USE OF INSTRUMENTED REVENUE VEHICLE TO MANAGE 40 TONNE AXLE LOAD OPERATION AT FORTESCUE METALS GROUP LTD

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SUMMARY

The paper discusses the implementation of a system at Fortescue Metals Group (Fortescue) to identify track and operational performances by measuring the dynamic responses from an instrumented ore car used for standard revenue service, commonly known as Instrumented Ore Car (IOC). IOC provides a method to continuously and autonomously collect valuable track condition and rolling stock operational information. The Fortescue IOC system was commissioned in 2012 and has since provided timely and reliable data for the condition of both track and rolling stock.

The data from the IOC system has been used extensively by Fortescue to monitor track condition for immediate maintenance activities, as well as predict long term deterioration. Fortescue has used the IOC system for track evaluation including commissioning of new infrastructure, monitoring turnout condition and identifying track weld issues. In-train force data collected by the IOC system is used during commissioning of the train unloader systems. The IOC data has shown that upwards of 50% of the damage related to in-train forces is accumulated during the train indexing through the unloader and the availability of in-train loads has allowed Fortescue to optimise throughput while minimising component failures.

This paper discusses the latest developments to the IOC system and how they are being used to manage a track network operating the highest axle loads in the industry.

INTRODUCTION

New technologies are constantly being developed to increase productivity and reduce costs while providing a safe working environment. Rail operators are continuously improving to increase tonnage without dramatic infrastructure costs and one of the ways of achieving this is by heavier rolling stock axle loads. Fortescue’s rail operations in the Pilbara region of Western Australia (see Figure 1) was the first heavy haul railway to achieve the milestone of 40 tonne (t) axle loads and is now operating up to 42t, another industry first. Innovative strategies for design, construction and maintenance were required to enable these very high axle loads, one of them being the continuous collection of track and operational information using the Institute of Railway Technology’s (IRT) Instrumented Ore Car (IOC) system.

Existing inspection methods for heavy haul railways such as manual track inspection, hi-rail inspection and track recording vehicles require regular dedicated track access which can be problematic in rail systems that are as extensive and remote as the Fortescue rail network.

The IOC concept overcomes the issue of track access by implementing a measurement system which is part of the normal revenue fleet. The principle concept of the IOC is that the measurement of vehicle dynamics and corresponding track locations provides a mechanism to identify elevated responses and prioritize focussed maintenance activities.

![Figure 1: Fortescue’s Pilbara rail network](image-url)
History of IRT Involvement with Fortescue

The Institute of Rail Technology has been working with Fortescue since the opening of its Pilbara rail network in 2008, providing expertise in both track welding and failure analysis of rolling stock components.

In 2012, Fortescue commissioned IRT to instrument an ore car to measure the dynamic responses of the Fortescue network. The project was completed in the same year providing continuous feedback on the track and operating conditions. The project has highlighted the benefits of a continuous, embedded measuring system and there are plans to expand the IOC fleet over coming years to further improve the network coverage.

Relative Benefits of IOC to Track Recording Systems

There are advantages and disadvantages associated with any track recording or monitoring system, whether it is the more traditional dedicated track recorder (e.g. AK car) or instrumented vehicle. However, with developments in instrumentation and communication technologies, it is now possible to provide faster and more regular feedback on track condition and potential risks to the railway operation through the use of instrumented vehicles.

It is important to note that an instrumented vehicle is not a track recording car in the traditional sense, and it is generally not possible to connect all features of a track recording car to an in-service instrumented vehicle.

In high axle load operations, the suitability of a track recording car becomes more questionable. Since the axle loads of the recording car are significantly less than the rolling stock used for revenue, the track irregularities seen by the recorder car are likely to be significantly different (in magnitude) to the actual track form experienced by the revenue fleet vehicles.

Furthermore, the track structure in heavy haul railways is often built to a higher quality than other freight railways, hence there may be no need to monitor all the parameters measured with a track recorder car. For example, track gauge is unlikely to vary much in heavy concrete sleepered track and, provided rail wear is captured by other means (e.g. non-contact profile measurement systems), the reporting of this parameter by track recorder or other means becomes redundant.

Most railroads have clearly defined intervention criteria as a function of track geometry. These limits have been developed empirically or theoretically to ensure that wagon dynamic behaviour remains within appropriate levels. What the IOC does is actually measure vehicle dynamic response, instead of relying too much on the actual geometry, which may cause the dynamic responses. Ultimately, track needs to be maintained when vehicle response is unacceptable. In other words, while the IOC recorded parameters differ from those measured by a dedicated Track Recording Car, an IOC provides information that is important for operation.

IOC Hardware and Software

The IOC concept is a flexible, automated, remote condition measurement system which can be scaled to measure various train parameters. The IOC system integrates several separate subsystems which enables the measurement and analysis of data related to the train dynamics, track locations and the communication of these results, as well as controlling the on-board power and storage systems.

As the IOC would be part of the general revenue fleet, the equipment installed needed to be highly robust and transparent to the operation. The IOC installed wagon carries the same amount of iron ore as any wagon in the network and is part of standard maintenance schedules. Substantial work was conducted to ensure that equipment would not be damaged when the wagon is rotated during the unloading of iron ore at the port or interfere with other aspects of the network such as maintenance inspections and shunting operations.

A critical element of enabling the remote nature of the IOC is to provide a constant and reliable power source. In-train power sources are not accessible on ore trains so the IOC has to be capable of generating, storing and controlling its own power system. Solar technology was chosen for the Fortescue network (see Figure 2) as it is the most efficient and reliable option for the conditions that the IOC will be exposed to. The system includes a group of high efficiency solar cells storing energy to deep draw batteries. The optimisation of the solar system and duty cycle are critical to the continuous operation of the IOC. To this end, a control system has been developed to ensure that the available stored energy is used in the most efficient way ensuring continual operation even when there are extended periods of overcast weather. As an example, the on-board systems will automatically power down when the train is stationary for extended periods of time.
The IOC at Fortescue have now been in continuous operation for over three years with minimal maintenance covering operations including loaded and empty runs as well as dumping.

The IOC uses a customised low power programmable logic controller system that administers its remote operation. Activities conducted by the control system include logging and communicating the status of the IOC and ensuring that its systems are switched on and off to maximise battery life. The system is also capable of controlling software and hardware based on the GPS position of the IOC.

The data collection unit used in the IOC has proved to be capable of working in extreme conditions which are common in the Pilbara with temperatures ranging from freezing to more than 60°C. The units are capable of high sample rates and real time data analysis. The internal memory of the IOC allows, if required, up to 40 trips of data to be stored before it has to be downloaded and cleared to make room for new data.

The IOC is able to record a broad range of parameters but there is a standard configuration (see Figure 3) which has been used in Fortescue’s system to allow analysis of track and in-train force data:

- Bogie suspension displacement for track geometry defects;
- Unsprung sideframe acceleration for rail surface defects;
- Lateral accelerations and bogie steer for the calculation of hunting parameters;
- Drawbar force as well as brake pipe and cylinder pressures;
- Differential GPS which is capable of sub metre accuracy; and
- Superelevation and twist via an Inertial Measurement Unit (IMU).

Communication for the IOC is conducted via a combination of 3G and satellite based systems. 3G is used whenever coverage is available for transfer of data and satellite for tracking the IOC position and health. Using this method allows the IOC to be tracked continuously during its trip, even in the most remote parts of the network.

Software and Control

The IOC control systems are based at Monash University in Melbourne and their function is to automate the tracking, downloading and analysis of the trip data. Prior to these systems being developed, the IOC was tracked, downloaded and processed manually leading to turnaround times of up to four days. Automation has reduced the turnaround time of critical response data, referred to as Severity 1 locations, to typically within six hours.
Tracking the position and status of the IOC is conducted through a virtual network. A request is sent to the IOC every 10 minutes checking its position, speed and status of critical on-board systems. The results can be viewed via either Google Earth or a website control interface (Figure 4) from any PC, tablet or smart phone connected to the internet.

Using this approach, weekly reports are provided to Fortescue track inspectors highlighting locations requiring attention. The severity system also provides a method of tracking the maintenance status of the entire network.

Fortescue requires a rapid notification of Severity 1 locations to track inspectors, so inspection can be conducted and maintenance planned at these critical locations.

Figure 5 shows an example of a Severity 1 report which is communicated to the appropriate Fortescue track inspector once reviewed by IRT staff.

**Track Maintenance Planning**

Severity 1 and weekly reports process the IOC data independent of the type of track features or its location in the network.

This method is somewhat limited in that certain track features such as insulated rail joints (IRJ) and rail welds accumulate greater fatigue damage for a given rolling stock load than normal rail. For this reason, potential failures at these locations may not be identified using standard IOC response thresholds. In addition, the IOC responses at bridges require specific analysis, as parameters relating to impacts at entry and exit and stability across its deck must be evaluated.
An analysis method using track feature locations stored in a specifically designed database has overcome these issues and provides greater flexibility for analysis and maintenance prediction. The process has the advantage that each class of track feature can be processed separately allocating appropriate maintenance intervention limits. As an example, response data for all IRJs or bridges in the network could be compared and work prioritised for those being exposed to highest loads. For example, Figure 6 shows bounce response at the exit of a bridge.

**Figure 6: IOC Responses on a Bridge**

The detailed track database developed for the Fortescue network (as shown in Figure 7) includes all major classes of track features. The survey data stored in the system has sufficient resolution to allow areas such as the frog and points of a turnout to be identified and processed separately. For any given IOC trip, an analysis is conducted of the track features along its route and the resulting parameters are stored to an output database.

**Figure 7: Track Feature Database of Bridges, Crossings, IRJs and Turnouts**

Analysis is conducted on the IOC data taking advantage of the larger number of measurements conducted by the system to predict track deterioration. Figure 8 shows the output from Track Feature dashboard developed for Fortescue, highlighting the track deteriorating responses at a bridge over seven months. The underlying trending model identifies deterioration as well as providing estimated dates at which the response levels will exceed the maintenance intervention limits.

**Detection of Damaged Rail Welds**

Due to material changes during the welding process, the weakest points in railway tracks are the rail welds. Significant research has been conducted by researchers, including IRT, to minimise the likelihood of weld failures. The steps taken to minimise rail breaks at welds is extensive, ranging from selection of rail material, controlling welding processes, to ongoing condition monitoring of weld dips and monitoring defects using ultrasonic measurement techniques.

An important factor of reducing rail breaks is to minimise weld stresses related to rolling stock dynamics. An imperfect weld creates misalignment resulting in peaks and dips. These tiny bumps or troughs in the rail can increase the impact loads dramatically compared to the static weight of the wheels as the train traverses the weld. On a 240-car iron ore train, this will lead to 960 high load impacts to the weld dramatically increasing the likelihood of failure.

IOCs directly measure the unsprung acceleration and therefore provide a method of determining weld loading caused by dips and peaks. In addition, these high impact loads will cause deterioration of the underlying ballast at defective welds, further increasing rail stresses. Movement of the rail due to deteriorated ballast is also detected by the IOC’s spring nest displacement transducers.
Figure 9 shows the IOC responses at a location on track where dipped welds have been measured. The data clearly shows repeated responses at each weld every 25 metres (bottom plots) from the IOC acceleration measurements. The spring nest displacement also shows movement of the rail at the welds. Results such as these have been used extensively by Fortescue to identify and prioritise maintenance of welds.

![IOC Data](image)

**Figure 9: IOC Data showing sideframe acceleration and spring nest movement from Misaligned Flashbutt Weld**

Unlike the Track Feature process discussed previously, acquiring GPS details of all the welds in the network can be difficult due to the quantity. For this reason, a specific weld detection technique has been developed for the IOC data taking advantage of the 25 metre periodic spacing of welds in new track to identify high response spacing locations. Using this technique, weld responses were filtered from other acceleration ‘noise’ signals. Figure 10 shows a heat map of locations on track where potential weld issues have been detected in the data. The colour represents the level of response from the IOC at these locations.

![Heat Map](image)

**Figure 10: Heat Map Showing Output from Weld Detection System**

**IOC Superelevation and Twist Measurements**

The applied superelevation (cant) of a railway track is the difference in vertical level between the top surfaces of opposing rails within a curve.

The primary purpose of superelevation is to better distribute wheel loads across both rails and reduce the effect of lateral forces. The implementation of an appropriate superelevation design and management strategy is a catalyst to reduce or control rail and wheel wear and damage in a heavy haul environment.

The setting of appropriate superelevation levels is largely based on the actual speed profile of trains operating through each curve on the network. Changes to the speed profile subsequent to the initial design of curves can significantly affect performance.

Superelevation changes over time for a number of reasons including re-railing of one leg of the curve and issues related to track support. In addition, superelevation requirements may change over time due to operational issues such as extended periods of speed limits or changes to driving schedules.

Inappropriate superelevation can lead to rail wear and crushing due to uneven loading of the two legs. In extreme situations, inappropriate superelevation can also lead to increased risk of derailment and hence must be managed carefully.

The IOC superelevation measurement system provides valuable information for the management of track including:

1. Rapid and more frequent reporting relative to other track recording systems;
2. IOC record the superelevation of the track under the axle loads of rolling stock where lighter vehicles may produce a differing result due to variable ballast compliance.
3. The large amount of data collected by the system enables a detailed overview of the current operational speeds. This data can be used to establish if the original design specification speed profiles need to be modified.
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Figure 11 shows the IOC superelevation outputs from IOC including twist calculations for both two metre and eight metre chord lengths. Combined with the IOC’s ability to measure the true operational speeds of Fortescue’s rolling stock, the data has been used to conduct audits of curves in the network, identifying where superelevation may be incorrectly set.

Figure 11: Superelevation Output from IOC including 2 m and 8 m Twist Estimations

IOC Analysis of In-train Force Data

Driving a train close to three kilometres in length and a total mass nearing 40,000 tonnes over undulating terrain is challenging. Trains at Fortescue are between 240 and 250 ore cars with three 4,500hp locomotives. Train partings from high longitudinal dynamic loads is an ongoing issue with trains of this length, due to costs associated with delays.

The IOC measures in-train forces through strain gauges installed to the drawbar. These strain gauges have been calibrated in both tension and compression to indicate in-train forces in tonnes. The data from the system is used extensively by Fortescue to quantify where high loads are occurring in their operation.

While the IOC can monitor only one location in the train at a time, the information derived from it can still provide very valuable feedback both to drivers and rolling stock engineers. Multiple trips of the IOC can be processed at various locations within the train to construct an overall damage duty cycle for components within the rail operation.

Figure 12 shows a typical trip from the port to the mine and back. In the example shown, the IOC is located towards the front of the train. The graph includes coupler force, brake cylinder pressure, speed and calculated track chainage. The trip starts with the train being unloaded in the dumpers, shown in the green shaded section. The blue shaded section shows the empty train moving to the mine. The final pink section shows the train, now loaded with iron ore, travelling back to the port.

Figure 12: Measured In-train Force for Entire Trip

Reports of high in-train forces are automatically generated from the IOC data. Figure 13 shows a sample of the type of report produced by the system. High force reports indicating high force locations on track are sent to Fortescue at the completion of the trips for analysis by drivers to review their driving strategies.

Figure 13: Sample in-train Report

Analysis of the IOC in-train data has shown a significant proportion of the total fatigue damage is accumulated during the indexing of cars through the dumper at the port. IOC measurements have often shown the damage accumulated during dumping can exceed what occurs during normal operations on the mainline. A great deal of work has been conducted to tune the speed profiles of dumpers and maximise the total tonnage throughput while managing the in-train forces created by the system.
Figure 14 shows the in-train forces through a dumper with the IOC positioned approximately mid-way along the train. The position of the IOC within the train can be identified by reviewing the in-train forces in the graph. Prior to entering the dumper, the IOC is pulling the remaining loaded ore cars and hence exposed to high tensile forces represented in the positive part of the graph. Once the IOC has exited the dumper it is pushing the empty cars as seen by the slightly lower negative compression forces shown in the second half of Figure 14.

![Figure 14: In-train Forces Through the Dumper Showing Loads Associated with Each Index](image)

The in-train forces through a dumper are highly sensitive to the speed profile of the indexing process of moving the next car into position. Although computational models have been developed to predict indexing forces, the process is so complex it is still accepted that real world measurements are needed for validation of any changes. Figure 15 shows the IOC in-train forces and speed profiles through a dumper for three trial indexing speed profiles.

![Figure 15: IOC in-train force and speed data for 3 indexing cycles](image)

IOC in-train forces through the dumper can be reduced to load spectrums called level crossings as shown in Figure 16. These graphs provide a concise method of reviewing the distribution of the forces and major changes between trials.

![Figure 16: In-train Forces Reduced to Level Crossing Plots for Several Speed Profiles](image)

In-train forces measured by the IOC can be converted into a series of relative damage comparisons using fatigue analysis techniques. The process involves reducing the in-train load time historical data to a range-mean matrix using the Rainflow process. Damage levels are then calculated for each element of the matrix using fatigue weighting factors and summed to a single damage number assuming Miners rule. The resultant number represents an indicative fatigue "damage" value for the load spectrum. Damage numbers do not represent the absolute life of components subjected to these loads but rather an indicator for comparison to other loading duty cycles. The process simplifies comparison between different driver strategies, coupler positions in train and identifying where in the operation components are receiving substantial levels of fatigue.

Fortescue uses the IOC system to monitor in-train forces to manage train partings. A major benefit of the IOC is that measurements are continuous and covers all aspects including mainline and yard operations allowing a true picture of the damage to be constructed. The data presented to Fortescue is in an easy to understand format and clearly identifies where in-train damage was happening and highlights systemic changes that occurred as new dumpers were brought on line and driving strategies are modified.
Figure 16 shows a sample output from the IOC in-train dashboard developed for Fortescue which can be accessed remotely via a web interface. The dashboard provides an interactive method for Fortescue engineers to review data from the IOC in-train system providing current and historical records of IOC trips. Both relative damage numbers and peak forces are provided through the interface with detailed summaries of both mainline and dumpers.

Figure 16: Dumper and Mainline In-train force Dashboard

Other IOC Projects

The IOC system is utilised for a variety of the other projects including:

- Evaluation of in-train forces and track loading from increasing axle loads;
- Evaluation of train stability at increased mainline speeds;
- Root cause analysis of rolling stock issues; and
- Provision of IOC data for track surveys.

CONCLUSIONS

A leader in rail innovation with the heaviest haul railway in the world, Fortescue introduced Instrumented Ore Car technology to ensure safe and optimal performance from its rail assets.

The key elements of the IOC are its remote capabilities, continuous operation and automated methods to deal with the large amount of measured data. The IOC systems represent a significant step forward in terms of the data presented, the usability of IOC data and the frequency with which the information is updated.

Since Fortescue commissioned IOC in 2012, the system has been used extensively for a variety of track, rolling stock and operations projects. The system has proven to be reliable and capable of providing invaluable information for Fortescue rail operations.

REFERENCES

