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## Prototype Performance-Based Track Geometry Inspection System

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### Summary

Transportation Technology Center, Inc. (TTCI) has developed a prototype performance-based track geometry (PBTG) inspection system for implementation on track geometry cars. The PBTG system relates measured track geometry to vehicle performance on a real-time basis to help identify track segments that will likely produce poor vehicle response due to track geometry and operating conditions. The main features of this system include:

- Users can specify vehicle types sensitive to track geometry input
- Users can specify vehicle operating speeds
- Outputs vehicle response results directly relevant to derailment potential (e.g., maximum L/V and minimum vertical wheel load)
- Identifies track segments that will likely produce poor vehicle performance (PBTG defects)
- Generates recommended track geometry maintenance actions to the identified PBTG defects
- Outputs PBTG track quality index

Demonstration tests were conducted on both revenue service tracks and the High Tonnage Loop (HTL) at the Transportation Technology Center (TTC), Pueblo, Colorado. These tests have shown that:

- The prototype system, configured to run on a real-time basis, performed efficiently. Interfacing with the Track Geometry Measurement System (TGMS) worked as designed. The PBTG system kept up adequately with the track geometry car at various operating speeds and showed a good deal of stability.
- Application of the neural network technique in the PBTG system made it possible, in a real-time manner, to predict likely dynamic responses of railroad vehicles due to track geometry. Prediction of wheel/rail forces can be done for more than one freight vehicle and for multiple vehicle running speeds simultaneously.

The prototype was designed to help railroads optimize track geometry maintenance for preventing derailments and reducing track and vehicle component degradation.

#### Suggested Distribution:

- Safety
- Maintenance-of-Way
- Track Maintenance
- Planning & Analysis



## INTRODUCTION AND CONCLUSIONS

TTCI has developed a prototype performance-based track geometry (PBTG) inspection system for implementation on railroad track geometry cars. The system was designed to help optimize track geometry maintenance for preventing derailments and reducing track and vehicle component degradation. The system relates measured track geometry to vehicle performance on a real-time basis to help identify track segments that will likely produce poor vehicle response due to track geometry and operating conditions.

To investigate the design and performance of the PBTG system and the neural networks that have been built and incorporated in it, TTCI conducted demonstration tests using the prototype system. During these tests, the PBTG system performed adequately and was stable during real-time applications. Predictions of vehicle responses were made for more than one freight vehicle and for multiple vehicle running speeds simultaneously.

The neural networks used in the PBTG system have learned the dynamic characteristics of the test cars through track geometry at various operating speeds. The results of the predicted vehicle responses were reasonably consistent with the test results, when available.

## METHODOLOGY

### Neural Networks

A typical neural network used in the PBTG system consists of an:

- Input layer that captures complete track geometry conditions (track feature such as curvature and superelevation, and deviations in cross level, gage, surface, and alignment) and vehicle operating speeds, and an
- Output layer that gives vehicle responses to track geometry and operating speeds.

Given the random and complex dynamic relationships existing between vehicle types and track geometry, PBTG inspection emphasizes that car dynamic response directly results from a combination of many geometry variables acting together with vehicle operating conditions. Unwanted vehicle responses that exceed the pre-determined limits do not always result from individual track geometry defects, but from when vehicles dynamically interact with all track geometry parameters over a track

segment. Use of trained neural networks in the PBTG system empowers it to relate all these parameters to vehicle performance and hence identify the track segments with the likelihood of generating such unwanted vehicle responses.

Neural networks incorporated in the PBTG system have been trained to predict interaction forces between wheel and rail for three freight cars: a tank car, a covered hopper, and a coal gondola. These neural networks are trained to learn and recognize patterns and relationships in the vehicle/track interaction data. Once a neural network is trained for a specific vehicle, it acquires the aptitude to predict the dynamic response of that particular vehicle. In consequence, track segments are identified if the vehicle response exceeds the pre-determined limits.

### PBTG Analysis System

The basic functions of the PBTG analysis system are illustrated in Figure 1 and include:

- Interface with the existing TGMS to accept and process measured track geometry so track geometry data can be used as input to neural networks
- Carry out real-time vehicle performance analysis based on measured track geometry and operating speed
- Identify track segments that produce vehicle responses above the pre-determined limits (PBTG defects)
- Generate maintenance actions on the track segments identified with PBTG defects

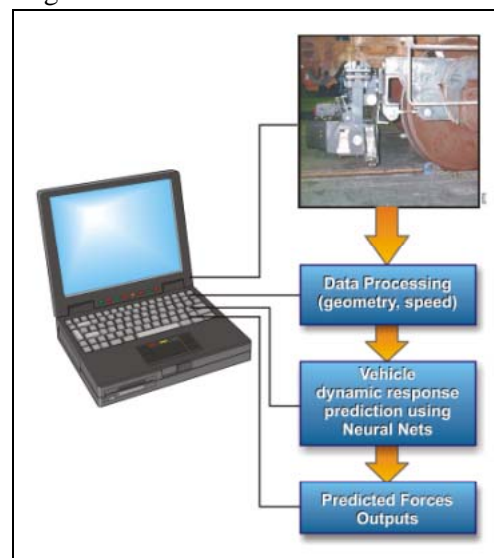


Figure 1. PBTG Analysis System

One feature of the PBTG system is its portability. It can be mounted on a geometry car to be interfaced with the existing track geometry system. It is configured to run on a real-time basis. Such configuration allows it to run instantaneously as the TGMS turns on, shortly after the inspection car begins traveling. Track geometry measurement is sent to the PBTG system right after it is generated. Predictions of wheel/rail forces are carried out for specific car types and operating speeds. Three vehicle performance parameters that can be predicted are (1) vertical wheel load, (2) lateral wheel load, and (3) lateral over vertical (L/V) force ratio. Predictions can be done on both sides of the car. It is also possible to do predictions based on historic track geometry data without having the PBTG system mounted on the geometry car.

**DEMONSTRATION RESULTS**  
**Demonstration on the HTL**

The main objective of the demonstration on the HTL was to test the system’s real time performance. The PBTG system was set up on TTCI’s TGMS, and the interface was established between TGMS and PBTG system. The demonstration was done as part of the track geometry measurement for HTL. The test consist was run at operating speeds up to 45 mph. The measured track geometry was used as real-time input for vehicle performance analysis. Overall, the PBTG system performed as designed and was capable of doing vehicle response analysis on board at the same pace as the track geometry measurement vehicle ran. The PBTG system was stable and performed satisfactorily during each run.

Most of the neural networks performed as expected. Figure 2 shows the vehicle performance results obtained real time for two different freight cars: covered hopper and empty tank car. The analysis was done at 40 mph for both vehicles. The responses shown are the maximum L/V ratios predicted on both rails. Direction of travel was clockwise. For illustration, the measured track curvature is also included in Figure 2. It is worth noting that the response patterns of L/V ratios are similar due to geometry inputs from the same track even with two different cars. However, as illustrated, the magnitudes of vehicle responses can be different. In this example, the empty tank car generated higher L/V ratios than the covered hopper car, especially on high rail in curves.

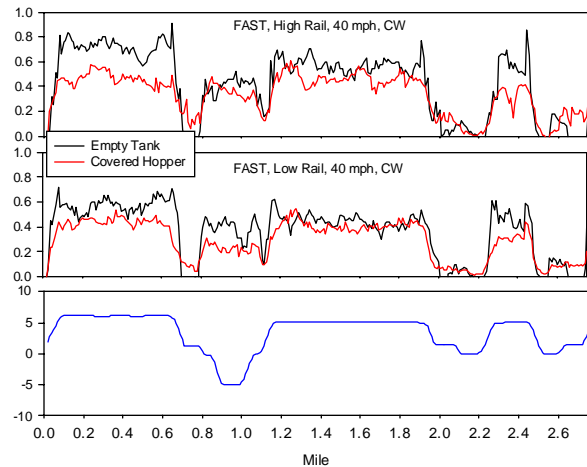


Figure 2. Demonstration Results on HTL

**Demonstration in Revenue Service**

Demonstration tests were also done in revenue service, using TTCI’s TGMS. In the revenue service test, instrumented wheelsets were used to measure actual vehicle responses of two empty tank cars, which provided an approximate verification of the predicted results using the PBTG system.

Figure 3 shows the predicted maximum L/V ratios of the three different freight cars, which are also compared with the actual test results of an empty tank car. The example was for a 3-mile stretch of track with various curvatures. Again, as illustrated, L/Vs ratios were similar for dynamic response patterns due to the same track geometry inputs, although the actual magnitudes were different for different vehicles. In addition, comparisons with the measured L/V ratios indicate validity of the predicted results.

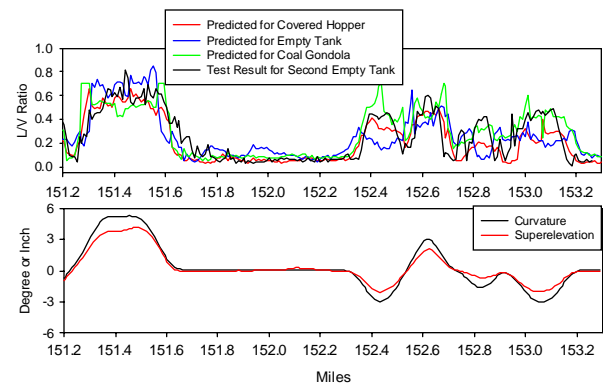


Figure 3. Results for Revenue Service Track

## “WHAT TO DO” AND PBTG INDEX

Another major feature of the PBTG system is that it will output recommended maintenance “what to do” actions and identify track segments that produce poor vehicle performance (PBTG defects). To do so, track geometry conditions for an identified PBTG defect segment are categorized into four maintenance parameters: cross-level, surface, gage, and alignment. Each maintenance parameter is calculated based on maximum deviation, number of repeated deviations, and whether it is a segment in a curve, spiral, or tangent. There are also weights associated with each maintenance parameter. These weights are developed based on the effect of each geometry parameter on vehicle performance.

The calculated result of each geometry maintenance parameter indicates the contribution of that particular parameter to poor vehicle performance (PBTG defect). Depending on the ranking of the results of these four maintenance parameters and their comparisons with the pre-determined target values, track geometry maintenance actions are recommended for spot surfacing, spot lining, and/or re-gaging activities.

The PBTG track quality index is a single parameter developed to sum the combined effect of all track geometry maintenance parameters. Unlike other track quality indices, the PBTG track quality index is a performance-based quality index and was developed based on the effect of track geometry parameters on vehicle performance. It gives an overall quantification of track geometry condition for a given track segment as far as how it may affect vehicle performance.

Figure 4 shows the comparison of the calculated PBTG index values with actual vehicle performance for 90 track segments selected from the revenue service test. Among those segments, 60 of them produced poor vehicle responses (L/V ratios > 1.0). As shown, use of the performance-based track geometry index gives a reasonable indication of track geometry quality as it relates to actual vehicle performance.

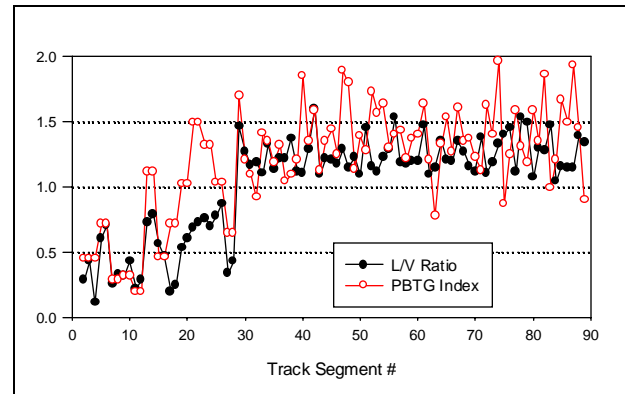


Figure 4. PBTG Index and Vehicle Response Results

## FUTURE WORK

The next stage of implementation of the new technology is to demonstrate and implement the PBTG system on railroad track geometry cars. TTCI will continue to improve this system based on demonstrations and implementation results. As a first joint endeavor, BNSF and TTCI have started the implementation of this system on BNSF track geometry cars.

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