



***Condition
Monitored
Maintenance
using self-powered
sensors & vibration
based analytics***



By


perpetuum

EXECUTIVE SUMMARY:

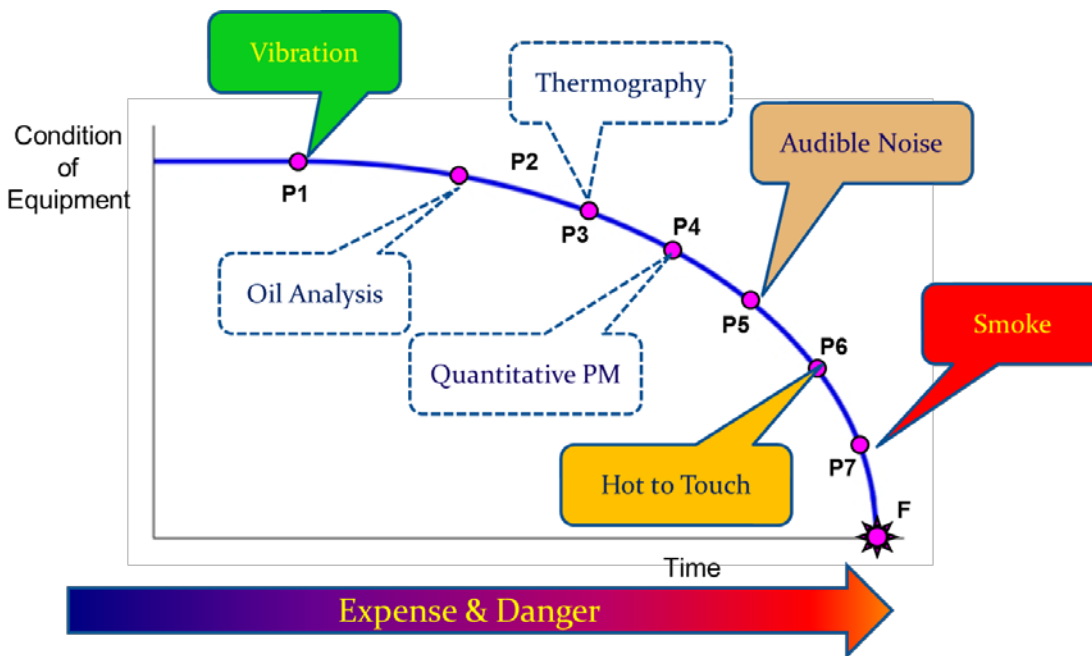
Condition Monitored Maintenance allows train operators to optimise the performance of their assets to maximise safety, maximise reliability of operations and to minimise costs. At the heart of this approach is a real time knowledge of the condition of an operators key assets.

There are 2 key outcomes that result from real time condition monitoring:

1. No Surprises - the system will provide very good advance warning of impending problems so in service breakdowns and the safety and service implications that they cause can be avoided
2. Optimised maintenance - Maintenance and overhauls can be postponed to when the specific asset requires it, rather than based on a generic time or distance milestone.

Perpetuum is a global leader in the provision of information to enable this. Its award winning, self-powered, wireless sensing technology, combined with its vibration engineering expertise and rich analytics, provides real time information that enables the rail industry to optimise railway operations.

Perpetuum use vibration and temperature sensors to provide this monitoring capability. This is because vibration is the earliest and most sensitive monitor of degradation of these key components



Perpetuum has key skills and expertise to enable this data to be collected efficiently and analysed so as to give the operators a clear view of the condition of their assets. These key skills include:

- Expertise in vibration engineering to allow the development of the *most reliable algorithms* for many of the most critical assets in your railway system – bearings, wheels, gearboxes, traction motors, track etc
- Understanding of vibration data that allows the algorithms to identify condition changes at the *very earliest stages* of degradation.
- Analytical capabilities to enable the extraction of bearing, *wheel & track condition simultaneously* from data produced from the same single sensor.

- Patented *sensor nodes that are self-powered* and completely wireless allowing a typical installation time of less than 30 minutes.
- Experience from many 1000s of sensors already deployed and *over 1 000 000 000 miles of operational service* allow Perpetuum to provide sensors that are capable of withstanding the most aggressive environments, and being mounted directly onto the bearing case.

PERPETUUM BACKGROUND:

Perpetuum was created in 2004 as a spin off from the University of Southampton (UK), with the target of developing and commercialising its revolutionary vibration energy harvester. Today it is focused on the railway markets, a sector that is seeing significant investment. Perpetuum has ongoing contracts with market leading operators in the UK, and has been successful in exporting its products and services to continental Europe, APAC and to the US.



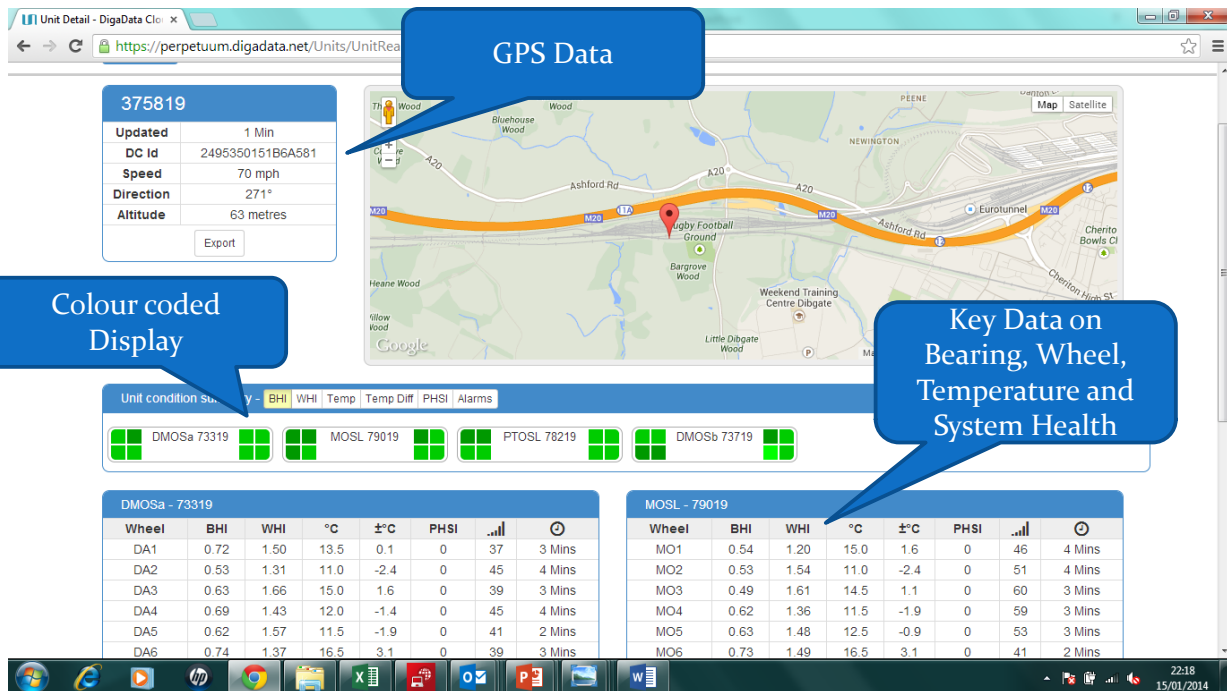
The Rail Supply Group Council with Vince Cable, UK Business Minister and MP



Our innovation is widely recognised – most recently receiving the UK Modern Railway Engineering and Design award in 2014 and being applauded by the vice-president of the European Commission, Neelie KROES, as an example of excellence in rail innovation. Our president, Roy Freeland, sits on the council for the UK Government's Rail Supply Group.

HOW THE SYSTEM WORKS

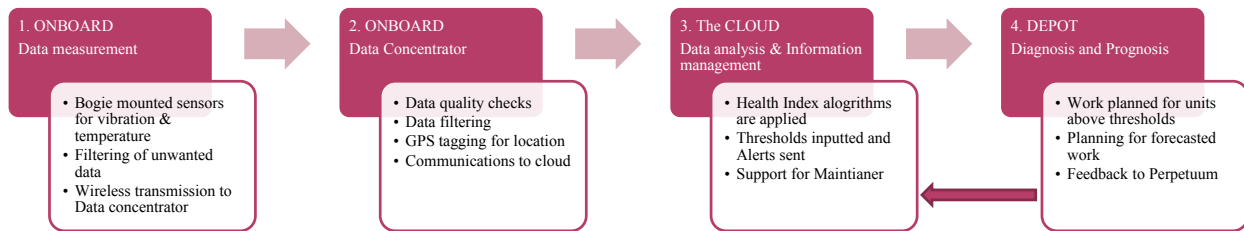
The Perpetuum system provides information in an easy to use format to provide a clear view of the condition of the operator's fleet. Train operators have access to a secure website to view key information such as Bearing Health Index (BHI) and Wheel Health Index (WHI). Alternatively the information can be transmitted to the train operator for integration into other condition monitoring displays.



When the health of any monitored component deteriorates beyond set levels emails or texts are sent to a defined recipient list to notify them of an emerging problem. This has enabled train operators to restructure the way they approach maintenance because they now have access to information on their fleet’s condition that they never had before.

Wayne Jenner, Engineering Director at Southeastern, said of the Perpetuum product: “We have been very impressed by the information it provides us and the ease of use. We foresee a very rapid return on the investment and a solution to unlocking a number of important issues. The system has the potential to redefine the way we undertake some significant and costly elements of fleet maintenance.”

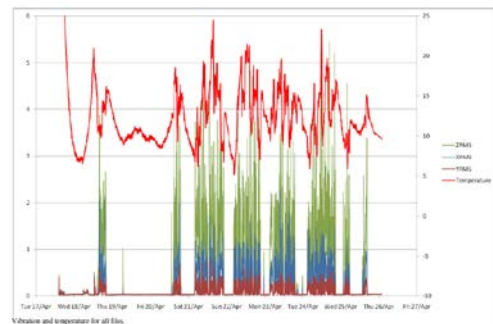
There are 4 key parts to the Perpetuum system – (i) the bogie mounted vibration and temperature sensors and vibration energy harvester contained in the Wireless Sensor Node (WSN), (ii) the onboard Data Concentrator and telecommunications unit, (iii) the Perpetuum ‘cloud’ where the vibration data is processed by the algorithms and (iv) the depot where the information is acted on by the maintenance teams. Perpetuum are primarily responsible for the first 3 scopes and the Operator/Maintainer for the final one but there is close co-operation throughout the value chain to ensure that the right information gets to the right user at the right time.



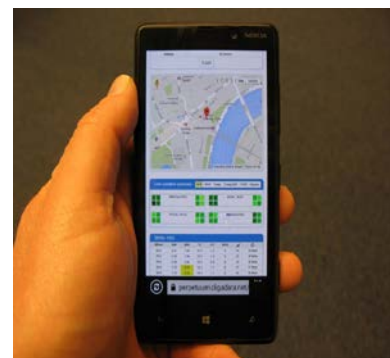
The onboard technology is a “fit and forget” system as it is wireless, self-powered and requires no upkeep beyond basic housekeeping. The innovative vibration energy harvesters convert vibration energy into electrical energy to power the sensors and communications from the bogie mounted units. No wires or connectors brings the installation time down to less than 30 minutes per wireless sensor node. No batteries are needed so the unit is maintenance free

The sensor node contains a 3-axis accelerometer (vibration sensor), the vibration energy harvester, a temperature sensor, electronics and wireless radio communications.

In the case of wheel bearing monitoring, the Perpetuum system provides a bearing health index (BHI) that allows the Operator/Maintainer to monitor bearing wear in real time. The index is the output of Perpetuum’s algorithms, which take the complex vibration and temperature data that have been sent from the train and populate the maintenance tool with the corresponding BHI readings as a single digit score or a colour coded icon. This stage ensures that the Operator/Maintainer teams only have to work with useful information and not the vast amounts of raw data that might otherwise be generated.



With automatic email alerts being sent to the technical team when vibration levels move beyond set parameters, the system offers a 24-hour monitoring solution. The information is highly reliable and hasn’t generated any ‘no-fault found’ alerts. Neither has there been any example of faults not identified by the Perpetuum system. In fact since its introduction there have been no in service breakdowns on components monitored by the Perpetuum system.



This is a combination of complex engineering and the robust high sampling rate that is possible from continuous and onboard measurement.

Perpetuum support this information during the life of the asset, providing the following services to its clients:

- Collection of Data from train fleet
- Supply of the Health Index/es and alarms
- Data processing using Perpetuum proprietary algorithms
- 24X7 access to output data via secure portal
- Data disaster protection, redundancy and recovery
- Engineering and technical support from Perpetuum
- Upgrading to improved Perpetuum algorithms as they become available
- Ongoing training and operational assistance
- Failure analysis services
- Obsolescence management

WHEEL MANAGEMENT

In addition to bearing monitoring the same data produces condition information for wheels. By developing a bespoke algorithm to generate a Wheel Health Index (WHI) the same vibration data can be used to optimise wheel condition and life. The system identifies wheel damage via live data so that trains can be maintained according to the reprofiling that is actually required, rather than on the basis of a rolling programme of checks or scheduled work. This means the wheels can be prioritised, ensuring that the units that most need the corrective work are seen first and the better units are allowed to continue operating as normal.

The Perpetuum system can identify not only flats but also Rolling Contact Fatigue. RCF is a growing issue with new fleets due to their highly effective WSP (Wheel Slip/Slide Protection) systems compared to legacy fleets, which tend to suffer more from flats. As this damage is primarily subsurface it cannot be easily identified using conventional techniques but with the Perpetuum system the wheelset operator can see beyond the surface months in advance and while the unit is in service. Quick identification of wheel flats and other faults helps to reduce future damage to bearings and the track.



Figure: light “feathering” or “shadowing” on the wheel surface



Figure: Subsurface damage after 24mm of material has been removed

TRACK MONITORING

Since the system is measuring the shock and vibration at the wheel rail interface, information is being collected on the track condition by the same hardware. This data, coupled with the GPS location data, is allowing Perpetuum to provide a real time map of shock and vibration in the network. The track asset has been notorious for maintenance teams due to the sheer volume and accessibility issues that it presents but this can now change.

Vibration is best transferred and measured through stiff materials like steel. Analysis of this data by Perpetuum is allowing valuable insights to be provided to rail infrastructure providers about the quality of their network and where the degradation is happening. Because this is monitored on a continuous basis it will identify track degradation at an earlier stage than traditional methods.



Figure: Condition map of the south east of the UK measured by Perpetuum equipped passenger trainsets

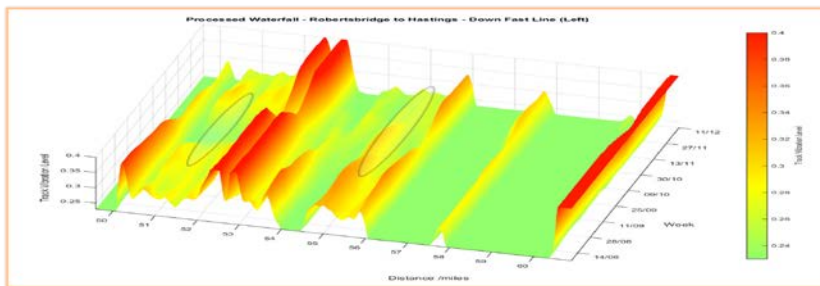


Figure: a section of mainline track with degradation presented over time and distance helping maintenance teams to prioritise work

The data that is collected by the Operator/Maintainer fleet across the network can therefore provide real-time insights into the infrastructure and the dynamic behaviour between the vehicle and the track, and even the ballast.

"Network Rail is committed to reducing unnecessary delays and increasing dependability, that being availability, reliability, maintainability and safety and improving whole system performance so that the growing traffic demands can be met. Enabling service trains to report 'live' information back to the maintainer about changes in the condition will provide the necessary time to mitigate delays, limit the dependency on measurement trains and increase the safety for track inspection teams. Real time condition monitoring of the track would also enable a fundamental change in the way the whole system interfaces are managed between operators and infrastructure managers"

Simon Taylor, Systems Manager LNW, Network Rail

Now track maintenance teams are able to identify in real-time the locations where the rail or track is deteriorating and at what rate, allowing them to prioritise their planning, optimise the use of plant machinery and increase safety by reducing the frequency of manual inspections. Research and development is ongoing, with the likes of Network

Rail, into the different health indexes for the track that could diagnose crack propagation, track voids and ride quality, amongst others, through data collected by service trains rather than measurement trains or manual inspections.

OTHER CAPABILITIES



Gearboxes and traction motors are also being monitored with a number of operators using many of the same concepts that Perpetuum have applied successfully so far to bearings and wheels.

This offers the prospect of evolving to a fully monitored train where other monitoring functions are added over time such as gearboxes, traction motors, doors, compressors, ride quality, and suspension monitoring.

The Perpetuum system is designed to be scalable thus allowing other monitoring functions to be easily added as they become available

Figure: Gearbox WSN

BENEFITS OF THE SYSTEM:

The Perpetuum technology allows Operator/Maintainers to be much more proactive and anticipate potential bearing issues up to 6 months before they occur. This has helped them to move from a time/distance based maintenance schedule for the fleet to condition monitored maintenance, resulting in better planning and less disruption to their passengers.



Figure: a wheel bearing being monitored over nearly 6 months of degradation prior to overhaul

Our clients see fewer costs in maintenance related to wheels and bearings because of the additional mileage that trains achieve before inspections or repairs. Where previously parts were changed as standard according to an expected lifespan, they are now changed at the point of need when a fault has been identified, preventing wastage. This allows maintainers to extend the overhaul periodicity for wheelsets and bogies by a number of years in most cases. These overhauls represent 10s £millions in material and labour meaning the annual savings can be in the £millions for a modest sized fleet.

The trains are being monitored while in service, rather than when they are in the depots, which means that utilisation of the assets is improved as well. Discussions between the fleet manager and the maintenance team can now be based

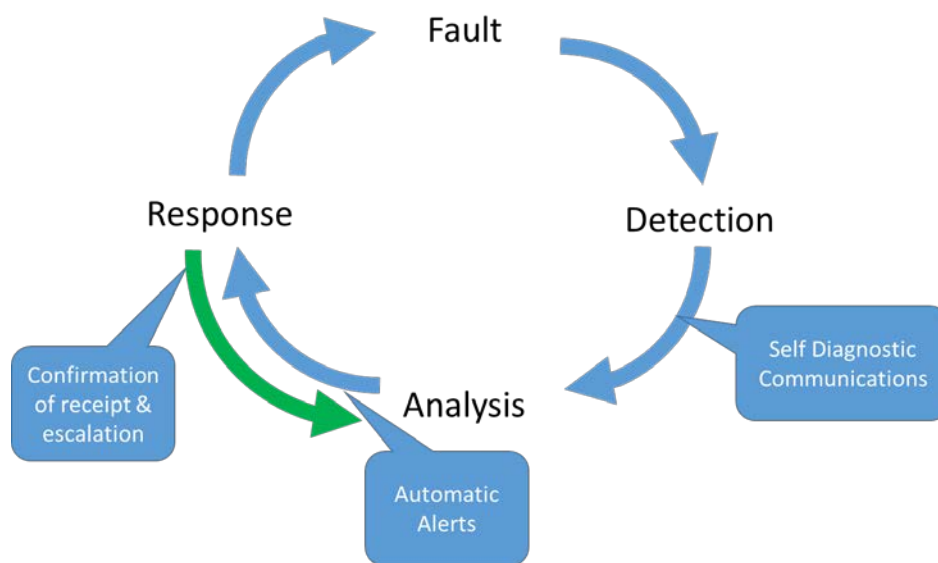
on actual information on the precise status of the units, removing some of the dependency on hot and cold spare trainsets.

SAFETY

On the subject of safety, there have been no monitored bearings that have failed in service and no false negatives reported by the algorithms. The Perpetuum condition monitoring system provides the confidence of knowing the actual condition of all critical assets and the means of identifying and measuring risks the moment they appear.

In addition to monitoring vibration every 3 minutes the system also measures temperature every minute to better catch any fast evolving failure modes.

There is also an escalation mechanism which is triggered for more serious alerts if the fault is not acknowledged



BUSINESS CASE

Maintenance regimes that are based on distance or time inevitably create waste because perfectly good components are removed because it is difficult to distinguish between good and bearings.

Rollingstock and track maintenance regimes are both very capital intensive and therefore the payback for customers is very fast, even for modest extensions in the programming of overhauls.

For the rolling stock the key drivers of the business case are as follows:

- **Maintaining on condition** – allowing maintainers to extend overhaul periodicity initially (and then to move to full maintain on condition) to provide significant savings in materials and labour
- **Higher asset utilisation** – monitoring assets while they are being operated results in less downtime.
- **Eliminating breakdowns in service** – no more surprises with up to 6 months warning; improving operating reliability and safety
- **Improved maintenance efficiency** – reduction in unexpected maintenance tasks which improves efficiency of operations

- **Early Intervention** - allows faults to be addressed before the damage becomes too high thus reducing cost of repair and extending the life of other components that would suffer due to the results of e.g. wheel flats
- **Better use of resources** – automation of monitoring enables maintenance teams to move highly skilled railway technicians and engineers into more valuable and productive areas of the business.

There are similar benefits for the Infrastructure that real time network monitoring can deliver:

- **Faster Problem identification**
 - Fewer Derailments
 - More efficient maintenance operations
- **Earlier interventions**
 - More cost effective repair
 - Extended asset life
 - Identify where assets need to be replaced and where not
- **Better asset condition**
 - Improved Rolling Stock Life
 - Lower Energy Consumption
- **Increased Capacity**
 - Less disruption to operating services
 - Better Punctuality
- **Better Use of Skilled Workers**
 - Focus skills where there are problems
- **Safer workplace**
 - Automation of monitoring removes high risk track inspections

"We are looking forward to the partnership with Perpetuum as this forms part of Metro's wider Rolling Stock Condition Monitoring strategy," said. "The success of the sensor trials will enable Metro to realise changes in maintenance, which will be driven by quantitative fact. Ultimately, this will lead to significant financial savings in the maintenance of wheel sets and bearing components, and the additional benefits from the system of indicative track condition will also have a considerable impact."

Dan Ward, Systems Engineer, Metro Trains Melbourne

FULL DEPLOYMENT

Because the Perpetuum system is so easy to fit the full deployment can be done very quickly and with minimal disruption to service operations. For example Southeastern Railways in the UK installed the Perpetuum equipment on 600 cars (5,000 sensors) in just 3 months whilst avoiding disruptions to their service operations

“Perpetuum is a British business that, as part of the EU's FP7 research programme, has developed self-powered wireless sensors that monitor how the ball-bearings in train wheels wear out. A humble enough idea; but one with potentially a massively significant and global potential.”

Vice President of the European Commission - Neelie KROES

*“We've never had a remote condition monitoring system that provides information on mechanical performance of bearings **before so this is a real step forward**. As the first company to trial and then implement it, we're pleased to be at the forefront of assisting with the development of this technology.”*

Mainline manager at Southeastern - Mick HURLEY