ANALYSIS OF TRACK TAMPING EFFECTIVENESS USING CONTINUOUSLY MEASURED PERFORMANCE DATA

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SUMMARY

Settlement of railway track caused by the cyclic loading and vibration of network traffic, leads to degradation of geometry which therefore needs to be systematically maintained. Tamping is an effective maintenance procedure which repacks ballast particles in order to restore the correct geometrical position of track. The goal of this study has been the development of a tool to evaluate the effectiveness of track tamping. Continuously measured performance data from instrumented ore cars (IOCs) is used for the analysis. The wagon-track dynamic interaction is studied by investigating the dynamic behaviour of the IOC's suspension system. The wagon suspension response data is then utilized to identify locations where tamping has been effective or ineffective. A maintenance planning system is used to conduct predictive modelling and forecast wagon dynamic responses to identify priority tamping locations. Using linear regression, the rate of track degradation over time and locations where tamping is required can be identified. The results of this work facilitate the development and improvement of maintenance planning operations. Particular tamping strategies or equipment that has had an adverse impact on track can also be identified. It therefore becomes feasible to develop a preventative tamping program that reduces surface and lining requirements and consequently the need for the introduction of temporary speed restrictions.

INTRODUCTION

Track geometry is an important aspect of railway construction because degradation of many track components is closely related to the track geometry condition. Moreover, track geometry can trigger a wide range of track maintenance procedures and renewals. In the past, railway maintenance procedures were mainly planned based on the knowledge and experience of the infrastructure owner. Today however, the competitive market and budget limitations are forcing railway operators to optimise operations and maintenance procedures. Optimising maintenance requires estimating track degradation and the consequences of the degradation mainly in terms of cost and safety. Obtaining knowledge about degradation helps to estimate the right time and procedures for inspections, maintenance and renewals.

Track geometry degradation is a complex phenomenon affected by many factors such as dynamic loads, time and usage intensity [1, 2]. Track geometry degradation can manifest itself in the form of track irregularities. For a newly built track, the tolerances for track irregularities are very low. As the train travels on the track, larger deviations will arise. Horizontal deviations occur due to track side movements and vertical deviations happen due to crushing and settlement of the ballast.

Track irregularities can be classified into different groups depending on their extension in length and type of irregularity: isolated (single point) defects, short wave irregularities (wavelength of 1-25 meters), and long wave irregularities (wavelength of greater than 25 meters) [3]. Long wave irregularities mainly cause problems at high speeds, creating swaying motions of the wagons.

Figure 1: Substructure contributions to settlement [4]
The settlement of track occurs as a result of long-term operational exposure as well as climatic events [4]. Ballast contributes the most to the track settlement [5] as shown in Figure 1. Excessive track support degradation and ballast settlement, as a result of fouling, can cause track instabilities, unwanted speed restrictions, and increased risk of derailment. Repairing or correcting the progressive settlement of ballast can be conducted by tamping the ballast to bring track geometry back to acceptable levels.

**TAMPING AND LINING**

Railway tamping and lining is the most common procedure for restoring the variable ballast settlement which leads to poor geometry. Tamping is performed to correct long wavelength faults caused by repeated traffic. Short wavelength faults cannot be removed by tamping; grinding or weld straightening can be used for this kind of defect. In essence, tamping can be explained as the compaction of the ballast to increase its supportive effect on the sides of sleepers and under the sleepers. The tamping and lining machine has tamping tynes that are inserted in the ballast on each side of the sleeper. The lifting rollers raise each sleeper to the target level which also creates a space under the sleeper. Then, the tamping tools squeeze the ballast to adjust the position of individual particles in order to reduce cavities. Simultaneously, the lining tool of the tamping machine adjusts the position of the rails so that the whole track is straightened. The tamping sequences are shown in Figure 2.

![Figure 2: Sequence of tamping](image)

**MEASUREMENT AND EVALUATION OF TRACK GEOMETRY QUALITY**

In order to keep a safe track quality it is important to perform continuous measurements. The quality of track geometry can be assessed in several different ways: manually during maintenance work, visually via track inspectors or train drivers, with an automated track recording car or using instrumented wagons. The measured data can be used to identify critical parts of a railway network and to evaluate the type of corrective or preventive measures that should be taken. The data forms the basis for a long-term maintenance plan and controls their effectiveness.

The method used to measure the quality of track geometry in this case was a series of instrumented ore cars (IOCs) which are in operation at Rio Tinto’s railway network in the Pilbara region in the north of Western Australia. An IOC is a standard ore wagon equipped permanently with advanced measuring systems including different types of sensors and logging units. The primary use of IOCs is for track condition monitoring. An example IOC is shown in Figure 3.

![Figure 3: Instrumented ore car (IOC)](image)

The advantages of IOCs over traditional track geometry measurement vehicles are:
- It does not interfere with network operations.
- It is cheaper to purchase and operate.
It provides a more frequent and continuous coverage of the rail network.

It provides and measures the same dynamic responses (speed, axle load, suspension, and in-train forces) as the fleet.

Multiple recording units can be used on a train consist and across the network.

Additional measuring equipment can easily be added.

IOC field recordings are automatically downloaded to the main logging unit. The data is then remotely transmitted to the data processing centre at the Institute of Railway Technology, Monash University in Melbourne for further analysis and reporting. To describe the quality of track geometry, outputs from IOC measurements are analysed, using a number of signal processing and data analysis methods, to generate numerical characteristics of the track. These results have been a useful tool for evaluating the effectiveness of tamping activities.

An example contour plot showing response activity for a known high response location is given in Figure 4. This data can be used to study the variation of response with time at different locations on a daily, weekly, or monthly basis.

![Figure 4: Track maintenance evaluation using IOC data](image)

**TRACK GEOMETRY MONITORING AND IOC DYNAMIC RESPONSE**

To monitor vertical instability and track irregularities in this study, wagon suspension dynamics as a result of vehicle body vertical motion are investigated. Three modes of vehicle body motion, i.e. pitch/bounce, roll, and individual spring nest deflection are studied. As illustrated in Figure 5, the maximum value of spring nest vertical displacement defines the spring nest deflection. The rotary motion of the vehicle body about the X axis is defined as roll. And, the linear vertical motion of the vehicle body along the Z axis is called bounce. Longitudinal level deviations can affect the car body motion in two different ways. If the irregularities on the two rails affect in different ways. If the height deviations are equal for both rails, a bouncing movement in the vertical direction is generated.

![Figure 5: Modes of vehicle body motion](image)

The travelling distance of suspension springs are measured at all four corners of the wagon on each side frame. The aim of the sensing arrangement was to capture vehicle body modes of motion at the front as well as the back of the vehicle. The three studied modes of vehicle body motion can be described as follows:

- **Spring Nest Deflection** = \( \max(ST_1, ST_2, ST_3, ST_4) \) \[1\]
- **Bounce** = \( \max\left(\frac{ST_1 + ST_4}{2}, \frac{ST_2 + ST_3}{2}\right) \) \[2\]
- **Roll** = \( \max(|ST_1 - ST_4|, |ST_2 - ST_3|) \) \[3\]

where \( ST \) denotes the spring nest travel distance at each corner and the subscript defines the corner (side frame) number as illustrated in Figure 5.

**DATA COLLECTION AND ANALYSIS**

The analysis of measured data, the effectiveness of tamping and identification of future tamping locations were conducted using Rio Tinto’s IOC fleet data collected during their service in the field. The method used to perform the analysis relied on developing a batch processing sequence to collate the IOC dynamic response in terms of spring nest deflection, bounce, and roll. Utilizing a computer program developed using "imc FAMOS", IOC trips from the beginning of 2013 were batch processed collating the response level and speed variations for each trip for the entirety of Rio Tinto’s track network.

IOC field recordings incorporate variability in both operating environment as well as other uncontrollable operational factors. It should be noted that different segments of track were subjected to varying number of IOC trips from the beginning of 2013. To assure reliability and accuracy of results and predictions, only track data with sufficient number of IOC trips were used.
segments with sufficient number of IOC trips were considered. Because the wagon dynamic response to a track irregularity is more pronounced when the wagon is loaded, only the loaded trip of IOC runs were considered. Analysis of data was performed according to the following considerations:

- The data was aggregated on a weekly basis.
- Suspension responses were normalised against a respective response threshold known as severity 1 thresholds.
- The maximum suspension response of the wagon was calculated over 50-metre blocks of the track.
- The maximum of the three suspension response parameters was used as the representative response of the wagon for a given IOC run.

A normalised suspension response of greater than 1 means that the suspension response has exceeded the severity 1 threshold and vice versa.

**RESULTS AND DISCUSSION**

Contour plots of the maximum normalized suspension response across the entire railway network were prepared in FAMOS. Utilising these in addition to contour plots of average train speeds, correlation of IOC suspension response to speed restrictions becomes possible. Examples of FAMOS contour plots are given in Figure 6 and Figure 7.

Further to FAMOS output results, Tableau software was used to visualize tamping data analytics for easier understanding and analysis of information. Tamping records received from Rio Tinto were integrated into the IOC data. Multiple views of data can be combined in Tableau to achieve a richer insight into the tamping effectiveness. Data can be filtered by track name, maximum of IOC suspension response, speed, chainage, date, effective/ineffectiveness of tamping events, and also severity rating. An example of the tamping dashboard in Tableau is shown in Figure 8.

For the purpose of predicting locations where tamping is required by a given time in the future, a linear regression line (line of best fit) was used to extrapolate the mean suspension response from the last known tamping date at each location on the track. The slope of the regression line represents the rate of track degradation over time.

**Table 1: Predicted locations across the Rio Tinto’s rail network where tamping was required by 15 April 2014**

<table>
<thead>
<tr>
<th>No</th>
<th>Data Points</th>
<th>Projected Mean Response</th>
<th>Confidence Level</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>0.33</td>
<td>82%</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>0.41</td>
<td>100%</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0.3</td>
<td>83%</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>0.82</td>
<td>85%</td>
<td>Low</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>0.55</td>
<td>82%</td>
<td>Med</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>0.31</td>
<td>88%</td>
<td>Med</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>0.71</td>
<td>84%</td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>0.47</td>
<td>99%</td>
<td>Low</td>
</tr>
</tbody>
</table>
A number of prediction parameters were used to define the regression as follows:

- Suspension response mean threshold $\geq 0.3$ (approximating an equivalent maximum normalised suspension response of 1)
- Confidence level $\geq 50\%$ (goodness of the linear fit to suspension response data)
- Number of data points $\geq 3$ (representing at least 3 weeks of data since last tamping)

As an example Table 1 summarises the identified locations to be tamped by 15 April 2014.

Projected forward to the above mentioned date, a total of 23 locations were identified by the prediction tool where tamping would have been required. Each location has been given a priority value. The priority classification is defined as follows:

- High: Location shows clear degradation and tamping of this location is recommended.
- Medium: Locations shows some evidence of degradation which may be supported by historical trends or other factors. Tamping may be considered in this case.
- Low: Location has not yet shown sufficient evidence of degradation to confidently recommend tamping. Condition monitoring of the location is recommended.

Tamping ratio is an objective way to measure how good the tamping event was at a particular location. The tamping ratio was defined as the ratio of average wagon suspension response 3 weeks after and before the tamping. An effective tamping event has a tamping ratio of smaller than 1 and ineffective tamping event has a tamping ratio of greater than 1. The results of this work allows the comparative study effectiveness of tamping at different locations across the entire rail network. Overall, although ballast tamping was effective in many occasions, there were many tamping events which were not effective.

An example of the Tableau prediction dashboard is given for a selected location in Figure 9. The location is highlighted on the GPS map (top left) in addition to a satellite image of the location (bottom left). The graphs show the normalised IOC response values (top middle) and the corresponding average speed of the IOC (bottom middle). The tamping dates are overlaid as red bars and the inset marker text describes the tamping date and the assessed tamping effectiveness. The selected locations are summarised in the "selected results table" (top right). All data filters and prediction parameters are variable and located on the right hand side of the dashboard. The location shown in Figure 9, has an obvious upward trend in the data inferring rapid track degradation following October 2013.

**CONCLUSION**

The outcomes of this study suggests that the historical changes of wagon dynamic responses as a result of track degradation can be used to generate maintenance plans more efficiently. The validity of the prediction model was also assessed by comparing the predicted tamping locations to those that would otherwise be identified during standard maintenance planning. The developed tamping and predictions dashboards present all the relevant data in one place. This would give large operations such as Rio Tinto the possibility of having real-time access to up-to-date and accurate field recordings which explain the quality of track geometry across the entire network. It also provides the operation with the capability to
interact with the data and redefine the prediction parameters that suit the operation’s requirements. Further investigations can be undertaken to optimise the best set of statistical measures for the purpose of analysing tamping effectiveness and tamping location predictions. The best statistical measures would ideally be independent of external parameters such as IOC wagon class, IOC position within the train and train speed. A retrospective analysis against actual severity 1 events is suggested as a future work to improve the regression models for tamping predictions.

REFERENCES


