Vehicle/Track Interaction

continuous real-time autonomous condition monitoring to effectively manage 'state of good repair'

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INTRODUCTION

With the need that railroads and transits have for sustainable service delivery, there is an ever-increasing demand to improve transportation efficiency, the challenge being to determine and understand the 'state of good repair' of a rail or transit system in real-time or near real-time. Prioritising track maintenance before conditions cause vehicle damage or derailments, and balancing the risk between operations, safety and maintenance cost, are fundamental to delivering a world-class transportation service. Railroads throughout the world are turning to new technologies to optimise track maintenance planning. This includes the use of revenue service vehicles equipped with sensors that quantify conditions and automatically report the location and severity of potential and functional failures to maintenance managers and engineers. This article gives a broad overview of how railroads and transits in the USA, Canada, Mexico and Australia utilise vehicle/track interaction diagnostic equipment to determine the 'state of good repair'.

BACKGROUND

Vehicle/track interaction (V/TI) monitors are autonomous systems installed on revenue vehicles and provide near real-time detection of vehicle acceleration events that are caused by track condition risks. The ENSCO Inc V/TI system has been utilised in the railway industry for over fifteen years and is currently in operation in the USA, Canada, Mexico and Australia. Presently there are over 364 V/TI systems operating on locomotives, and on passenger and freight cars in daily revenue service. In total, these V/TI monitors survey over 32 million km per year. The system includes on-board measurement equipment, as well as a central server data-management and reporting system.

The V/TI monitoring system continuously samples all accelerometer sensor inputs which measure vehicle response, due to the interaction with the track, to detect irregularities that can be categorised into five types of potential failures. These include car body vertical (CBV), car body lateral (CBL), wagon bogie lateral (TRL), axle vertical (AXV1&2) and a calculated mid-chord offset (MCO). If the system detects inputs which exceed defined thresholds, it will send an exception message, which includes all the sensor waveforms, back to a central data-management system. When the sensor waveforms are received by the data-management system, they are evaluated using an automated algorithm to eliminate false-positives. Valid exceptions are sent to the railway or transit's internal database system to identify divisions/regions and subdivisions/sections. In addition, based on the location, it will provide a linear referencing position in terms of either mile post or kilometre post master data, and will report the severity of the potential failure/defect. Industry employs primarily three levels of severity that can be classified as high, medium and low. The system can be configured to trigger notifications to maintenance personnel by using an automated phone message and/or email notification, depending on the severity level and the business rules setup. Figure 1 illustrates the locations of the V/TI equipment installed on a freight locomotive. A summary of the V/TI exception types will be discussed in the next section.

SENSOR LOCATIONS

The **car body sensor** measures vertical and lateral acceleration near the locomotive cab floor. The car body vertical (CBV) and car body lateral (CBL) exceptions are the peak-to-peak acceleration within one second. These exception types are typically associated with track profile and alignment conditions respectively.

The **bogie/truck sensor** measures lateral acceleration of the truck frame. The truck lateral (TRL) exceptions are the root-mean squared acceleration. TRL exceptions are generally caused by sustained oscillations caused by truck hunting.

Two **axle sensors** are installed on a single wheel set, with each sensor installed on the left and right side bearing axle boxes. These axle sensors measure acceleration in the vertical direction. The axle vertical impact (AXV1 and AXV2) exceptions calculate the wheel/rail impact force in kN or pounds using the acceleration information. AXV exceptions are associated with high wheel-rail impact conditions.

In addition, the same two axle sensors are used to calculate the vertical profile, using a 3 m mid-chord. Utilising the same sensors for an additional purpose is a novel approach that was first led by Union Pacific. The MCO1 and MCO2 exceptions are measured in millimetres/inches and are associated with short-chord profile conditions.

'STATE OF GOOD REPAIR' DIAGNOSTICS

Internationally there has been a shift in the focus of service and service delivery

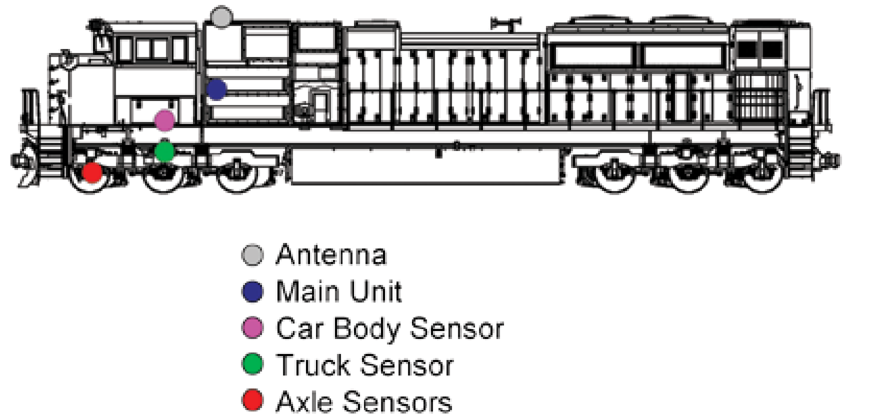


Figure 1: V/TI equipment locations on a freight locomotive

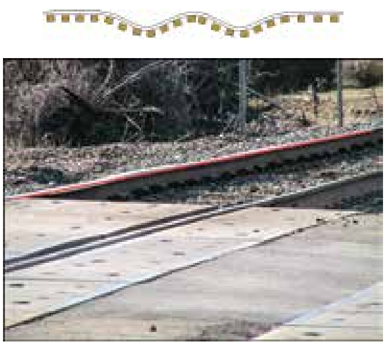
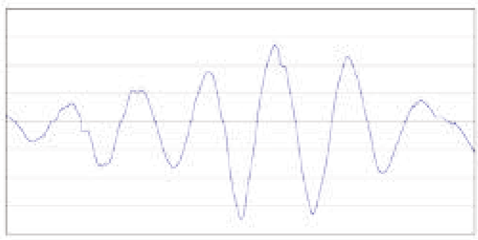
Detected condition	Condition characteristics	Characteristic V/TI measurement
	▪ Repeated vertical profile dips in track ▪ Mud and pumping conditions	

Figure 2: CBV peak-to-peak exception

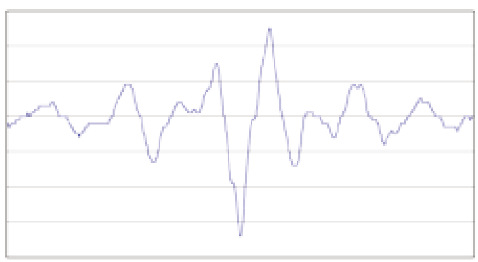
Detected condition	Condition characteristics	Characteristic V/TI measurement
	▪ Lateral alignment irregularity in the track	

Figure 3: CBL peak-to-peak exception

sustainability of strategic assets, specifically within asset-intensive organisations such as railroad and transit agencies. As mentioned earlier, railroads and transits are investing in autonomous track inspection systems that, unlike manned systems, are capable of surveying much bigger territory while forming part of the in-revenue system. In this section the authors provide a description of the V/TI diagnostics equipment, as well as details on, and examples of, the different potential failures. Lastly we will discuss the use of diagnostic measurements to assist in performance management – through performance analytics that will provide railroads and transits with near real-time decision-making capability to identify areas that require either immediate risk mitigation through slow-order implementation, or assistance in identifying areas that require maintenance in the short to medium term.

V/TI equipment specification

A standard V/TI monitor comes equipped with five on-board measurements (car body vertical/lateral, truck lateral, axle vertical, and 3 m mid-chord offset) sampling at 400 Hz. The sensors are sampled and filtered in compliance with the Federal Railroad Administration Standard CFR213.333 Vehicle/Track Interaction Safety Limits.

V/TI condition/potential failure terminology

This section focuses on V/TI railroad terminology. It presents the fundamentals of the functional measurements to generally identify potential failures in near real-time, based on the permanent way condition. It forms the basis of the decision-making analysis to identify maintenance areas, assisting the business in optimising the management of its assets.

Car body vertical (CBV)

Car body vertical accelerations are measured at the locomotive cab floor above the leading bogie. This is a peak-to-peak acceleration algorithm aimed at identifying pitch and bounce motion. CBV exceptions are typically produced by repeated long wavelength track profile irregularities, as seen in Figure 2. It is quite common to find these anomalies near a road crossing and bridge approaches.

Car body lateral (CBL)

Car body lateral accelerations are measured at the locomotive cab floor above the leading bogie, similar to the car body vertical sensor. This is a peak-to-peak acceleration algorithm aimed at identifying track alignment issues as seen in Figure 3.

Axle vertical (AXV)

Axle vertical accelerations are measured on the leading axle of the vehicle. The acceleration is converted to an impact force. AXV exceptions are typically produced by defects along the rail associated with joints, switches, engine burns, diamonds and broken rail, as seen in Figure 4. The amount of the impact measured depends both on the physical depth or size of the spot defect and on the stiffness of the support conditions.

3 m Mid-chord offset (MCO)

In 2007, the FRA Office of Research conducted a study to assess the effectiveness of deriving mid-chord offset from axle sensor measurements. The FRA recommended the use of a 3 m MCO to detect localised track issues that are likely missed when looking at an MCO track measurement of 9 m or 19 m. Thus, a 3 m MCO algorithm was developed for the V/TI monitor to detect pumping joints, heaves, mud spots, and other poor support conditions, as seen in Figure 5.

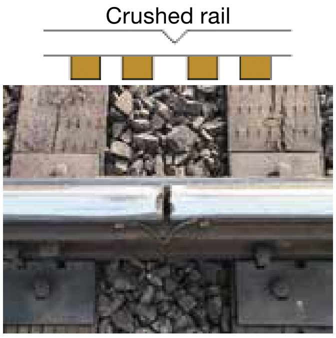
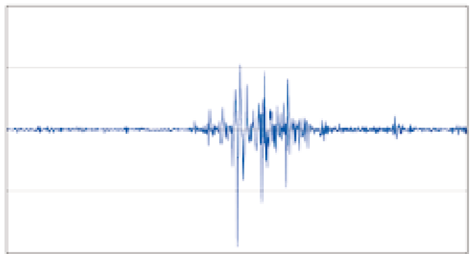
Detected condition	Condition characteristics	Characteristic V/TI measurement
	▪ Broken rail, broken joint, broken frog, battered joint, engine burn, crushed rail head, loose/missing bolts	

Figure 4: AXV impact exception

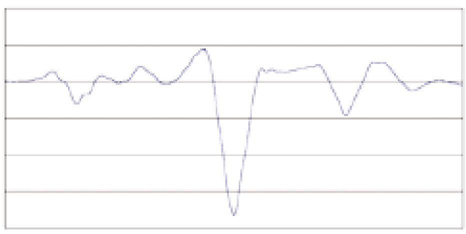
Detected condition	Condition characteristics	Characteristic V/TI measurement
	▪ Mud and pumping conditions ▪ Look for pumping joints or mud spots	

Figure 5: 3 Metre MCO exception

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In addition, truck lateral measurement detects any sustained lateral bogie movement associated with car hunting. When this exception occurs, it indicates, in the vast majority of cases, that the instrumented vehicle is in need of maintenance. Keeping the vehicle in good working order ensures that the other measurements are not degraded. A typical characteristic measurement is depicted in Figure 6.

REAL-TIME DATA MANAGEMENT FOR DECISION-MAKING

Near real-time information provides railroads with the ability to have real-time situational awareness, and visibility of asset risks and conditions. This enables and supports decision-making to ensure the ability to render a service to clients. Remote servers are used to store data sent from V/TI monitors. The server end is responsible for post-processing of all data received, and for transmitting alerts to field personnel and the person in charge of a specific section. All exception data collected can also be reviewed and retrieved through an online application.

Location, and the alignment of condition data within the linear asset management environment, is fundamental to the success of diagnostic solutions. Once a potential failure is detected, it is tagged with a GPS position and forwarded to remote servers for processing. This GPS latitude and longitude is transformed into typical 'railroad language' comprising a division, sub-division/section and km post + m. It is accomplished by using a particular railroad's network map of layers, defined by vast amounts of GPS vertices, and referenced to linear location points, e.g. km post, that then transform the defect GPS location to a km post + m location.

ANALYTICS

These days the greatest challenge of condition monitoring is often not the method of obtaining the data, but rather the task of interpreting the vast amounts of 'big data', and setting realistic and useful thresholds for the measured and calculated parameters or indices. A further challenge is the need to understand the influence that a combination of various parameters has on risk, and being able to predict risk areas that require in-depth monitoring and maintenance, thereby assisting in the decision-making process.

The V/TI has long been used as a device to plan track maintenance and identify dangerous track conditions. Inspections of identified high-level exceptions have yielded locations at risk for derailment, requiring immediate preventive action (e.g. broken joints, broken rail). However, low-level severity exceptions can result in too many notifications, causing 'data overload', becoming counterproductive, as these are not necessarily inspected or used for risk and long-term maintenance management.

Their importance was revealed when an extensive study of derailment sites was conducted. The investigation found that low-level exceptions tend to recur and persist near derailment locations. This study resulted in the investigation and development of a performance cluster considering potential failure defects that occur in close proximity of one another, namely car body vertical, axle vertical and MCO exceptions. Consequently, an algorithm was developed and implemented to identify these performance cluster areas/locations that might be at higher risk.

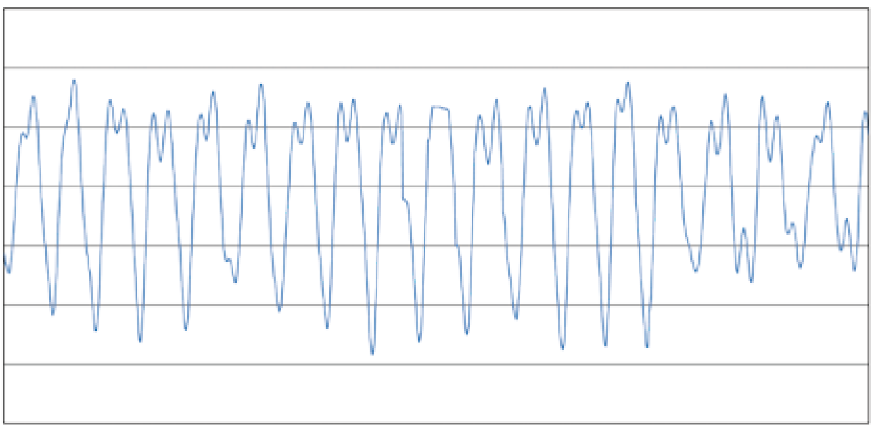

Figure 6: Truck lateral characteristic measurement

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V/TI PERFORMANCE CLUSTERS

Unlike V/TI monitor exceptions, cluster exceptions are generated on all exception data recorded over a week. The purpose is to identify repeating defects of the same type within a defined location. As soon as all the repeated defect clusters of the same type have been identified, a second clustering analysis is conducted whereby the performance cluster is determined. The algorithm for the performance cluster looks for exception clusters of the same type that are located within a defined diameter of one another. The following points briefly explain the algorithm process:

1. Retrieve historical data for processing.
2. Linearise exception locations of all levels on track centre lines.
3. Identify the three exception type clusters, namely AXV cluster, MCO cluster and CBV cluster. (Exceptions of the same type are considered 'repeated' if they can be encircled within a 36 m diameter.)
4. Determine performance cluster locations. (During this process AXV, MCO and CBV clusters will be grouped if the centres of their repeat events are within 18 m of one another.)

The algorithm process is illustrated in Figure 7, demonstrating the difference between a single-repeat exception type cluster and a performance cluster.

Performance clusters provide a paradigm shift in risk and maintenance management to direct the rail industry towards a proactive approach and a managed 'state of good repair'. The majority of field inspections conducted were identified as problematic areas, but not necessarily as out of compliance by government or internal maintenance standards. This allows railroads to better establish long-term maintenance plans.

Table 1 contains observations from field reports based on performance/combo cluster exceptions.

CONCLUSION

The use of autonomous track inspection systems is becoming more common throughout the railroad industry. Most notably, the need to use operational data and 'bid data' analytics to monitor and detect change to trigger 'state of good repair' management will become the norm in the rail industry over the next five years. V/TI diagnostics used with revenue-service trains has been at the forefront of this movement. The flexibility of the system to operate under various conditions, and its adaptability to incorporate multiple sensor types and algorithms, have made it a proven candidate amongst railroads and transits in North America and Australia to improve track safety, and now also for proactive maintenance planning.

A critical part to the success of the V/TI monitor relies on the data management process. This encompasses filtering out false alerts and ensuring that field personnel receive notice of high-level alerts. Additionally, the growing use of V/TI monitors has prompted railroads to adopt an open-data policy to some extent, where V/TI monitor exceptions are shared with one another.

Furthermore, autonomous track inspection systems and technology are key to moving towards a proactive and predictive mind-set. It also provides near real-time management data, while not influencing capacity and utilisation, as is the case with manned systems. Through an approach of continuous improvement, railroads will be able to set lower thresholds and use various techniques to analyse 'big data' to improve their 'state of good repair'. In the case of V/TI diagnostics, a clustering technique has proved to be an effective preventative risk and maintenance management method.

REFERENCES

The list of references is available from the editor. ◻

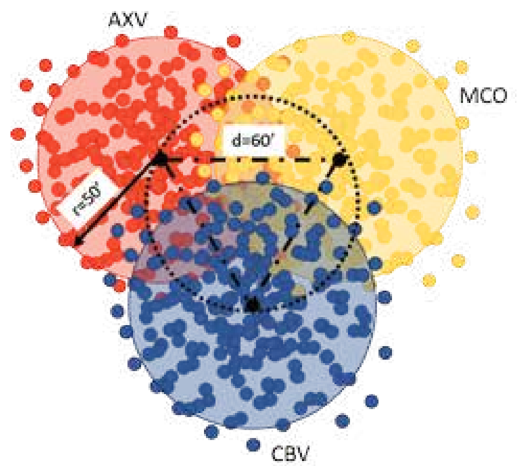

Figure 7: Diagram depicting search window for single-type and performance/combo clusters

Table 1: Combo cluster field inspections

Location	Findings	Maintenance
Cluster 1	Marginal ties	Placed in maintenance plan
Cluster 2	Hard impact joint	Joint was welded
Cluster 3	Weak tie cluster for one rail length	Plan to install new ties
Cluster 4	Weak tie cluster with 1 inch of profile	Written up as SFR for effective tie distribution
Cluster 5	Damaged frog	Frog was welded, including a joint-off of the heel of the frog
Cluster 6	Two broken ties	Replaced ties and re-tamped