisite for a proactive Life-Cycle Cost Management Approach with the evolution of the development prognosis is the all-encompassing data collection of the continuous online condition monitored on all track assets; see K.U. Wolter et al. in Eisenbahntechnische Rundschau, ETR, 7 +8, p. 32-36, 2014, eurailpress, Hamburg, Germany. 2004. In a further pilot-project, German Federal Railway (DB) had equipped a High-Speed ICE train with an axle-box mounted accelerometer device, measuring daily approx. 1500 km track on alignment defects.

The Institute for Transport System Technology of the German Aerospace Centre (DLR) conducts the development of modern Data Management Systems for collecting, transferring and telemetry. The data must be precisely geo-referenced according the track locations. On lines with sufficient global satellite reception, the monitoring cars communicate directly with the central databank. The data can also be locally stored and transmitted in intervals by WILAN over the internet at stations or depots. For lower data volumes, the mobile telephone networks can be used. The System is under trial on Swiss Sections; Lars Johannes et al. in DER EISENBAHNINGENIEUR, EI, 11, November 2015, p. 12, eurailpress.
Fitting monitoring equipments on commercially operating trains to provide an in-depth analysis of track conditions is increasingly common: see FROM DATA CRUNCHING TO PREVENTIVE TRACK MAINTENANCE in International Railway Journal, May 2017, Volume 57, Issue 5, page 52. The traditionally strategy of Railways and infrastructure managers is to measure regularly track geometry to identify irregularities and inform maintenance works. This data is retrieved by dedicated track inspection vehicles. Recent trend is to deploy on commercially operated trains measurement devices, increasing the frequency of measurements. By using scheduled trains, infrastructure managers can retrieve inspection data every day. Margin of track-defects (track-condition) can be evaluated in a predictive way; see also: https://www.railwayage.com/analytics/bentley-rail-predictive-maintenance-video/; ANNEXURE II.

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By means of Frequency-Analysis with axle-box mounted accelerometers, Swiss Railway, SBB-CFF, is analyzing track sub-structure components. The information is used for planned sub-structure rehabilitations; see Fabian Angern et. al. in Eisenbahn Technische Rundschau, ETR, No. 3, March 2016, eurailpress.
Belgium Railway is mining data retrieved from *TELVIC RAIL* Sensors installed on bogies of scheduled running Belgium passenger coaches with the objective of developing a predictive maintenance tool; see: *Research aims to develop predictive Maintenance Tool* in Railway Age, [https://www.railwayage.com/analytics/research-aims-develop-predictive-maintenance-tool](https://www.railwayage.com/analytics/research-aims-develop-predictive-maintenance-tool).

*TELVIC SENSOR* mounted on the Axle-Box of a commercial Belgium Passenger Coach

Information on Drainage and Ballast Conditions, Rail Defects, Effectiveness of Fastenings have becomes available over video-graphing of the route with mapping systems mounted on commercial and scheduled running rail-vehicles.

*RILA* track laser 3D video measurement and mapping system mounted on scheduled running passenger trains in England gather regularly GPS-positioned accurate, up-to-date rail-track, infrastructure and analysis data, without disrupting the service; see [www.fugro.com/rail](http://www.fugro.com/rail):

*FUGRO-RILA Track System mounted on scheduled Passenger Train in UK for GPS positioned 3D Laser Video Scanning and Mapping*
III. The Dynamic Vehicle Performance of running Indian Passenger Coaching Stocks

Oscillating rail-vehicle movements, self-exited or exited by track alignment and rail-surface defects, like Shuttling, Lurching, Bouncing, Rolling, Pitching, Nosing and Hunting increase the deterioration rate of an already deteriorated track following Newton’s Laws of Mechanics.

The standard Indian ICF passenger coaching stocks of Indian Railways are commissioned for a speed of 110 kmph:

![Indian ICF Standard Passenger Coach](image)

The new stocks of LHB (Linke Hoffman Busch Design) coaches, commissioned for 160 kmph, with Fiat Bogies, have a different oscillation frequency, and the vertical and lateral sways are better damped; see Paragraph 20.12.4. of the handbook, J.S. Mundrey/F.A. Wingler INDIAN RAILWAY TRACKS, which you find free for download on the website: http://www.drwingler.com.

The problems with the standard passenger coaches are the oscillating movements, the “nosing” and “hunting” in resonance with lateral track alignment irregularities of welded 13 m rail panels. If one sleeps in a sleeper coach at one of the ends, one get often terrible disturbed by these oscillating lateral movements (nosing and hunting jerks). In response according Newton’s Third Law: “ACTIO = REACTIO” the track alignment gets vertical and lateral disturbed. The nosing and hunting of the Indian standard passenger coaches is a big problem for the IR Tracks. The remedies are longer milled rails, better aligned welds and new longer coaches with better damped more track friendly bogies. But exchanging the fleet of a stock of
over 1 lakh cannot be performed in short period. On LWR/CWR, constituting of welded 13 m rails (often poor aligned welds), speed increase is hampered because of the track unfriendly running quality of the standard ICF coaching stocks on LWR/CWR’s consisting of welded 13 m rails. Not the longer new LHB coaches with Fiat type bogies disturb the track at up to 150 kmph, but the old standard ICF coaches are the track distorting culprits when running at the lower speed of 80 to 90 kmph.

Following the “NEWTON’S LAWS OF MECHANICS” the acceleration rate ‘g’ values can be measured by an accelerometer, positioned as close as possible over the centre of the bogie or better direct on the axle box. This transmits INDICES for the TRACK DISTORTING FORCES the rolling stocks are exerting onto the rails. If a value of 0.35 ‘g’ for the lateral acceleration is measured, this means that at the relevant speed a 120 tons locomotive will exert with its relevant bogie a lateral counter vector-force of $60 \times 0.35 \times 10 = 210$ kN onto the rail (note that 1 metric ton generates a force of say 10 kN). The cumulative track torturing forces of consecutive running trains can print dangerous UNDULATIONS into the track. Once this self-destroying rail-wheel process had been initiated by a certain degree of vertical and lateral track distortion, the deterioration process grows with increasing (logarithmical) rate (velocity). Short wave length undulations are therefore the most dangerous. Measuring of accelerometer indices with schedule passenger trains is a most valuable, effective, cheap and easy mode in order to describe the quality, state-of-affairs and the development of defects over the time. The positioning can be determined with GPS location detection.

According US Standards, lateral/horizontal acceleration indices over 0.35 ‘g’ and vertical indices over 0.5 ‘g’ of rolling stocks, especially of heavy locomotives, are regarded as unhealthy for a track. Since the acceleration rates are speed dependent, train-speed has to be reduced, when the rates become intolerable high. What counts is not so much the absolute value in
mm of a misalignment measured by a TRACK RECORDING CAR, but what counts is the effect of the misalignment or track defect on the running wheel at given train speed, how the wheels jump over the defects and respond with what acceleration and deceleration values (in terms of corresponding extra impression forces measured in [MN/m²] inflicting according the Newton’s Laws of Mechanics further damage to the track in vertical as well in lateral directions. **The DYNAMICS of the Rolling Stocks on the Track is what counts!!**

### IV. COACH-DEFECT MONITORING SYSTEMS ON IR

**THE ECONOMIC TIMES**, March 24, 2018, reports: In a move to create a "Zero Accident" network, Indian Railways has decided to install **“Coach-Defect Monitoring Systems”** on 65 rail sections across the country.

Officials said, these include 25 sections on Central and Western Railway, both of which have an extensive rail network in Maharashtra. "The sections on WR and CR, where we plan to have these systems, include Wardha-Nagpur and Bhusawal-Jalgaon on CR and Mumbai-Surat and Surat-Baroda on WR," a senior official of Northern Railway said. It will cost Rs 115 crore to set up the system in these 25 sections, the official said.

Explaining the mechanism, Arun Arora, Principal Chief Mechanical Engineer, NR, said, "The Online Monitoring of Rolling Stock (OMRS) System involves the placing of microphones and sensors in such a way that they record any audible noise or measure forces generated while a wagon, coach or locomotive is in motion."

"The OMRS equipment is extremely sensitive and accurate and can detect the minutest of abnormal noises emanating from rolling stock and will alert the control room immediately", he said.

He informed that the trial of the OMRS on the busy Lucknow-Delhi stretch was successful following, which it was installed on the Delhi-Panipat section. "This system allows us is to do away with the current method, which involves the physical examination of rolling stock in workshops," Arora said.

Another official said that it would ensure faster maintenance of coaches and also allow coaches to be monitored using mobile communication facilities.

See: **THE ECONOMIC TIMES**, March 24, 2018:  
Summary:

Railway networks globally are steadily growing with significant capital investments in infrastructure and modernisation. The railway operators are demanding higher productivity and throughput to meet increasing patronage and changing needs. These coupled with shrinking maintenance windows and tightening of available asset repair budgets necessitate responsive strategies to ensure continued safe operations, service reliability whilst at the same time looking at ways to create greater efficiencies.

Increasingly, technology and system approaches are being utilised by leading railway organizations to overcome these challenges and to improve their operations. The Instrumented Revenue Vehicle (IRV) Technology and associated sophisticated automatic data processing system are key technological innovations providing significant benefit to these railway organizations. The IRV is an intelligent automated condition monitoring tool, which is integrated into normal railway operations.

IRV automatically collects dynamic vehicle performance data and identifies high risk track related defects and the precise locations of the defects, capable of sending remote data, that can be analysed in real time. It prompts appropriate operational responses, such as the application of temporary speed restrictions and rescheduling of maintenance activities, thus limiting risk associated with catastrophic consequences such as derailment and any further damage to rail assets. The IRV technology is also used to measure the effectiveness of maintenance activities and to identify track deterioration trends and any irregular operational movements.

This paper outlines the IRV technology and how the shift from reactive to proactive maintenance and operation using new technological innovations are providing significant benefits to the railway industry. Through the integration of the IRV intelligent, automated condition monitoring tool, into normal everyday operations, the railway industry has an opportunity to create greater efficiencies, reduce maintenance costs and to ensure safer operations, whilst at the same time extending asset life.
**Introduction:**

With developments in technology it is now possible to provide faster and more regular feedback on track condition and to reduce potential risks to railway operations through the use of instrumented revenue vehicles (IRV).

IRV technology was developed and has been successfully implemented in various leading heavy haul railway operations by Monash University’s Institute of Railway Technology (IRT). IRV technology is an automated measurement platform, which is embedded on standard revenue vehicles. These vehicles are permanently equipped with advanced measuring systems including different types of sensors and logging units (refer to Figure: 1) to provide continuous feedback on track condition, vehicle dynamics and train operation.

Some of the key features of IRV technology include:

- IRV is highly robust and is embedded in the operation; it is therefore treated as any other wagon in the network operating under harsh railway conditions and is generally maintained as part of the standard train running schedules.

- Track condition is measured as part of normal railway operations. Accordingly, there is no downtime, which would otherwise be required when dedicated track condition monitoring devices are used.

- Dynamic responses of standard vehicles are measured during normal operating environments including loaded and empty conditions. Track conditions and vehicle responses are correlated, and strategies can be developed to improve system performance.

- Continuous measurement during each loaded and empty run provides frequent information, which can be utilised for various short and long term trending analysis, including identifying maintenance effectiveness.

- Accurate sub-metre (within 1m accuracy) track location identification of any track response.

- Additional measuring sensors can be easily added to this flexible platform to monitor various component performances under normal operating condition.

- Flexible platform, that can be utilised effectively to understand underlying system performance. For example, multiple IRV units can be installed on a train to assess the performance improvements after the introduction of new components such as ECP braking system.

The ability of the IRV to directly communicate over 3G/4G mobile and satellite networks greatly increases the defect detection to response time of any track defects. IRV Field recordings are automatically downloaded to the main logging unit mounted on the revenue vehicle, and the data is then remotely transmitted to the data processing centre for further analysis and reporting (refer to Figure: 2).
These instrumented vehicles are capable of monitoring a broad range of track conditions (including track geometry defects using bogie suspension displacement and rail surface defects using unsprung side frame acceleration) as well as in-train coupler/drawbar forces, brake pipe and brake cylinder pressures. In addition, the IRV measurements can be used to calculate vehicle dynamic modes roll, pitch, body bounce, body rock and hunting. Table: 1 outlines IRV platform capabilities.

One of the important features of any continuous monitoring platform should be timely feedback in the form of reports and warnings. IRV reports and warnings are provided to operational personnel including track inspectors, train control centres, maintenance engineers and planners via email and sms as well as customized web dashboards (refer to Figure: 3).

Figure 1: Typical Instrumented Revenue Vehicles Iron Ore (top left), Coal (top right) as well as Passenger Coaches (bottom)

"One of the important features of any continuous monitoring platform should be timely feedback in the form of reports and warnings."
**Timely Identification of Track Defects:**

IRV technology would provide railway organisations with a mechanism to assist in identifying weld, rail surface and track-related defects in a timely manner to improve its current inspection methodology. Since the dynamic vehicle performance is monitored by the IRV under loaded conditions, this would significantly improve the probability of detecting track deterioration before it is too late, thus avoiding potentially catastrophic consequences. The elevated vehicle dynamic responses, such as side frame acceleration on each side of the bogie, bounce or rock of the vehicle (see Figure 4) can be directly correlated to accurate track location(s). They can then be attributed to track features such as welds, IRJs, corrugation and turnouts and adequately maintained to improve the overall ride of the rolling stock. Similarly, track geometry measurements and associated vehicle dynamic responses measured by the IRV (Figure 5) can be utilised to prioritise track maintenance.

The ability of an IRV to accurately locate track features can be utilised to investigate the condition of each weld on the track, and whether they are peaked or dipped (refer to Figure 6). Furthermore, the shape of each weld, including its heat affected zone, and the vehicle side-frame accelerations in both directions of traffic over the weld, can be accurately monitored as shown in Figure 7.

![Diagram showing the flow of data collection, processing, and reporting](image)

**Figure 2: The Flexibility of responding Systems allow IRV Monitoring Data to inform a Variety of Asset Management Strategies.**
STRETCHING THE MAINTENANCE DOLLAR USING STATE-OF-THE-ART AUTOMATED IN-SERVICE VEHICLE-TRACK CONDITION MONITORING

<table>
<thead>
<tr>
<th>Vehicle Dynamic Response to Track</th>
<th>Super-Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll, Pitch, Bounce &amp; Vehicle Hunting</td>
<td>Twist</td>
</tr>
<tr>
<td>Vehicle In-Train Force</td>
<td>Curvature</td>
</tr>
<tr>
<td>Rail Running Surface Acceleration</td>
<td>Does not require separate Train Path &amp; Operators</td>
</tr>
<tr>
<td>GPS Position</td>
<td>Continuous Measurement</td>
</tr>
<tr>
<td>Altitude</td>
<td>Measurement under dominant Vehicle Loading</td>
</tr>
<tr>
<td>Surface</td>
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</tbody>
</table>

Table 1: IRV Platform Capabilities

Figure 3: The IRV Package provides Users with a customised Web-Dashboard to interrogate the processed Data.
FIRST SESSION

STRETCHING THE MAINTENANCE DOLLAR USING STATE-OF-THE-ART AUTOMATED IN-SERVICE VEHICLE-TRACK CONDITION MONITORING

**Figure 4**: Elevated dynamic Responses detected by an IRV

**Figure 5**: Track Geometry and Vehicle Dynamic Responses measured by IRV
Speed Restrictions:

Poor condition of track is mitigated by application of temporary speed restrictions (TSR) prior to scheduling maintenance to improve the quality of the track. The reduced speeds are often pre-defined within engineering standards. Generally these speed reductions are conservative, and unnecessarily disrupt operations, without any measured relationship between the poor track condition and its influence upon the vehicle ride and consequent derailment risk.

IRV technology continuously measures both the track condition and the related vehicle dynamics, allowing an understanding of the relationship between the two, and aiding characterisation of the system performance. IRV technology enables the setting of speed restrictions sufficient to minimise the dynamic response and reduce the risk of derailment, thus improving operational efficiency. IRV can also automatically confirm whether the applied speed restrictions are having the required effect in reducing dynamic responses to manage the risk as shown in Figure: 8(a-c) ⁵.

Evidence based Track Maintenance Strategy:

Track maintenance should be performed to minimise vehicle dynamic responses. Undesirable vehicle dynamic responses will increase track loading, which in turn reduces infrastructure life and increases the risk of vehicle derailment.

The current routine maintenance strategies are based on the track condition reports and experience of maintenance personnel. However, the continuous drive for increased efficiencies within railway operators necessitate the need for a greater understanding of maintenance performance and its effectiveness in reducing vehicle dynamic responses. An IRV’s continuous measurement of track geometry parameters and vehicle dynamic responses can be used not only to identify the effectiveness of the maintenance activities (refer to Figure: 9) but also to identify maintenance frequencies to keep the vehicle dynamic responses within acceptable levels.
**Figure 6**: The Condition of Rail-Welds can be identified from the Record-Data.

**Figure 7**: There is a clear Correlation between Weld-Shape and the corresponding Vehicle Dynamics.
IRVs can be used to tailor temporary Speed-Restrictions. The Plots show an elevated Bounce Response at 72 kmph (Figure 8a), and the reduced Bounce at 56 kmph under a 60 kmph Speed-Restriction (Figure 8b), and the Bounce is removed at 37 kmph after the Speed-Restriction is lowered to 40 kmph (Figure 8c):

Figure 8a: Elevated Bounce response at 72 kmph under 60 kmph Speed-Restriction

Figure 8b: Reduced Bounce at 56 kmph at the same Location under 60 kmph Speed-Restriction
Figure 8c: 37 kmph at the same Location under 40 kmph Speed-Restriction
Figure 9: The Effectiveness of Tamping can be assessed by considering the Suspension Response before and after the Work.
The continuous monitoring of track condition and vehicle dynamics during the normal operating environment facilitated a paradigm shift in maintenance planning. Railway operators are able to shift from either a firefighting reactive or a routine maintenance approach to a more effective predictive maintenance approach. Reactive maintenance is often costly and unscheduled, whereas routine maintenance is less costly but at times can be inefficient. This is because the cyclic nature of the maintenance activities, which may not be essential at that point in time. Some other locations require track maintenance over a shorter maintenance cycle, but maintenance is not undertaken because of scheduling and/or lack of resources.

The continuous monitoring capabilities of an IRV to collect up-to-date dynamic responses along with a significant amount of historical information will assist in determining the localised track deterioration as well as predicting future track deterioration for each section of track\(^2\). This valuable information is the basis for the implementation of a proactive evidence based maintenance strategy. IRV technology would enable scheduled maintenance activities to be prioritized to locations exhibiting rapid deterioration rates. This would present an effective and efficient maintenance approach, which would assist railway entities to optimise its rail operations and to achieve its strategic objectives.

**Conclusion:**

Continuous monitoring of track condition and vehicle response using the IRV fleet has been considered by leading railway organizations to assist with improving efficiency and effectiveness of maintenance activities.

The responses measured by IRV technology reflect track conditions and the corresponding vehicle dynamic behaviour, which can be utilised to implement proactive evidence based track maintenance strategies.

IRV technology offers the ability to obtain regular and rapid identification of any track and operational issues and to address them in a timely manner.

Continuous monitoring collects up-to-date dynamic responses, which together with historical data can assist in predicting future deteriorations for each section of track\(^2\). Based on the IRV feedback, scheduled maintenance activities can be prioritised at locations exhibiting rapid deterioration.
References:


**ANNEXURE II**

Data Acquisition and Handling by BENTLEY, UK; "Analyse Rail and Track Condition".

*BENTLEY* Systems’ Rail Predictive Maintenance platform “enables railways to understand rail asset condition to improve maintenance decisions, predict asset deterioration to help optimize maintenance schedules, and allow to access to data wherever it adds the most value, in the office or on site,” the company says.

“Optimizing maintenance for rail assets is essential for delivering a safe, reliable, and profitable rail network. Having accurate information about rail assets is a crucial part of a predictive maintenance decision support environment.”

Rail Predictive Maintenance combines asset condition data with environmental, financial, and design data, which allows users to understand the state and operating condition of key rail assets to improve the overall integrity and safety of a rail network.

“A common data environment for railway maintenance decision support allows proactive management of railway assets based on current and historical track and rail asset data,” Bentley notes. “Users can combine asset condition data with environmental, financial and design data to understand the state of the assets and how they are deteriorating over time. Budget, resources, and access constraints can be reviewed visually along with the predicted deterioration of the asset and the impact of asset failure on the overall system. This allows users to improve the effectiveness of maintenance work planning.

“Our Predictive Maintenance solution combines current and historical rail asset data. This is presented in linear, thematic track charts. You can also interactively reference more than 200 types of railway asset data, including track layouts, curves, track elements, planned work, work history, events history, rail defects, maintenance zones, area zones, track category and mileposts”, Bentley notes.

*BENTLEY RAIL PREDICTIVE MAINTENANCE*; written by William C. Vantuono, Editor-in-Chief of RAILWAY AGE, April 12th, 2018; [https://www.railwayage.com/analytics/bentley-rail-predictive-maintenance-video/](https://www.railwayage.com/analytics/bentley-rail-predictive-maintenance-video/)

**BENTLEY notes further:**

*Analyse Rail and Track Condition:* Quickly assess every dimension of the railway infrastructure and its condition over time. Assess and learn from past maintenance activities. Make better decisions about track and other
maintenance-of-way assets. Determine what work needs to be done, where
the work should be focused, and predict when the work should be performed.
Interactively reference and analyze more than 200 types of railway asset data
simultaneously, including track layouts, mileposts, curves, planned work,
work history, rail defects, gross tonnage, maintenance zones, track category
and predicted future asset conditions. Achieve and maintain a state of good
repair for rail and transit assets and increase safety, performance, and
reliability of your railway network.

**Big Data and the Internet of Things:** Data collection systems such as track
goometry vehicles, ground penetrating radar, laser scanners, video recorders,
track walkers, and more can produce many gigabytes of data in a day. AssetWise efficiently stores, links to, and correlates this data for rapid access
and analysis, enabling you to make timely and accurate maintenance
decisions. AssetWise supports managing datasets containing hundreds of
thousands of surveys and can be terabytes in size.

**Data Analysis and Rules Engine:** AssetWise has a library of 200+
linear network-aware data processing rules and commands, that can be
applied to extract actionable information. These rules can find clusters of
defects, trend track-degradation to plan surfacing, filter spikes and
flaws at lines from measurement data and much more. Furthermore, these rules can be combined to perform sophisticated
data analysis to extract more value from existing data.

**Data Visualization:** Data visualization is critical in transforming vast
quantities of complex linear data into actionable information, that users
can readily access, understand and utilize. Straight line diagram visualization features provide you with instant access to an informative
representation of any combination of configured data types and at any
location on the railroad network.

**Source Data Integration:** AssetWise brings together linear asset data
from any number of sources and correlates the data by location and
time. AssetWise includes a number of integration capabilities for
importing files, linking to existing databases and web services to
communicate with other systems. AssetWise extends value to discrete
or hierarchical asset data systems like EAMs and other CMMS or
asset management systems, by combining linear with discrete data
analysis, then feeding results back to the non-linear systems.

Linear asset decision support capabilities enable you to:

- Achieve and maintain state of good repair.
- Analyze rail asset information.
- Assess rail conditions.
> Integrate mapping information.
> Plan rail maintenance.

The Bentley Company offers an informative video on the subject matter.

**BIG DATA CRUNCHING**

“**BIG DATA**” is data whose volume, scale, diversity and complexity require new architectures, techniques, algorithms and analytics to manage it, and to extract hidden values, information and knowledges from it in making decisions and in evolving planning and strategies in order to come to right actions to be taken.
Track Monitoring; courtesy by Plasser&Theurer

Track Monitoring Vehicle, USA, in early 1900’s