Development of Performance-based Track Geometry Inspection

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Summary: This paper discusses the latest advances in the performance-based track geometry study conducted by the Transportation Technology Center, Inc. (TTCI), a wholly owned subsidiary of the Association of American Railroads. The new method and technique, accounting for vehicle/track interaction, is being developed for inspecting track geometry. This study has involved extensive field tests as well as modeling efforts. Vehicle/track interaction tests have included measurements of both track geometry and responses of several typical freight vehicles under revenue service conditions. The modeling efforts have led to the successful development of neural networks relating complex track geometry inputs to vehicle response. As a result, a "black box" is being developed to predict vehicle performance on a "real-time" basis, using geometry measurements and vehicle operation speeds as inputs. By implementing such a performance-based system in the future, railroads can expect to reduce track geometry-caused train derailments and improve prioritization of track geometry maintenance.

Index Terms: Track geometry inspection, vehicle performance, vehicle/track interaction test, neural network modeling

1.0 INTRODUCTION

Railway track maintenance and timely renewal is vital to ensure that track meets safety and quality standards. One of the main components of track maintenance is detection and correction of adverse track geometry conditions. Poor track geometry conditions can lead to rapid deterioration of vehicle and track components, lading damage, poor ride quality, and train derailments. According to an unpublished internal Association of American Railroads (AAR) study, in North America alone, railroads spend more than $20 million (U.S.) a year in track geometry inspections and corrections. But track geometry related derailments, although declining in number in past five years, still cost railroads close to $50 million (direct and indirect total) per year. Obviously, any significant improvements over the current geometry inspection will not only improve train operation safety and quality, but also lead to more cost-effective maintenance resource allocation.

Currently, track geometry maintenance is based on exception criteria set by the U.S. Federal Railroad Administration (FRA) and similar criteria set by individual railroads. A track-geometry vehicle flags track segments that exceed FRA regulations or railroad standards, and maintenance is scheduled accordingly. However, exception reports based on these standards cannot be readily related to vehicle performance. An improved track-geometry system accounting for vehicle/track interaction will benefit railroads by identifying non-conforming track locations, as well as providing guidance as to the nature of possible vehicle response.

This paper describes the ongoing research conducted by Transportation Technology Center, Inc. (TTCI), a subsidiary of the AAR. TTCI to develop a performance-based track geometry inspection methodology. The main objective is to develop a "real-time" system that can be installed on a regular geometry car and will relate measured geometry conditions to likely vehicle responses. Assessment of track geometry conditions will be based on vehicle/track interaction rather than geometry exceptions alone. By implementing such a performance-based geometry system in the future, railroads can expect to reduce track geometry-caused train derailments and to improve prioritization of maintenance resources.

2.0 BACKGROUND AND RESEARCH APPROACH

Many studies have been conducted for effective and efficient maintenance planning based on track geometry or vehicle response measurement [1-9]. In Figure 1, methods for deciding track geometry maintenance can be divided into three major types. The first type is to use a geometry car inspecting a track for exceptions in terms of track-class based geometry standards. This method is widely used, but does not directly account for vehicle/track interaction. As a result, large vehicle responses do not necessarily correlate
well with current track geometry criteria.

The second method is to measure vehicle responses (such as wheel/rail forces and car body accelerations) directly and then compare these responses to safety and ride quality criteria. Track maintenance is subsequently focused on where large wheel/rail forces or poor ride quality occur. This method can directly relate poor vehicle responses to possible geometry causes, but measured response is vehicle dependent and operation specific. For a route with a mix of vehicles or fleet types, it is almost impossible to measure responses for all operating vehicles. In addition, vehicle response information alone cannot substitute for track geometry information, which is often required for assessing whether a track condition is responsible for a measured poor vehicle response.

In the third method, a geometry car is still used to measure track geometry conditions. However, measured geometry results are further fed into a real-time analysis system to determine likely vehicle responses and comparisons with vehicle/track interaction criteria. This method takes into account vehicle/track interaction and is thus referred to as “performance-based track geometry inspection.”

In TTCI’s performance-based track geometry inspection system, a computer “black box” will be developed for installation on a geometry car. Through the black box, the measured geometry information, together with vehicle type and operation speed, will be processed and used for segment-based vehicle performance analysis using neural networks (NN).

The black box output will include track segment-based fleet performance indices and vehicle/interaction exception reports. This output can be used together with track geometry exception reports for assessing track conditions and the sensitivity of vehicles operating under those conditions.

To develop such a system, TTCI’s research approach includes the following major tasks:

- Develop a portable track geometry system that can be mounted on any test vehicle.
- Instrument several typical freight vehicles for measuring vehicle responses and conduct vehicle/track interaction (VTI) tests under revenue service conditions.
- Develop NN models, leading to a prototype black box.
- Demonstrate the prototype system on a track geometry car.

3.0 VEHICLE/TRACK INTERACTION TESTS

A database reflecting a wide range of vehicle/track interactions has to be established in order to develop the neural networks relating geometry conditions to vehicle response. Therefore, several extensive vehicle/track interaction tests [10-12] were conducted from 1998 to 2000 using three typical freight cars (covered hopper, tank car and coal gondola). In these tests, TTCI simultaneously measured track geometry conditions and vehicle responses.

3.1 Test Vehicles, Instrumentation and Test Routes

The three selected freight vehicles were a 90.7-tonne (100-short ton) covered hopper (with constant damped trucks), a 90.7-tonne (100-short ton) tank car (with variable damped trucks), and a 99.8-tonne (110-short ton) coal gondola (with variable damped trucks).

Figure 2 shows the instrumentation setup for each test vehicle. As shown, each vehicle was instrumented to acquire both track-geometry conditions and car responses using a system provided by E.H. Reeves and Co. Track geometry was recorded by a non-contact system using laser light (infrared), video-arrays, and an inertial compensation package. The geometry system was suspended just ahead of the lead truck for each test vehicle. The measured track geometry parameters include space curves in both lateral and vertical planes, gage, cross level, curvature, superelevation, vertical and lateral profile offsets. For the space curves, the range of wavelengths recorded is from 1 to 30 m (from about 3 to 100 feet).
interface during travel. The car body was instrumented with accelerometers to fully describe its dynamic motion (e.g., roll, pitch and bounce, yaw and sway) at any time during the test. Depending on the specific test, additional instrumentation was applied including string potentiometers, strain gages, and displacement transducers to measure track warp, interaction of bolster and side frames, and bolster loads.

For each test vehicle, vehicle/track interaction tests were conducted on the test tracks at the FRA’s Transportation Technology Center (TTC), Pueblo, Colorado, USA, and on the revenue service railroad tracks. Altogether, more than 2,240 km (1,400 mi.) of VTI test data was acquired from revenue tracks on three North America Railroads. A wide range of track conditions was encountered with various combinations of track irregularities. Data was obtained at operating speeds from 16 to 112 km/h (10 to 70 mph) and for tracks with curvature up to 16 degrees.

3.2 Examples of Test Results

Most of the test data showed that the vehicle responded in a complex manner, due to the multi-axis inputs from the rails. Some simple relationships were easily identified, such as the results shown in Figure 3. As illustrated, this segment had significant periodic lateral deviations of more than 25 mm (1 in.) peak to peak. In the track vertical surface trace, a single vertical deviation of about 13 mm (0.5 in.) is also seen. The wheel lateral force recordings show the undesired effects of such track variations with lateral force deviations up to 80 kN (18 kips).

Figure 3. Example of Lateral VTI Test Results (Loaded Covered Hopper, 39 mph or 62 km/h, Tangent)

Figure 4 shows the data recorded on a tangent track. This was primarily a vertical event, with vertical deviations of 51 mm (2 inches) peak to peak. In response, the vertical reaction forces of the wheel increased to approximately twice the static reaction loads. Both the lateral deviations and lateral car responses were relatively insignificant during this bounce/pitch activity.

Figure 4. Example of Vertical VTI Test Results (Loaded Covered Hopper, 45 mph or 72 km/h, Tangent)

Many other events showed more complex track geometry and car responses. Figure 5 is an example of test results obtained in a turnout area. As shown, the track geometry conditions involved changes in superelevation and curvature, as well as significant alignment deviations. The measured vehicle response showed large variations in vertical and lateral wheel loads — obviously due to complex geometry inputs in this area. For the lateral wheel loads, the first portion corresponded to the curving action (gage widening force) while the second portion of large variation corresponded to a misalignment. The anti-phased vertical forces between the two wheels indicated that rolling was the major mode of car body rigid motion.

Figure 5. Example of Complex VTI Test Results (Loaded Tank Car, 31 mph or 50 km/h, Turnout Area)
4.0 NEURAL NETWORK ANALYSIS

One of the main tasks of this research is to develop an effective real-time approach for predicting vehicle response based on track geometry and operational inputs. Because of complex relationships between track geometry and vehicle response, it is difficult to use a conventional analytical approach to relate these two sets of input and output in a real-time manner. However, neural network technology has emerged as a powerful tool in recognizing patterns and relationships in complex problems similar to track geometry input versus vehicle response output [13-15].

Figure 6 shows the results of predicted and actual lateral loads using TTCI's neural network analysis methodology. The predicted results were obtained using the neural network models based only on the measured geometry conditions as inputs. The actual results were attained from the vehicle/track interaction tests on revenue tracks. In this figure, the actual vehicle responses are plotted in rank-order track segments (active segments to the right, inactive segments to the left). The corresponding neural network prediction is plotted directly with actual values. Each track segment is 0.16 km (0.1 mi.) in length.

Figure 6 also shows the results of lateral wheel load in terms of its overall statistical features (95th percentile). As shown, the predicted lateral wheel loads are consistent with the actual measured wheel loads.

Figure 7 gives a comparison of actual and predicted results in chronological order (i.e., segment-based distance history). For 19.3 km (12 mi.) of track, the trained NN was used for predicting lateral wheel loads using the geometry features based on geometry measurements. As can be seen, the predicted results agree well with actual measured vehicle response data.

To date, various preliminary neural networks have been developed using vehicle/track interaction test results for the three freight vehicles. However, work is in progress to develop a performance-based track geometry system using a black box as described earlier. To illustrate one of the outputs from the future black box, Figure 8 shows an example of predicted L/V ratios for an empty tank car, a loaded tank car, and a loaded covered hopper for an actual railroad route, about 144.8 km (90 mi.). The predictions were obtained using the trained NNs for the three car conditions based on the inputs of actual track geometry conditions measured on this route and the train operation speeds. As shown, the magnitudes of predicted L/V ratios are different for the three vehicle conditions; however, the general trends are similar regardless of vehicle type. Obviously, the vehicle performance results shown in this figure can be used together with track geometry exception report for prioritizing track maintenance.

Figure 8. Vehicle Performance Results (L/V Ratios) Predicted for Three Vehicle Conditions on the Same Track Geometry and Operation Conditions

5.0 CONCLUSIONS

Track geometry inspection is a practice critical to train operation safety and track maintenance efficiency. However, track geometry alone is a necessary but
insufficient measure of vehicle/track performance. Improvement of current inspection methods requires consideration of vehicle/track interaction. To develop a performance-based geometry system for cost effective advances in safety and maintenance, TTCI has undertaken research addressing how to predict vehicle performance in real-time for given track geometry conditions. To date, several extensive vehicle/track interaction tests have been conducted to collect both track geometry and vehicle response data for three typical freight vehicles. More than 2,240 km (1,400 mi.) of test data has been obtained from revenue tracks in three North American railroads covering a wide range of track and operation conditions. This data is being used for the development of neural networks relating geometry conditions to responses of various freight vehicles.

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7.0 REFERENCES


