ARTC V/TI MONITOR TRIAL RESULTS AND ANALYSIS

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SUMMARY

This paper discusses the results of an initial trial and continued use of a V/TI Monitor by ARTC in the Hunter Valley and how the data is utilized to evaluate track conditions. The Vehicle/Track Interaction Monitor (V/TI) is an autonomous measurement system that has been in use for over 15 years in the US for determining locations of excited vehicle/track interaction. Included in the paper are results of the system trial and assessment of exceptions detected. Additionally discussion is included on how ARTC plans to utilize the data for track inspection and maintenance planning, as well as, safety alerts. Lastly the paper discusses the V/TI Monitor's latest functional improvement to measure track top using a 3-metre (10-foot) mid-chord offset (MCO). MCO measurement with the autonomous V/TI Monitor has been found to be a very useful measurement of track surface conditions.

INTRODUCTION

A growing method for evaluation of track conditions is to use autonomous measurement systems. This allows for "Train Path Free" measurement, meaning that a standard revenue vehicle is used to obtain the measurement. This is greatly preferred to using a non-revenue vehicle which consumes track time. Additionally it has the added advantage of utilizing the vehicle weight to fully load the track during measurement. Lastly, the continuous monitoring and real-time reporting of critical conditions can allow for reduced manned track inspections by hi-rail. These attributes have been the primary reason for ARTC evaluating the V/TI Monitor system in the Hunter Valley. It is also important to note, that this V/TI Monitor evaluation was the first ever conducted in Australia. This paper outlines the background of the V/TI Monitor, the installation, trial results, defect threshold determination and the continued use of the system by ARTC.

NOTATION

AXV Axle Vertical

CBL Carbody Lateral

CBV Carbody Vertical

MCO Mid-Chord Offset

TRL Truck Lateral

QRN Queensland Rail National

V/TI Vehicle/Track Interaction

BACKGROUND

Vehicle/Track Interaction Monitors (V/TI) are autonomous track inspection systems that utilize acceleration measurements mounted on a vehicle with real-time reporting. V/TI Monitors have been in use for over 15 years in North America. Currently there are 253 V/TI Monitors in operation, including passenger and freight, locomotives and wagons. The entire fleet surveys over 64,000 km per day and create over 250,000 messages to the remote server per day. Figure 1 depicts the distribution of vehicle types that have V/TI Monitors equipped.

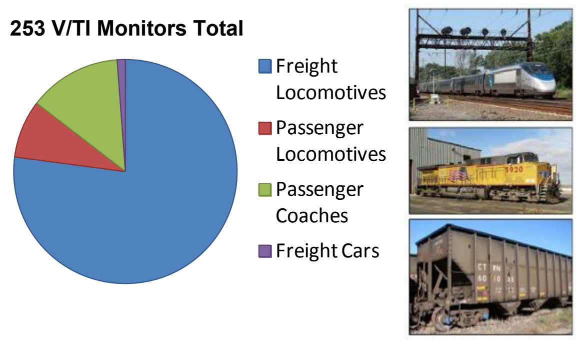

Figure 1 : Vehicle Types Equipped with V/TI Monitors.

The basic components of the system include a central CPU, mobile phone/GPS antenna, and accelerometers mounted at various locations on the vehicle. Each accelerometer is measured continuously and when a value exceeds a predetermined threshold, an exception is created which includes the time, GPS coordinates, exception value, and 4 seconds of continuous data of all the accelerometers (2 seconds before the event and 2 seconds after the event).

Each exception is transmitted via mobile communication to the nearest standard mobile phone tower. At the tower, the message is converted and transmitted via the internet to a remote server. At the remote server, the exception is processed to determine what Subdivision and KM Post the exception occurred at.

Additionally, the exception is processed with automatic "risk filters", which ensure that the exception is valid. If the exception is found to be invalid, such as a malfunctioning sensor, the exception is flagged and is not transmitted to field personnel. This functionality is a major advantage because it allows for rapid exception processing without human manual exception review.

The exception is evaluated for severity based on its value. There are three severity levels, "Urgent" which are typically inspected within 24hrs, "Near Urgent", which are inspected within 7 days, and "Priority", which are typically inspected within 30 days or are used in long term maintenance planning.

Finally, valid exceptions are emailed to the appropriate maintenance personnel based on the location where the exception occurred. Typically only Urgent and Near Urgent exceptions are emailed.

The entire process listed above from detecting the defect to receiving the email is generally within a few seconds.

There are five exception types measured by a V/TI Monitor which are detailed below.

1. Carbody Vertical (CBV)

This exception type is measured with an accelerometer mounted near floor height of the locomotive carbody above the lead bogie. Additionally, it is mounted on the lateral centreline such that it only measures carbody pitch and bounce motions. It is processed on-board to calculate the peak-to-peak acceleration.

Typically these exception are caused by repeated track top irregularities which excite the vehicle with pitch and bounce motions. An example is shown in Figure 2. This measurement is speed dependent because a vehicle's suspension behaves different at different speeds.

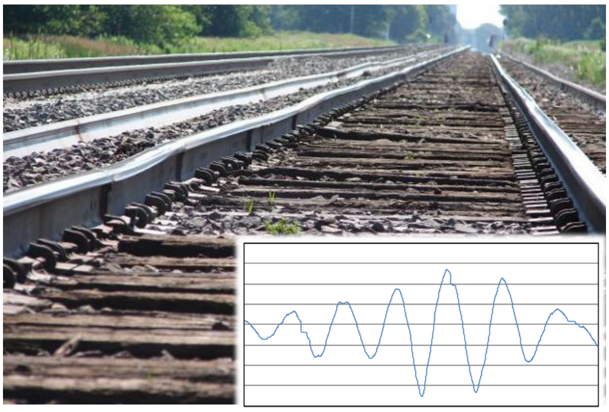

Figure 2 : Example Carbody Vertical Exception

2. Carbody Lateral (CBL)

This exception type is measured with an accelerometer mounted within the same sensor enclosure as the Carbody Vertical accelerometer. It too is processed on-board to calculate the peak-to-peak acceleration.

Typically these exceptions are caused by track alignment irregularities. Most commonly it detects lateral alignment conditions at bridges due to settling conditions. An example is shown in Figure 3.

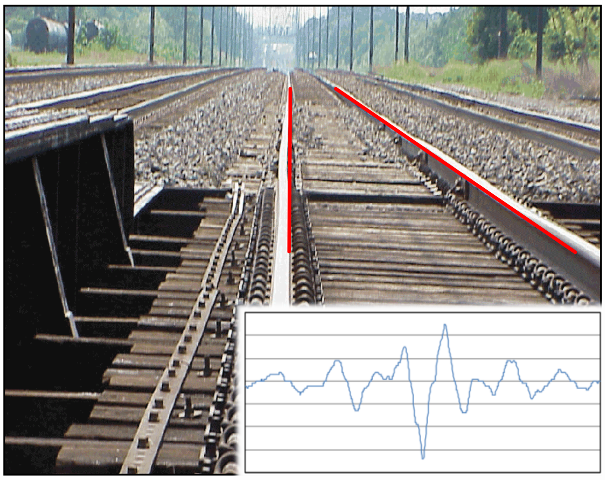

Figure 3 : Example Carbody Lateral Exception

3. Truck Lateral (TRL)

Also known as Bogie Lateral, this exception type is measured with an accelerometer mounted in the lateral direction on the bogie frame.

These exceptions are processed to determine continued oscillations caused by bogie hunting. This is done by calculating the exception value as a Root-Mean-Squared (RMS). Typically these exceptions are not caused by track conditions. Rather they are typically caused by vehicle conditions such as worn suspension components or wheel profiles. An example is shown in Figure 4.

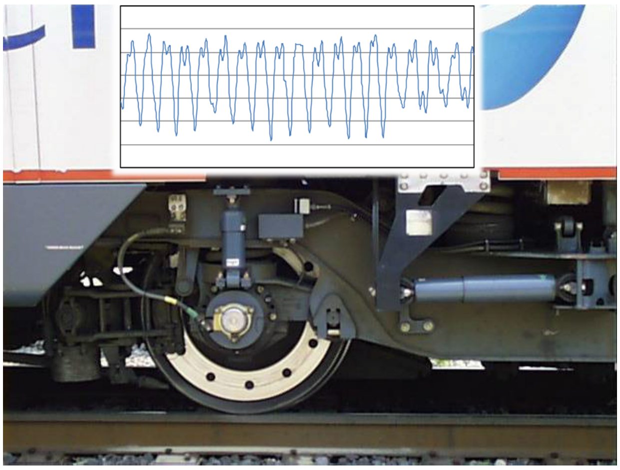

Figure 4 : Example of Truck Lateral Exception

4. Axle Vertical Impact (AXV)

This exception type is measured with two accelerometers mounted on the lead axle of the bogie in the vertical direction. One accelerometer is mounted on each end of the axle on the journal housing. Impacts are measured for both the left and right rails using the AXV1 and AXV2 accelerometers, respectively.

Typically these exceptions are caused by wheel/rail impact conditions caused by battered joints, chipped switch points or frogs, wheelburns, broken joints, or broken rail. An example is shown in Figure 5.

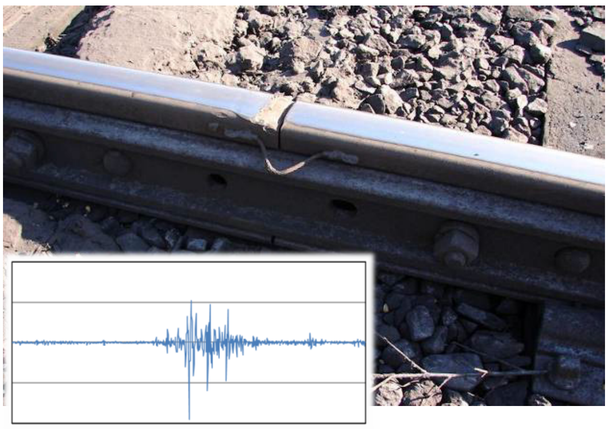

Figure 5 : Example Axle Vertical Exception

5. Mid-Chord Offset (MCO)

This exception type is unique for the V/TI Monitor because it is not a vehicle/track interaction style measurement. Rather it is a track geometry measurement. Top is measured using the Axle Vertical Impact accelerometers. A Mid-Chord Offset calculation is applied using a 3 metre (10 foot). MCO is calculated for both the left and right rails using the AXV1 and AXV2 accelerometers, respectively.

MCO is calculated by applying a real-time process that emulates the double-integration and band-pass processing while also applying a sliding mid-chord offset calculation. The real-time process was implemented because it was found to be less computationally intensive than traditional means, but was found to have satisfactory accuracy.

An important aspect of this short chord top measurement is that it focuses on top conditions that not only create track geometry risk, but also increased rail stress and associated failure risk. Typically MCO exceptions are caused by bog holes and pumping joints. An example is shown in Figure 6. Additionally, this short chord top measurement is advantageous with a V/TI Monitor because of its ability to continuously monitor track conditions to catch rapid top changes and deterioration rates. The MCO is also a good indicator of underlying track stiffness thus assisting with the prioritization of major sugbgrade rehabilitation.

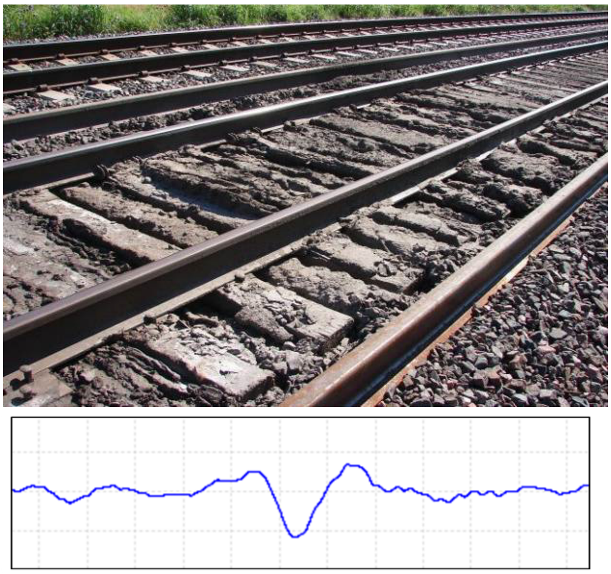

Figure 6 : Example Mid-Chord Offset Exception

INSTALLATION

On May 23-26, 2011 ENSCO, QRN, and ARTC personnel installed one V/TI Monitor on a QRN 5000 Class Locomotive, unit 5025. An overview photograph of the locomotive is shown in Figure 7. An overview of one of the installed axle sensors is shown in Figure 8. Additionally, Figure 9 is a schematic highlighting the locations of the major installed components.

Figure 7 : QRN 5000 Class Locomotive with V/TI Monitor Installed.

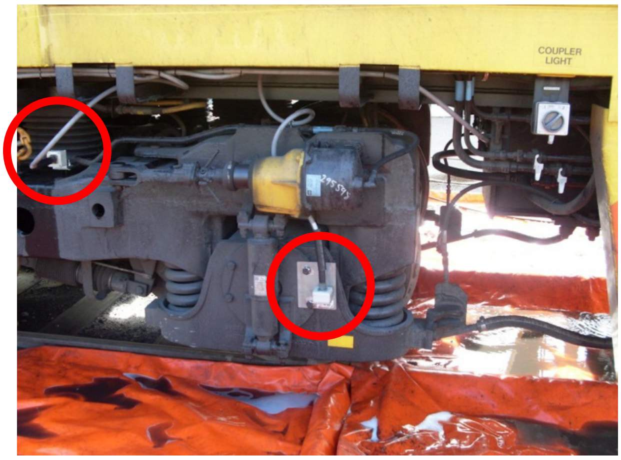

Figure 8 : QRN 5000 Locomotive shown with V/TI Monitor Axle Sensors

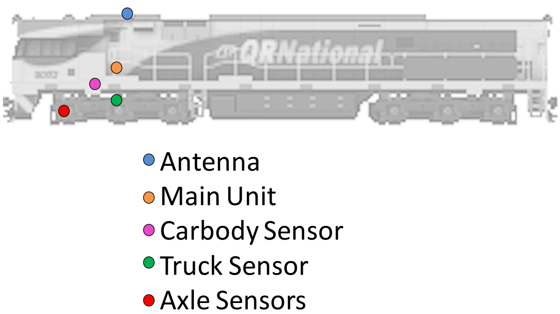

Figure 9 : Overview of Component Locations

TRIAL RESULTS

After the installation, ARTC evaluated the system during a trial period of June, July, and August 2011. During this time, the ARTC inspected track locations which the V/TI Monitor identified.

During the field inspections, it was quickly observed that there were differences in positive and negative MCO exceptions. Negative MCO exceptions are typical of pumping joints or bog holes where the track is physically depressed downward. However, positive MCO exceptions are generally caused by two downward depressions causing an upward heave in-between. When measuring this condition with a chord at the mid-point, it produces a positive value. Both a negative and positive MCO top condition create tensile stress in the rail that can cause increased risk of broken rail. However, a positive MCO exception places the rail in significant tensile stress on the top of rail. This in combination with common rail head stress concentrations such as spalling or gage cracks can cause a significant risk of broken rail due to fatigue fracture. Figure 10 is a schematic that outlines the differences of the negative and positive MCO exceptions.

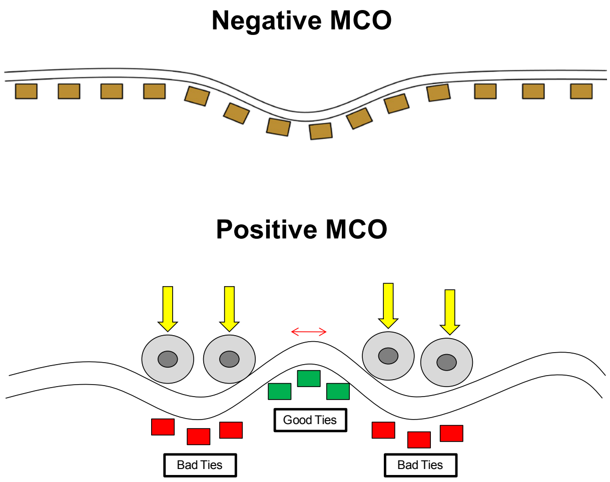

Figure 10 : QRN 5000 Class Locomotive with V/TI Monitor Installed.

Figure 11 depicts a positive MCO exception which was +16.7mm. Additionally a driver reported a hole in the road at the location after the V/TI Monitor identified it. A 30 km/h temporary speed restriction was applied and repairs were made.

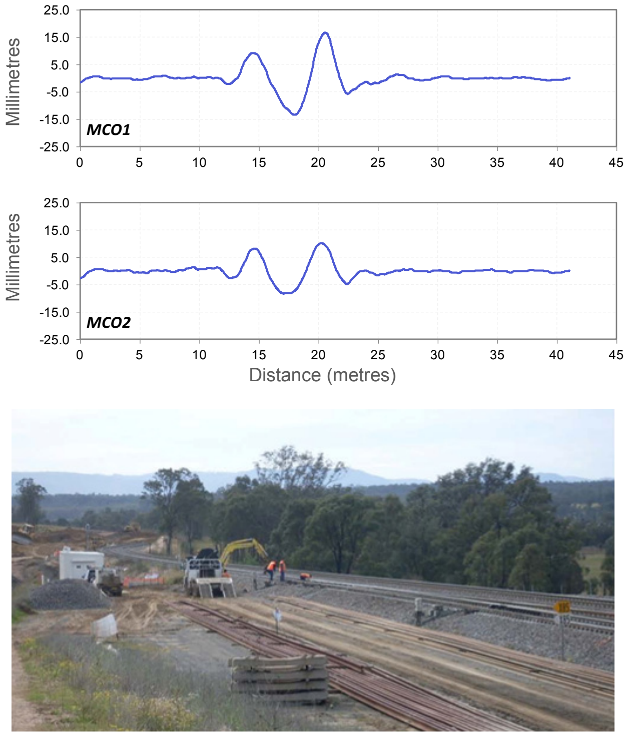

Figure 11 : Example Positive MCO Exception

Figure 12 is another positive MCO exception which was confirmed by a driver. Upon inspection it was discovered that there was a bog hole which created surface irregularities. This is a typical signature of a formation issue.

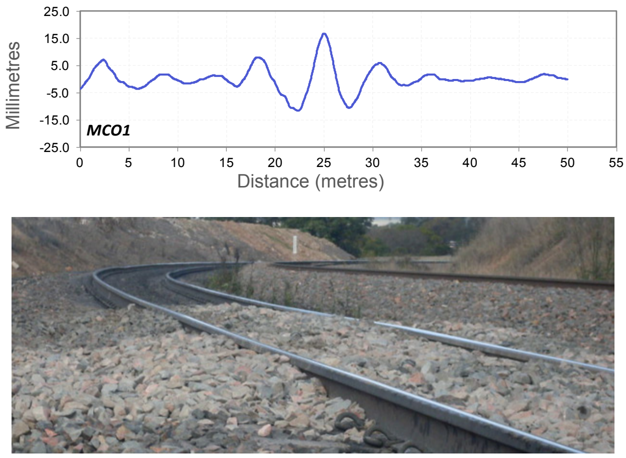

Figure 12 : Example Positive MCO Exception

Figure 13 is yet another example of a positive MCO exception. This exception occurred at a road crossing.

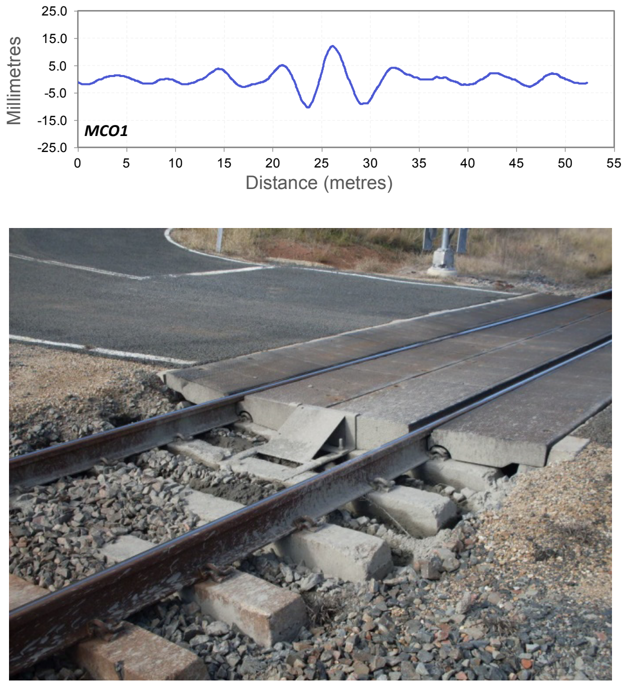

Figure 13 : Example Positive MCO Exception

Figure 14 depicts a couple negative MCO exceptions which was -17 mm. At the inspection, it was discovered two low joints were at the location. This is the typical signature of a pumping insulated and mechanical rail joints.

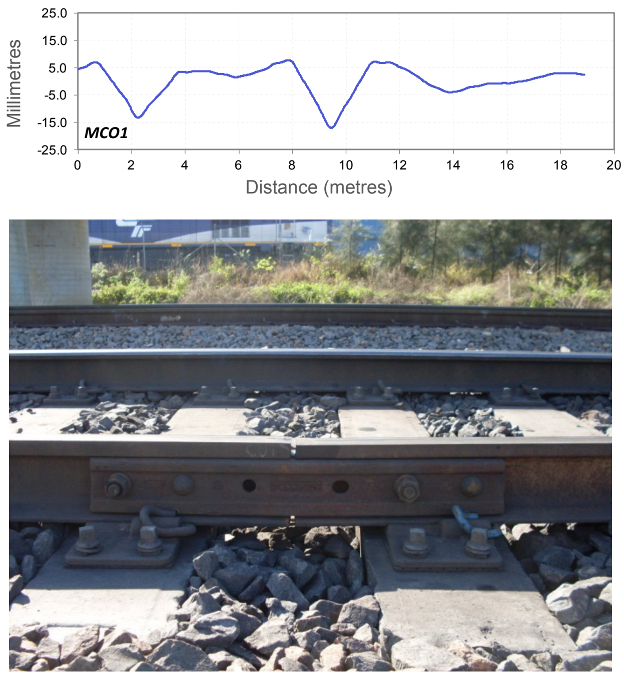

Figure 14 : Example Negative MCO Exception

Figure 15 depicts another negative MCO exception. During inspection it was found that a top condition existed at the site.

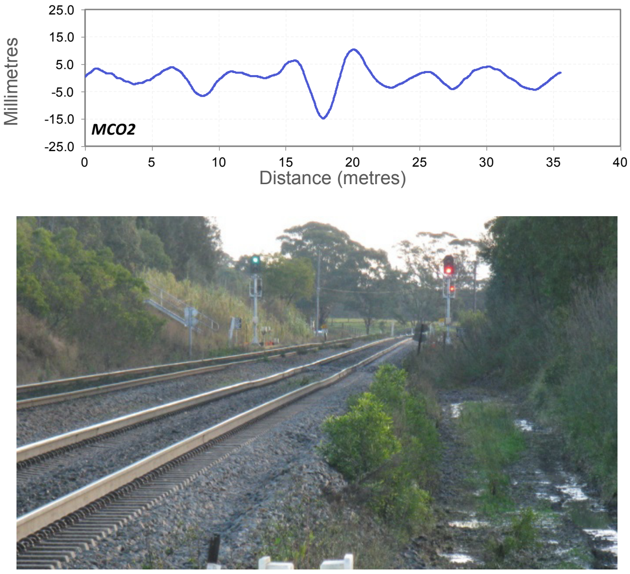

Figure 15 : Example Negative MCO Exception

Figure 16 depicts a Carbody Vertical (CBV) exception, which was 0.75 G's peak-to-peak. Inspecting the track, it was observed that it had poor top conditions.

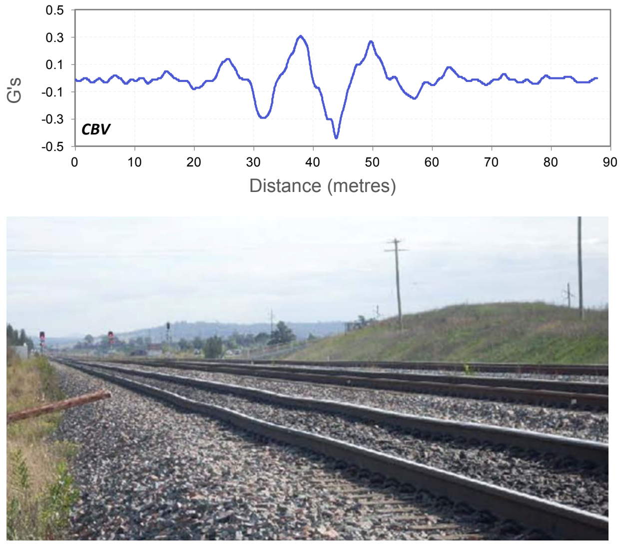

Figure 16 : Example Carbody Vertical Exception

Table 1 lists the overall assessment of the system and what track conditions it was able to identify.

Track Condition	Identification during Trial
Localised Shallow Type Formation Failures	Yes
Deeper 'Long Wave' Formation Failures	Yes, but not at speeds less than 70km/h (Speed dependency caused by carbody response)
Dipped and Pumping GIJs	Yes
Wheelburns	Yes, but depends on size
Worn Turnout Crossings	Yes
Poor alignment	Yes
Rail Head Defects eg squats	Mostly no, depends on defect size.
Broken Rail	Unable to verify, but temporary mechanical joints cut into the track show up as urgent negative MCO defects.

Table 1 : Summary Review of Trial Results

During the trial period, the Urgent, Near Urgent, and Priority thresholds revised four times to obtain the optimum values were based on the field inspections. *Table 2* lists the final threshold determined. During the trial it was noted that having different thresholds for positive and negative MCO exceptions was advantageous and so the system was modified to allow for this function. It is interesting to note, that the thresholds listed are significantly lower than the original thresholds, which were the default US freight thresholds.

Measurement	Urgent	Near Urgent	Priority
Carbody Vertical (CBV)	0.9G	0.75G	0.5G
Carbody Lateral (CBL)	0.8G	0.6G	0.4G
Truck/Bogie Lateral (TRL)	0.4G	0.3G	0.2G
Axle Vertical (AXV1 and AXV2)	500KN	450KN	380KN
Positive Mid Chord Offset (MCO1, MCO2)	15mm	11.5mm	8.5mm
Negative Mid chord Offset (MCO1, MCO2)	-17mm	-14mm	-10mm

Table 2 : Final Thresholds Implemented

CONTINUED OPERATION

Following the trial, the V/TI Monitor was allowed to continue to operate. In the six months following installation, it has surveyed over 35,500 km. Figure 17 depicts the V/TI Monitor route through the Hunter Valley and surrounding areas during this period.

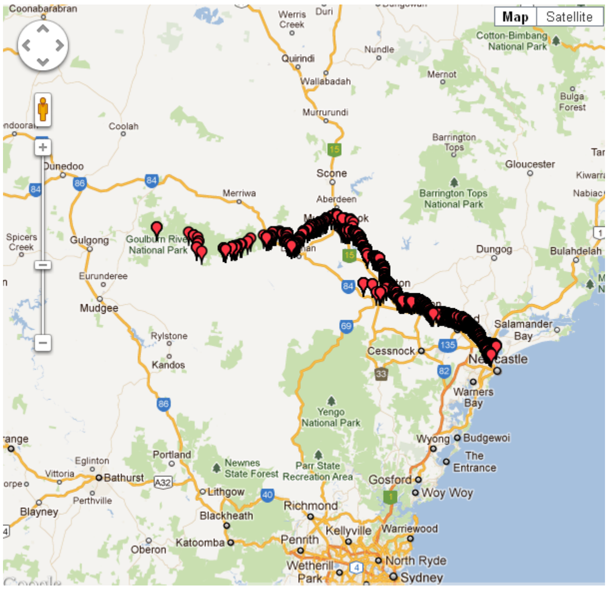

Figure 17 : Overview of V/TI Route During 6 Months After Install

Additionally ARTC has made several modifications to operations surrounding the V/TI Monitor. Canadian Pacific has graciously shared their data management document which was used to formulate the proposed Hunter VTI Management System, which is detailed in Table 3.

Severity	Action
Urgent	Email direct to the on call maintainer, cc to team manager
Near Urgent	Emailed to the Team Manager or delegate to form part of the weekly work programme.
Priority	Downloaded from the website and analysed by the performance engineer and will be a maintenance planning tool.

Table 3 : Management Plan Based on Severity

FUTURE WORK

Both ARTC and ENSCO have identified future work to perform for further improvements.

The first is the installation of two additional systems in the Hunter Valley The additional systems will ensure that consistent and continuous monitoring is achieved even when the locomotives undergo periodic maintenance or are put on different track routes.

Additionally ARTC plans to introduce a V/TI data management policy and procedure. This will also require workshops with field staff to discuss the policy, procedures and its implementation.

ARTC also plans to review the Technical Maintenance Plan for Hunter Valley with a view to reduce Hi-Rail track patrols. In order to accomplish these reductions, risk assessments will be needed to ensure that the addition of the autonomous monitoring is a sufficient supplement to track patrols to reduce them or in some sections completely eliminate them

Lastly, ARTC plans to add more route GPS information so that exceptions on otherwise unknown territory will be automatically identified with a subdivision and KM post. Currently there are only a few auxiliary routes from the Hunter Valley that remain to have GPS information added. Additionally, ARTC plans to discuss with private branch maintainers to determine if they would like exceptions emailed to them while the system is operating on those routes.

ENSCO observed that the most beneficial measurement during the trial was Mid-Chord Offset. This was because the MCO exceptions were the most prominent and corresponded to actionable track conditions and the operational characteristics of the Hunter coal network.. The Carbody Vertical and Axle Vertical Impact exceptions that occurred tended to be less severe than typically observed on US freight railroads. Further work should be performed to evaluate using MCO information to identify track locations that experience repeat exceptions, and as well, identify conditions when the track is degrading as indicated by a increased value, as compared to a stable track condition.

Additionally, ENSCO is evaluating the addition of twist measurement to the V/TI Monitor. Lastly, the V/TI Monitor has historically also been installed on wagons so to obtain the actual dynamic response of the rolling stock. In addition, further work is being conducted to use a locomotive mounted V/TI Monitor to produce the response of a wagon over the same track. This work towards a "Virtual V/TI" would allow for the benefits of measuring direct from a wagon, but have the power source benefits of the locomotive.

CONCLUSIONS

In summary, ARTC conducted a trial of an autonomous Vehicle/Track Interaction Monitor (V/TI) in the Hunter Valley. Results indicated that the system successfully identified safety risk track conditions. Most notably, the Mid-Chord Offset measurement was found to be the most beneficial. The other measurements were useful for providing continuous safety monitoring; however, it was not observed that these track conditions occurred as often as MCO conditions.

Overall, the system indicates that it should be a good addition to the ARTC track inspection program and should help towards the goal to reduced Hi-Rail track patrols. The (V/TI) proved to be very reliable, accurate system with repeatable results, each network will be different in some way with respect to threshold limits and relative importance of the measured parameters.

ACKNOWLEDGEMENTS

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