Innovations Deserving
Exploratory Analysis Programs

Safety IDEA Program

SYSTEM TO DETECT TRUCK HUNTING
ON FREIGHT RAILROADS

Final Report for
Safety IDEA Project 06

Prepared by:
Richard Morgan
Sam Chapman
Joe Brosseau
Transportation Technology Center, Inc.
a Subsidiary of the Association of American Railroads
Pueblo, Colorado

February 2006

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD

SYSTEM TO DETECT TRUCK HUNTING ON FREIGHT RAILROADS

Final Report
Safety IDEA Project SAFETY-06

Prepared for
Safety IDEA Program
Transportation Research Board
National Research Council

Prepared by
Richard Morgan
Sam Chapman
Joe Brosseau

Transportation Technology Center, Inc.
a Subsidiary of the Association of American Railroads

Pueblo, Colorado

February 2006

ACKNOWLEDGEMENTS

Table of Contents

1.0 EXECUTIVE SUMMARY

Railroad cars can be subject to a lateral instability called hunting while running at relatively high speeds on tangent track. Hunting causes car, lading and track damage, and as a worse case scenario, possibly leads to derailment. According to Federal Railroad Administration (FRA) statistics, the average annual cost of hunting-induced derailments over the last five years was $2,440,000. Railroads are currently deploying different wayside devices to assess car performance and car component condition as a means of reducing car and track damage and reducing the "stress state" of the railroad. If successful, a wayside truck hunting detection system could provide valuable information to the railway industry by monitoring the dynamic lateral stability performance of all passing freight car trucks.

The Transportation Technology Center, Inc. (TTCI) proposed and investigated a wayside truck hunting detection system that consisted of an array of paired displacement measurement sensors (DMS) placed along a section of tangent track on which trains operate at relatively high speeds. Speed, wheelset alignment, and lateral position relative to the track are established at each non-end sensor pair in the array to determine a particular wheelset's path through the array to identify, among other things, trucks with poor lateral stability.

The proposed system was developed using two stages. The first stage (Stage 1) was a laboratory stage, and the second stage (Stage 2) was on-track testing. During Stage 1, fiber-optic DMS were selected and tested for the performance characteristics necessary for truck hunting detection. Test results indicated that the selected sensors were unable to perform well in this application. An expert review panel recommended that an alternative DMS-based truck hunting detection prototype be evaluated in Stage 2 of the project. This prototype, developed by an Australian company known as Lynxrail, is based on an approach that uses inductive proximity DMS in an array along a section of tangent track.

Due to the timing of the completion of Stage 1, there happened to be a revenue service site evaluation opportunity for Stage 2. In July of 2004, Norfolk Southern (NS), in conjunction with the Equipment and Operating Practices Research Division of the Office of Research and Development at FRA, conducted a comparative test of truck hunting detection systems as part of their ongoing cooperative agreement for wayside component inspection demonstrations. TTCI was allowed to participate in the evaluation using the Lynxrail prototype.

TTCI leveraged Safety IDEA project funding by taking advantage of an established prototype and by utilizing NS and FRA resources that provided the test consist and revenue service test site. Furthermore, TTCI remained consistent with Stage 2 objectives and the research plan of the current Safety IDEA project by continuing to evaluate the arrayed DMS hunting detection concept. The

only refinement was the use of inductive proximity sensors instead of fiber-optic sensors, based on the Stage 1 findings.

The Stage 2 test results indicated that the Lynxrail prototype provided estimates of speed and root-mean-square (RMS) of carbody end lateral accelerations that were highly, positively correlated with those measured by onboard instrumentation. These results validated the concept of truck hunting detection via an array of paired DMS; however, variability was observed in the Lynxrail prototype estimates of RMS lateral accelerations, especially at higher vehicle operating speeds.

The Lynxrail prototype performed reasonably well when compared with onboard data. Additionally, the prototype performed comparably to the other systems evaluated at the NS/FRA hunting test in July of 2004, according to an NS presentation at the Wheel/Rail Interaction Conference at Chicago in May of 2005.

In the interim between the end of testing and the production of this report, Lynxrail completed several prototype enhancements needed to better support the operations of the North American railroad industry. These enhancements include: incorporation of Automatic Equipment Identification (AEI) interface capabilities, ruggedization of track-mounted system components, and protection of all system components so they can successfully function in all North American climates. Furthermore, the data from this evaluation was provided to Lynxrail, who was encouraged to continue optimizing its algorithms for improved detector performance at higher vehicle speeds. The Lynxrail system, now sufficiently mature, has been offered in several proposals to North American freight railroads. If desired, the Lynxrail system could equally serve to detect hunting for passenger railroads as well.

2.0 IDEA PRODUCT

This Final Report was prepared by the Transportation Technology Center, Inc. (TTCI), Pueblo, Colorado, for the Safety IDEA Program of the Transportation Research Board (TRB) for Safety IDEA Project SAFETY-06. The Safety IDEA Program focuses on innovations with applications to improve railroad safety and inter-city bus and truck safety. This contract defines a project to investigate the potential of using an array of on-track displacement measurement sensors (DMS) to detect railroad car truck hunting.

Railroad cars can be subject to this lateral instability while running at relatively high speeds on tangent track. This phenomenon arises with the degradation of the car suspension system and wheel profiles, which results in further accelerated degradation of these components as well as possible damage to the payload of the car. Hunting also causes track damage, and as a worse case scenario, possibly leads to derailment. As shown in Table 1, the average annual cost of hunting-induced derailments over the last five years was $2,440,000, according to Federal Railroad Administration (FRA) statistics.

TABLE 1 Truck Hunting Caused Derailments

Truck Hunting Caused Derailments		
FRA Accident/Incident Data Base		
Year	Number of Derailments	Track & Equipment Damage
2000	7	$2,800,000
2001	10	$3,600,000
2002	6	$1,400,000
2003	6	$1,500,000
2004	5	$2,900,000
Average	6.8	$2,440,000

Railroads are currently deploying different wayside devices to assess car performance and car component condition as a means of reducing car and track damage and reducing the "stress state" of the railroad. The methods of truck hunting detection include monitoring the motion of a truck's wheels and measuring the forces that such wheels induce on the track. As for monitoring the motion of a truck's wheels, if the lateral motion becomes sinusoidal and has a frequency typically associated with hunting or amplitude large enough to cause flange or near-flange contact with the gage face of the rails, the wheels and truck are considered unstable.

If successful, a wayside truck hunting detection system could provide valuable information to the railway industry by monitoring the dynamic lateral stability performance of all passing freight car trucks.

3.0 CONCEPT AND INNOVATION

The proposed system consists of an array of DMS (see Figure 1) along a section of tangent track on which trains operate at relatively high speeds. The sensors are paired across the track, with the pair at each array end acting as a single sensor to alert the data collection system and count the number of wheelsets per train pass.

Wheelset alignment and lateral position relative to the track are established at each non-end sensor pair in the array and the data from each sensor pair combine to determine a particular wheelset's path through the array (see Figure 2). Wheelset alignment is used to determine angle of attack relative to the rail, while the lateral position of the wheelset relative to the rail is used to identify trucks with poor lateral stability. A train's speed is detected by observing the rate at which its wheels pass the array sensors.

The proposed system was developed using two stages. The first stage (Stage 1) was a laboratory stage, and the second stage (Stage 2) was on-track testing. During Stage 1, DMS were selected based on their compatibility with a track wayside environment. Laboratory measurements were taken to verify sensor performance, and a test module was conducted to demonstrate the concept in a laboratory environment. Data was analyzed to define target parameters.

In Stage 2, an array of on-track DMS was built. This array was installed on a tangent track section and was tested using a train consist at different speeds. Finally, the data collected during testing was analyzed to determine the feasibility of the concept.

FIGURE 1 A displacement measurement sensor.
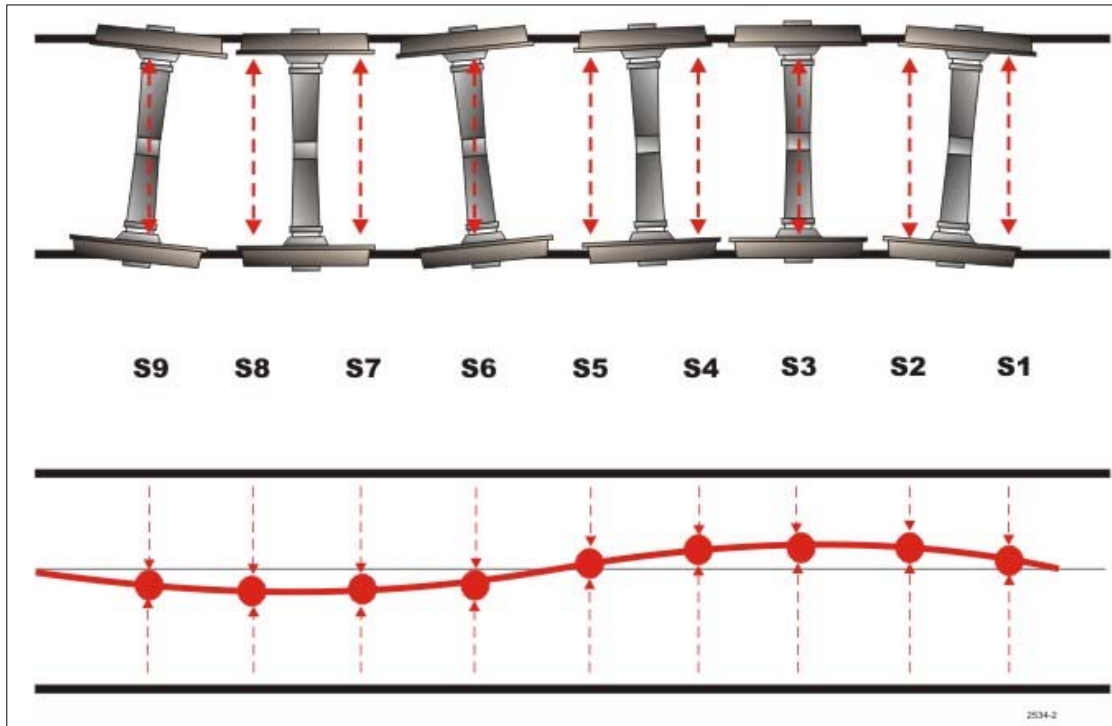
FIGURE 2 A wheelset's path captured by a multiple sensor array.

4.0 INVESTIGATION (STAGE 1)

The Stage 1 activities that were performed are detailed in this section. Fiber-optic DMS were selected and tested for the performance characteristics necessary for truck hunting detection. Test results indicated that the selected sensors were unable to perform well in this application. An expert review panel recommended that an alternative DMS-based truck hunting detection prototype be evaluated in Stage 2 of the project.

4.1 SENSOR SELECTION AND PURCHASE

A pair of Philtec D171-GOR fiber-optic DMS (see Figure 3) was selected and purchased based upon their estimated compatibility with a track wayside environment, performance, and cost. The selection factors included:

- Environmental parameters (operational temperature range, vibration, and shock)
- Performance characteristics (measurement accuracy, sample rate, and response time)
- Physical attributes (dimensions, power requirements)
- Estimated survivability and reliability
- Cost and warranty
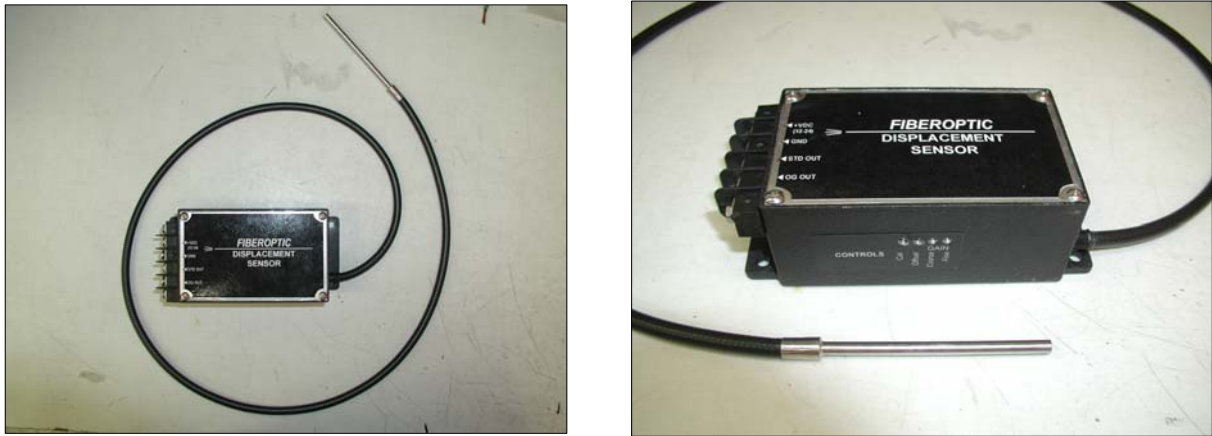
FIGURE 3 Philtec D171-GOR fiber-optic DMS.

4.1.1 Environmental Parameters

The environmental parameters of interest were those associated with a track wayside environment in North America. These primarily included operational temperature range, vibration and shock tolerance, and susceptibility to wind, dirt, and moisture. At wayside sites, exterior equipment needs to be able to withstand temperatures from -40°C to 60°C, possible shock and vibration, and constant exposure to dirt, grease, and all elements of weather.

The specification sheet for the selected sensors stated that their operating temperatures ranged from -55 °C to 175°C. Also, after conferring with the manufacturer, the sensors' tolerance to shock and vibration seemed more than sufficient for a wayside application. Since the sensor head was designed to be submersible in liquid, sensor vulnerability to rain, snow, and ice was not an issue. Overall, the selected sensors appeared adequate for operation in most North American wayside locations.

4.1.2 Performance Characteristics

Regarding sensor performance, the main considerations were measurement accuracy, sample rate, and response time. Based on TTCI's previous test experience, to reliably determine truck hunting requires that wheelset position relative to the track must be measured accurately to within 0.1 mm. Therefore, the sensor needs to measure at least as accurately. The sensors that were selected measured accurately to 0.016 mm, making them more than qualified for the application's accuracy requirements.

Another crucial factor is that a sensor's measurement sample rate must be sufficiently high to distinguish between two wheelsets on the same truck. Given a truck axle spacing of 5.5 feet and a maximum speed of 80 mph, the time between position measurements for the two axles is about 47 msec. Therefore, to distinguish between two successive axle measurements a Nyquist compliant sample rate of over 40 samples per second is necessary.

Further, the sample rate must be fast enough to measure the chord length of a single wheel moving through the measurement zone. Assuming that the sensor is installed perpendicular to the rail and

measures the distance to the gage face of the wheel at a point 0.5-inch below the top of the rail, a 36-inch wheel with a 1-inch flange will have a chord length through the measurement zone of about 12.1 inches. At 80 mph, this chord length will pass through the measurement zone in about 8.6 msec. In order to obtain 10 measurement samples for each chord length passing through the zone, the sample rate must be on the order of 1,200 samples per second.

Finally, TTCI's experience suggests that data analysis is enhanced if a sampled signal's leading and trailing edges each constitute less than 10 percent of the data. In this case, 12 samples are needed for each chord length measurement. Therefore, the sample rate needed is 12 samples in 8.6 msec, or about 0.7 msec per sample. This corresponds to a sample rate of about 1,400 samples per second. Since this is the highest of the needed sample rates, it represents the minimum required sample rate for the sensor.

The sensors that were selected for testing sampled at rates up to 20,000 samples per second, well within the specifications of the system discussed above. Furthermore, because this sampling rate was more than an order of magnitude larger than the minimum required, the provided response time was more than adequate.

4.1.3 Physical Attributes

The physical dimensions of the selected sensors needed to be such that the sensors could be mounted on the gage side of the rails without interfering with any normal railroad operations. The chosen sensors consisted of a small fiber-optic sensor tip attached to an amplifier with a fiber-optic cable, as shown in Figure 3. The sensor tip was a cylindrical sensor 0.187-inch in diameter and 3-inches long. It required placement perpendicular to the surface of measurement. The amplifier was 4.75-inches long, 2.64-inches wide, and 1.71-inches in height. It did not require any specific placement, only tethering to the sensor tip by a 3-foot fiber-optic cable. The sensor tip was small enough that mounting it below the top of the rail facing the gage side seemed adequate enough to prevent physical interference with normal railroad operations.

The sensors required 24 volts direct current (VDC) input power for operation. They output an analog voltage signal ranging from 0 VDC to 5 VDC based on the light intensity received. These input and output power requirements were small, considering power availability at a wayside inspection site.

4.1.4 Survivability and Reliability

Survivability of the fiber-optic DMS was a concern when determining the proper sensors for the application. Since the sensors would be mounted below the top of the rail, the risk of being struck from above was minimal. However, the sensors would also be placed near the gage face of the rail, so the risk of being struck by a wheel was still a concern.

A minimum standoff distance from the gage face of the rail needs to be maintained in order for the sensors to avoid being struck by a passing wheel. The three factors that determine this standoff distance are: the rail gage, the wheel flange thickness, and the distance between the backs of the wheels on a wheelset. Assuming the sensors would be installed on track where potential hunting speeds occur (i.e., Class 4 track and above), Figure 4 shows the worst-case scenario of a wheelset with minimum back-to-back distance combined with minimum flange thickness traveling on a track with maximum gage of 57.5 inches (FRA "Track Safety Standards," Code of Federal Regulations, Title 49, Subtitle B, Chapter II, Part 213). According to Rule 41 of the 2004 Field Manual of the Association of American Railroads Interchange Rules, wheelsets are out of gage if the back-to-back spread is less than 52.9375-inches, and a wheel is condemnable if the flange thickness is less than 0.9375-inch. The distance X in Figure 4 is therefore the minimum standoff distance of the sensor with no additional clearance. This distance is 3.625-inches.
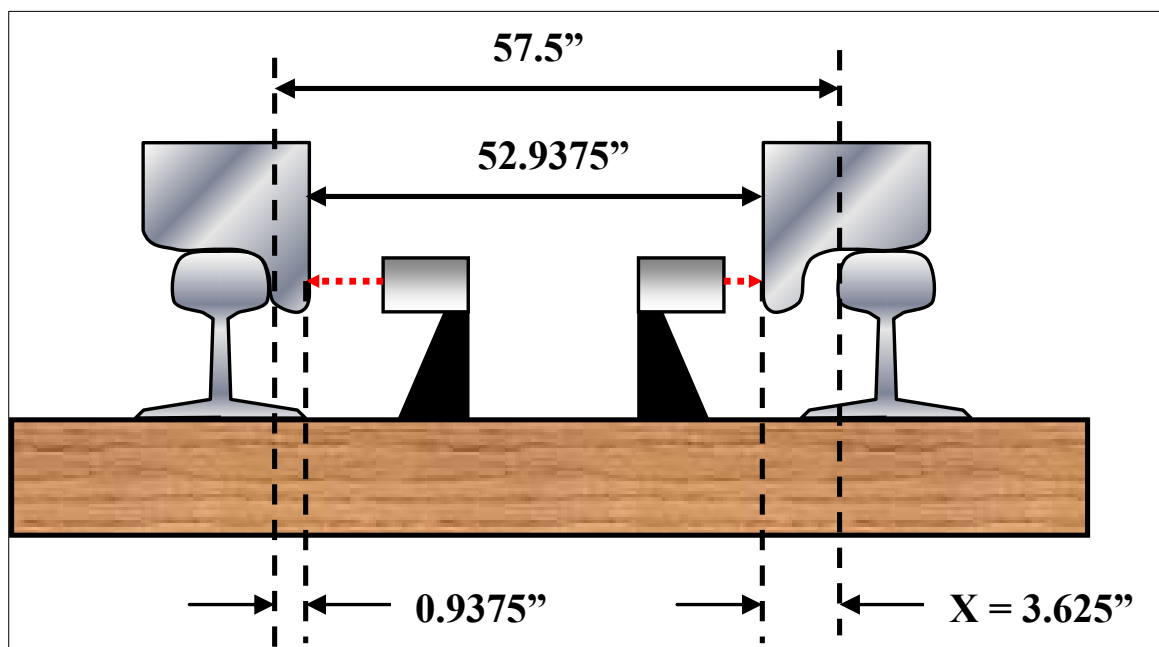
FIGURE 4 Minimum standoff distances for sensors.

The selected fiber-optic DMS had a measuring range of 2-inches with an additional 2-inches standoff distance. This meant that they could be mounted 4-inches away from the gage face of the rail. This mounting position provided at least 0.375-inches of clearance between the sensor head and the back of a passing wheel, a distance determined to be marginally adequate for continued exploration of the project concept.

Regarding reliability, discerning discussions with the manufacturer lead TTCI to believe that the sensors would function as required under the specified conditions for a long period of time.

4.1.5 Cost and Warranty

In order for the fiber-optic DMS to be implemented in a wayside truck hunting detection system, their cost must be such that the entire system can be realized at a reasonable expense. Since the number of sensors may be significant for the array, individual sensor cost becomes an important issue. The selected sensors were $1,400 each, and came with a 1-year warranty. This cost was only marginally reasonable due to the likely large array size, and TTCI thus deemed it appropriate to explore more cost effective means of implementing this DMS truck hunting detection approach.

4.2 SENSOR MOUNTING BRACKET DESIGN

To ensure the sensors in the installed array were reasonably safe, they needed to be located 0.5-inch below the top of the rail and 4-inches from the gage face of the rail, with no part of the system extending above the top of the rail. The sensor tip also required positioning so that it faced perpendicular to the surface of the rail in both the horizontal and vertical dimensions. To achieve these requirements, mounting brackets were designed to hold the fiber-optic sensor tip in the proper location.

The mounting brackets consisted of two pieces bolted together that held the fiber-optic sensor tip between them as shown in Figure 5(a). The fiber-optic sensor tip was held in place by tightening the self-locking nuts on the lower piece of the mounting bracket.

The bolts extended through a steel "C" bracket secured to the railroad tie as shown in Figure 5(b). The sensor position could be adjusted in or out of the mounting bracket to fine tune the exact position of the sensor in relation to the gage face of the rail. The 3-feet fiber-optic cable extended from the sensor tip to the amplifier, housed in a small enclosure mounted to the side of the tie.

(a)

(b)
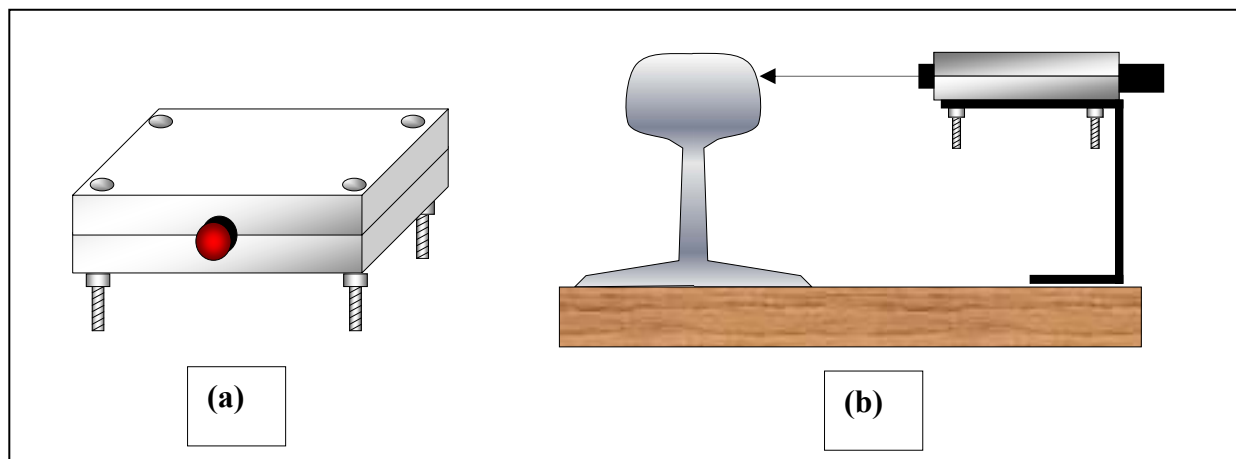
FIGURE 5 Sensor mounting bracket design.

Fabrication of the mounting brackets was not necessary to perform the Stage 1 tests. Fabrication of the mounting brackets was thus postponed until the beginning of Stage 2 of the project.

4.3 TEST PLAN

Following the selection of the fiber-optic DMS, a Stage 1 test plan was developed for investigating the sensors' capability to perform in the truck hunting detection application. The Stage 1 test plan (included as Appendix A) detailed the procedures for testing the sensors, as well as the test setups used and the purpose of each test. Test design discussions suggested that, in order for the sensors to be good candidates for truck hunting detectors, they needed to be able to do the following:

- Detect distances from rails of different but known reflectivity

- Detect distances from wheels of constantly varying and unknown reflectivity

The sensors' ability to perform the above was evaluated using the two tests described in the test plan and in Section 4.4.

4.4 TEST RESULTS

The tests detailed in the Stage 1 test plan were setup and performed in a laboratory of the Warehouse and Laboratory Facility (WLF) building located at the Transportation Technology Center (TTC), Pueblo, Colorado. Figure 6 shows the test setup with the fiber-optic sensor mounted so that it could be moved toward or away from an object of interest. Figure 6 also shows the fiber-optic sensor being calibrated against a reflecting mirror.
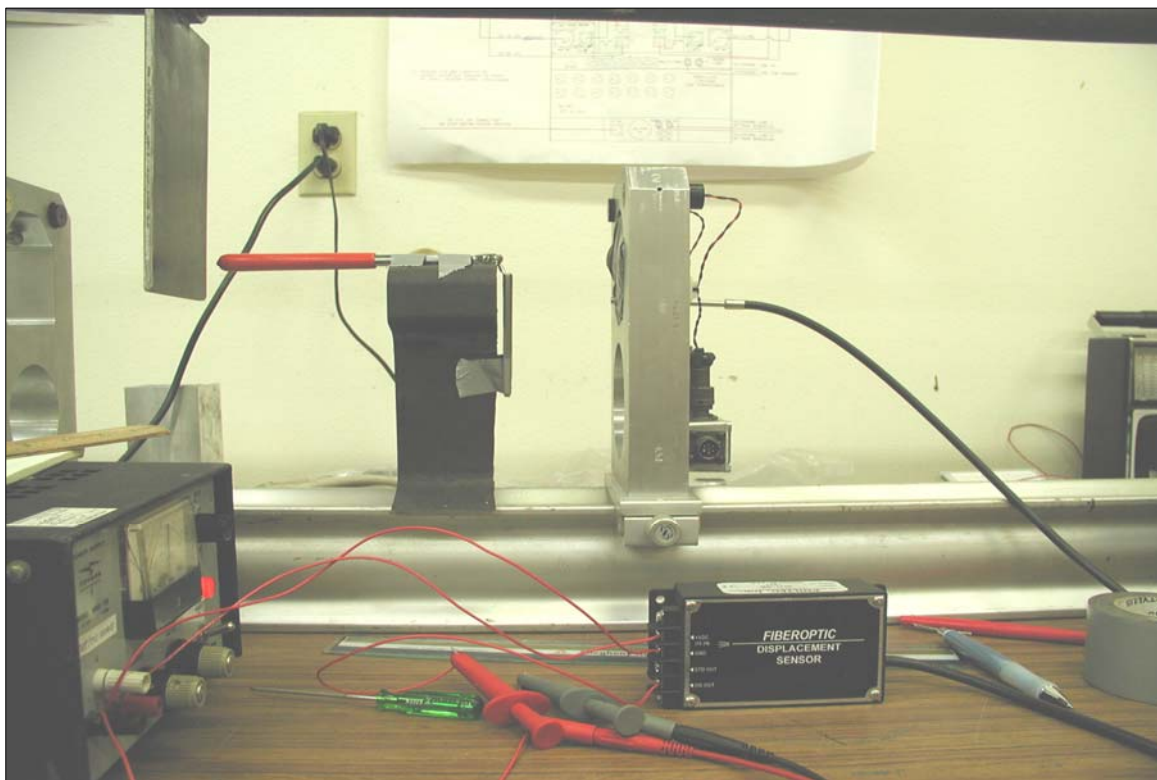
FIGURE 6 Laboratory test setup.

4.4.1 Constant Reflectivity Measurement Test

The purpose of this test was to determine whether the fiber-optic DMS could accurately determine distances from typical rail surfaces, regardless of their performance. Four different surface conditions were tested (ranging from a highly reflective mirror to very rusty and nearly non-reflective rail steel surfaces) to ensure that the sensors would operate properly even in the worst reflectivity conditions.

When running this test initially, calibrating the fiber-optic DMS was not possible on less reflective surfaces (shown in Figure 7) because the sensor gain could not be set high enough to compensate for the lack of reflectivity. To address this issue, the sensors were returned to the manufacturer for amplifier adjustments to allow for a wider range of gains.

FIGURE 7 Less reflective rail samples used in sensor tests.

Upon the return of the fiber-optic DMS, the test was repeated, and calibration curves were created from the data collected. Figures 8 and 9 show the calibration curves for sensors No. 1842 and No.1849 on a normal rail sample and a rusty rail sample, respectively. In general, the curves show an acceptable variation of output voltage versus measurement distance. However, because of the adjustments made by the manufacturer, the modified gain was too high for the sensors to be calibrated using highly reflective materials, such as the reflecting mirror and shiny rail steel. Since highly reflective surfaces are unlikely to consistently occur in a wayside environment, these gain adjustment limitations were judged not to be critical to successful system operation.
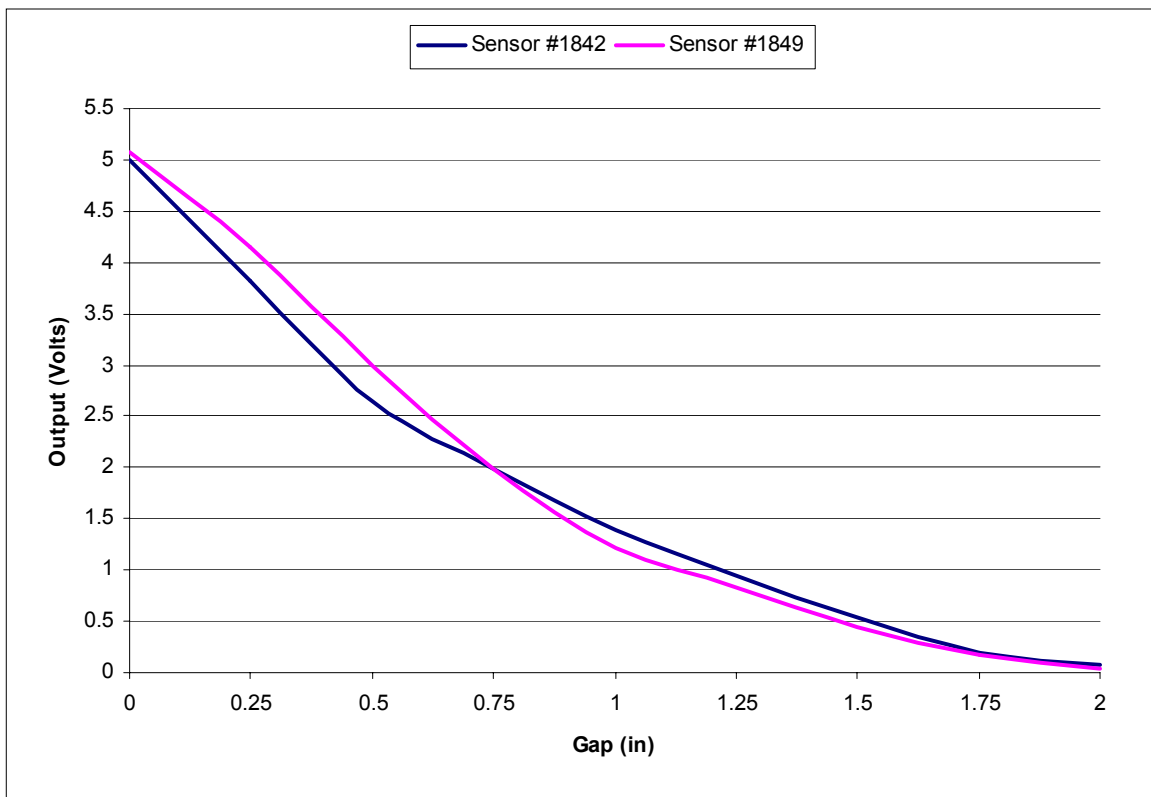
FIGURE 8 Calibration curves for a normal rail sample.
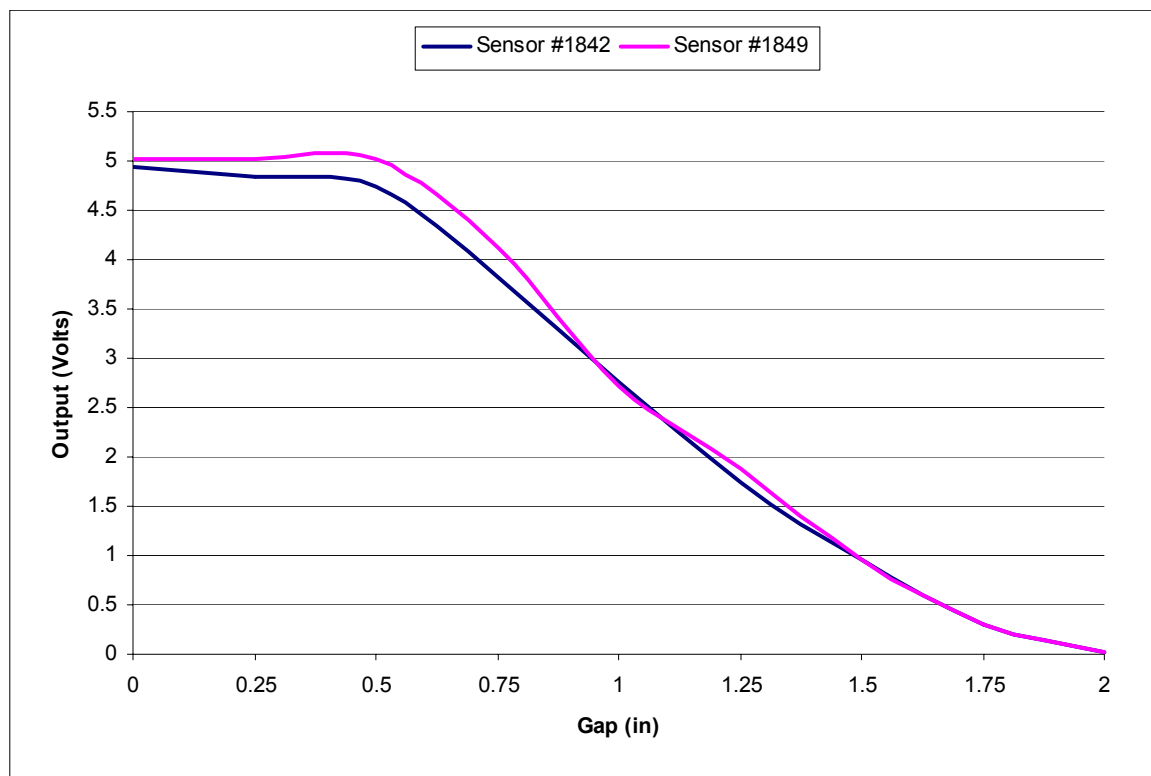
FIGURE 9 Calibration curves for a rusty rail sample.
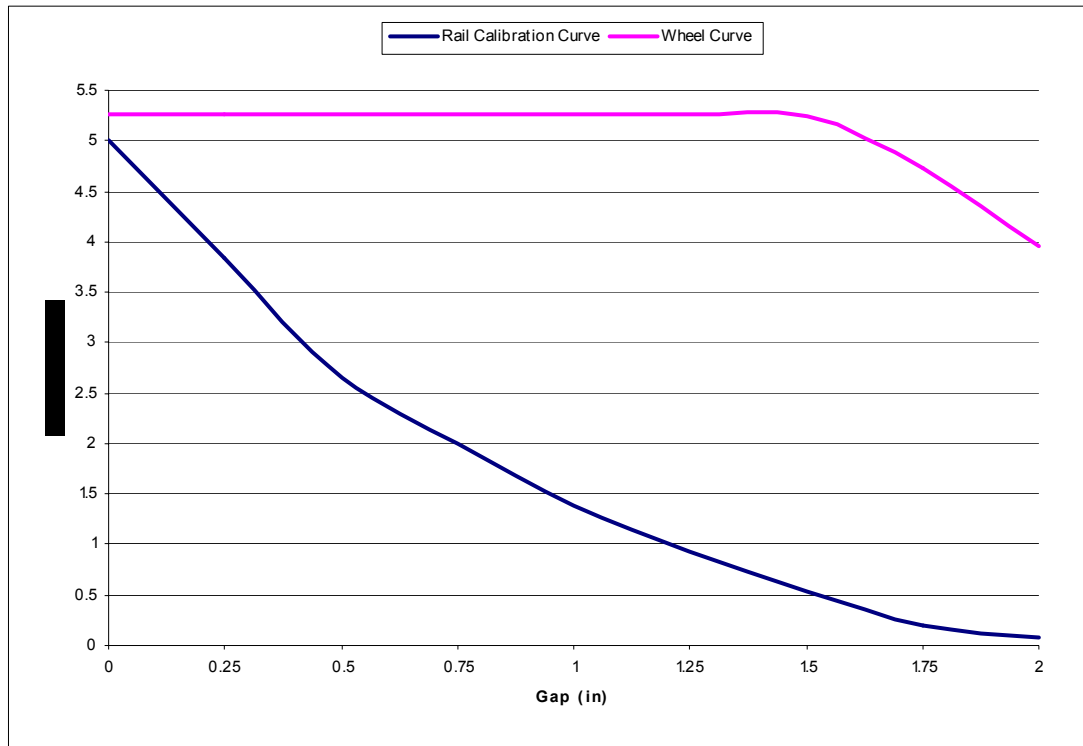
FIGURE 10 Wheel curve compared with rail calibration curve for the normal rail sample.

4.4.2 Varying Reflectivity Measurement Test

The purpose of this test was to determine the sensitivity of the fiber-optic DMS to the varying reflectivity of passing wheels. There was a concern that, if a passing wheel was of a different reflectivity than the rail the sensor was calibrated for, an inaccurate distance measurement would result. In order to test this, a sensor was first calibrated against a rail, and measurements were subsequently taken from a piece of wheel steel at varying distances. The output was then compared to the calibration curve for the rail to determine the accuracy of the measurements.

The results from this test for sensor No. 1842 are displayed graphically for a normal rail and a rusty rail in Figures 10 and 11, respectively. Displayed in the graphs are the calibration curves from the previous test compared with the curves created from the wheel steel sample. The results from sensor No. 1849 were similar, in that the measurement curve created from the wheel data was offset substantially from that of the rail curve. These results indicated the sensitivity of these fiber-optic DMS to changes in reflectivity. An important observation from this test was that the distances measured by these sensors were only accurate for surfaces with the same reflectivity as the surface for which the sensors were calibrated.

Because sensor measurement accuracy was so sensitive to reflectivity changes, a method of compensating for varying reflectivity was needed. Discussions with the manufacturer suggested a method of achieving this reflectivity compensation might have been possible. One proposed

approach was to use another sensor, not sensitive to distance, to determine the reflectivity of the measurement surface. In post measurement processing, the distance measurements would then have been adjusted to account for the reflectivity variations. An exploration of this modification's viability was initiated but was soon abandoned as Stage 2 proceeded in an alternative direction, as detailed in Section 5.
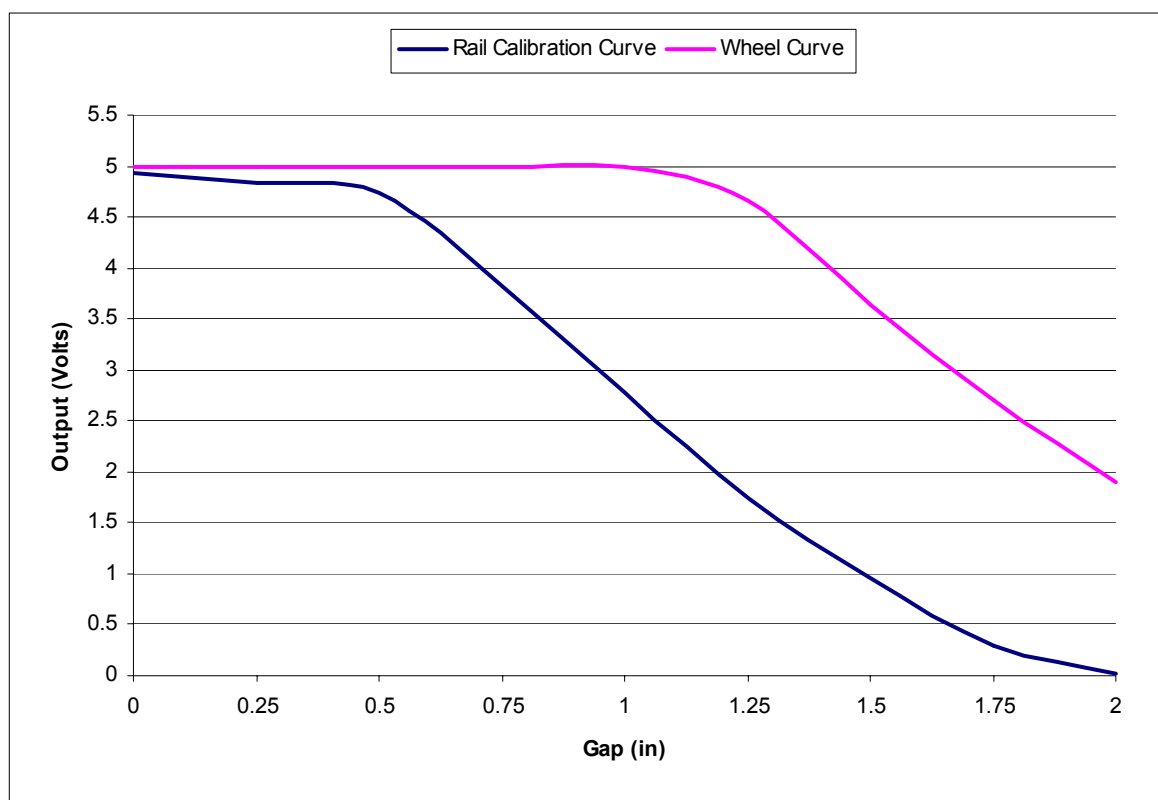
FIGURE 11 Wheel curve compared with rail calibration curve for the rusty rail sample.

4.5 EXPERT REVIEW OF STAGE 1

The expert panel review of Stage 1 of the System to Detect Truck Hunting on Freight Railroads project was held on May 3, 2004. Members of the expert panel included William Blevins, Chief Mechanical and Electrical Engineer for Canadian National Railway, as well as Curtis Urban and Darrell Iler, two of TTCI's most knowledgeable senior engineers concerning railroad vehicle dynamics including truck hunting.

The meeting consisted of a review of the project objectives and proposed approach, a description of the work completed during Stage 1 of the project, and a discussion of ideas and recommendations for Stage 2 of the project.

Several issues were discussed during the review of the proposed approach. One issue was that the fiber-optic DMS would not be placed back to back at the center of a railroad tie, as originally proposed, but rather separated with each sensor positioned closer to its rail. This change compensated for the maximum distance in the selected sensor's measurement field of view. Another issue discussed was the accuracy needed from the sensors in order to detect truck hunting. The panel agreed that a sensor with a measurement resolution of 0.1 mm was sufficient for this application. The final approach-related issue discussed was that of determining the optimum height of a sensor in relation to the top of its rail. Raising the height of a sensor to as close to the top of its rail as possible while still obtaining valid readings would minimize measurements along the curvature of the tip of the flange, improving the potential for measuring back-to-back distances. However, raising a sensor above the planned level may limit its survivability. It was agreed that further investigation of this issue would be requisite if these fiber-optic DMS were to be used in Stage 2.

The tests conducted to determine the feasibility of using the selected sensors were the next topic of discussion. Results of the first test showed these sensors could be calibrated to measure distances from surface textures representative of rail steel. However, there was some concern and discussion regarding the shallow slope of the calibration curves for the smaller distances measured by the sensors. It was agreed that further investigation to better determine the cause for the variation in response over the measurement range would be necessary if these fiber-optic DMS were to be used during Stage 2.

The results of the second test indicated that the selected fiber-optic DMS were too sensitive to changes in target reflectivity to perform well in this application. Due to the range of reflectivity in operational railroad wheels and rails, test measurements indicated these sensors would not have performed as needed without compensation for the changes in reflectivity. The expert panel stated that, if these sensors were to be used in Stage 2, additional testing would be required to resolve this reflectivity issue prior to purchasing any additional sensors for array testing.

A discussion of other truck hunting detection systems followed the description of the Stage 1 work completed. The Wheel Impact Load Detector (WILD) truck hunting detection upgrade was discussed first. A concern voiced about this method of truck hunting detection was that WILD sites are not necessarily located for optimum truck hunting detection.

Also discussed was a prototype truck hunting detection system developed by an Australian company known as Lynxrail. The Lynxrail prototype is based on an approach that uses inductive proximity DMS in an array along a section of tangent track, just like the arrayed fiber-optic DMS approach initially planned by TTCI for Stage 2.

The Lynxrail prototype was already demonstrated to effectively detect truck hunting during on-track testing at TTC in December of 2003, as described in Appendix B. The expert panel noted the fact that the prototype uses the same approach to detect truck hunting as the approach originally

planned by TTCI for Stage 2 investigation and hence provided this project with an excellent opportunity to test it and accelerate its availability for operational use. The only reservation expressed about the prototype was that the long-term survivability of the inductive proximity DMS had yet to be established.

Overall, the panel thought the existing maturity level and tested performance of the Lynxrail prototype, combined with it being based on the same detection approach as originally planned for the Stage 2 investigation, suggested that it would be more effective for TTCI to concentrate Stage 2 efforts on testing this prototype at a revenue service site, rather than to continue the investigation of the fiber-optic DMS approach.

TTCI submitted a Stage 1 Report to the Safety IDEA Program of the TRB in May of 2004.

5.0 INVESTIGATION (STAGE 2)

Due to the timing of the completion of Stage 1, there happened to be a revenue service site evaluation opportunity for Stage 2. In July of 2004, Norfolk Southern (NS), in conjunction with the Equipment and Operating Practices Research Division of the Office of Research and Development at the Federal Railroad Administration (FRA), conducted a comparative test of truck hunting detection systems as part of their ongoing cooperative agreement for wayside component inspection demonstrations. TTCI was allowed to participate in the evaluation using the Lynxrail prototype.

NS and the FRA used an instrumented test consist to compare the performance of three hunting detection systems installed at NS's integrated wayside detector site in Flat Rock, Kentucky, shown in Figure 12. The three systems evaluated were: Lynxrail's prototype system, Salient Systems' Wheel Impact Load Detector (WILD) – upgraded with lateral force measurements, and Wayside Inspection Devices' Truck/Bogie Optical Geometry Inspection (T/BOGI) system.

FIGURE 12 NS comparative test site for wayside detectors in Flat Rock, KY.

TTCI leveraged Safety IDEA project funding by taking advantage of an established prototype and by utilizing NS and FRA resources that provided the test consist and revenue service test site. Furthermore, TTCI remained consistent with Stage 2 objectives and the research plan of the current Safety IDEA project by continuing to evaluate the arrayed DMS hunting detection concept. The only refinement was the use of inductive proximity DMS instead of fiber-optic DMS, based on the Stage 1 findings.

5.1 PROTOTYPE INSTALLATION AND TEST PREPARATION

The first completed Stage 2 tasks were the installation of the Lynxrail prototype and the test train consist preparation at the NS integrated wayside detector site in Flat Rock, Kentucky.

5.1.1 Prototype Installation

Installation of the Lynxrail prototype was completed about a week prior to the actual NS and FRA test. TTCI and Lynxrail personnel assembled the array with the layout necessary to ensure proper system performance. The inductive proximity DMS were attached to non-conductive mounting blocks that were then adhered to the field side of the rails' webs, thereby providing a real advantage regarding system survivability.

Signals were transmitted over wiring from the sensors to a microprocessor trigger-box and then to another computer for processing, analysis, and data storage. Both the trigger-box and the other computer were housed in a temperature-controlled bungalow near the array of sensors.

After the installation, data was collected and superficially examined for accuracy over the course of the week leading up to the test. Just prior to the test, a walk-by check of the prototype was completed to ensure that the sensors were energizing correctly.

5.1.2 Test Car Selection

Ten rail vehicles comprised the test train consist: one NS locomotive, one NS research car, one NS box car, two NS covered hopper cars, one NS flat car, three NS gondola cars, and one TTX auto-rack. Of these 10 rail vehicles, five were instrumented at each end with accelerometers to measure carbody end lateral accelerations: the NS box car, one NS covered hopper car, the NS flat car, one NS gondola car, and the TTX auto-rack. These five cars were selected as known "hunters" and remained instrumented for the entire test. Data from the cars was collected using the NS research car.

5.1.3 Test Consist Assembly

On July 1, 2004, the test consist was operated with the following ordered assembly: the NS locomotive, the two un-instrumented NS gondolas, the un-instrumented NS covered hopper, the instrumented TTX auto-rack, the instrumented NS covered hopper, the instrumented NS box car, the instrumented NS gondola, the instrumented NS flat car, and the NS research car. On July 2, 2004, the NS locomotive pulled the test consist in the reverse order from the previous day.

5.2 TEST PLAN

Testing of the Lynxrail prototype was conducted over the mentioned two-day period. The instrumented consist was operated back and forth across NS's Flat Rock detector site at speeds ranging between 15- and 55-mph. Twelve recorded passes were completed over the two days of testing, as shown in Table 2.

TABLE 2 Recorded Test Train Consist Passes

Test Run	Date	Target Speed (mph)	Direction
1	July 1, 2004	50	North
2	July 1, 2004	35	North
3	July 1, 2004	45	North
4	July 1, 2004	50	North
5	July 2, 2004	50	South
6	July 2, 2004	20	North
7	July 2, 2004	45	South
8	July 2, 2004	20	North
9	July 2, 2004	40	South
10	July 2, 2004	20	North
11	July 2, 2004	35	South
12	July 2, 2004	20	North

The 20-mph runs represent consist push-backs by the locomotive through the wayside test zone to ready for subsequent speed runs. These were recorded on July 2, 2004, to judge wayside performance when a train passed by at a lower, non-hunting speed. On July 1, 2004, the consist was also pushed back between each speed run but was usually stopped while traveling through the wayside test zone, effectively invalidating any data collected at that time. Hence there are no recorded 20-mph runs in the southern direction on July 1, 2004.

On many test runs, TTCI noted visible hunting behavior and confirmed its appearance within the Lynxrail prototype data. Over the two-day test, TTCI also observed and reported that all parties present, namely the FRA, NS, TTCI, and Lynxrail, agreed that testing was completed fairly and according to plan.

5.3 TEST RESULTS

The data collected during prototype testing was analyzed using a simple, standard statistical technique. Sample correlation coefficients were calculated to examine relationships between prototype-measured speed and onboard-measured speed and between prototype-measured root-mean-square (RMS) lateral acceleration and onboard-measured RMS lateral acceleration.

It was important to verify that the Lynxrail prototype measured car speed correctly. As viewed in Figure 13, the test data revealed an almost exact match between Lynxrail measured speed and onboard measured speed. One comparison of such a paired collection utilized the sample correlation coefficient (R), which measures the degree of linear relationship between the two variable quantities. For the speed data, an R of 0.9999 expressed a near-perfect, positive linear relationship between the two measured speeds. An R of 1.0 would have occurred only if all data pairs would have lain on a straight line with a positive slope. Looking again at Figure 13, it is apparent that the alleged straight line would have been y = x. In other words, the Lynxrail prototype's indicated speed almost exactly equaled onboard speed, as anticipated.

The Lynxrail prototype also estimated the RMS of lateral accelerations experienced by each carbody end while traveling through the array of inductive proximity sensors. This RMS quantity was also independently calculated for each carbody end using onboard accelerometer data and a comparison between these values was made.

Using the onboard accelerometer data, NS calculated two RMS lateral acceleration values for each carbody end – one from a 2,000-foot window and one from a 300-foot window. Ultimately, NS and TTCI elected to use the narrower 300-foot window for comparison, which represented the specific time-period each carbody end passed through the wayside test zone. Comparing Lynxrail's RMS lateral acceleration estimates with these latter RMS lateral acceleration estimates, an R of 0.9499 was interpreted as revealing a strong, positive linear relationship between the on-board and wayside data, as apparent in Figure 14. In other words, an increase in Lynxrail's estimated RMS lateral acceleration corresponded quite linearly with an increase in onboard accelerometer RMS lateral acceleration.
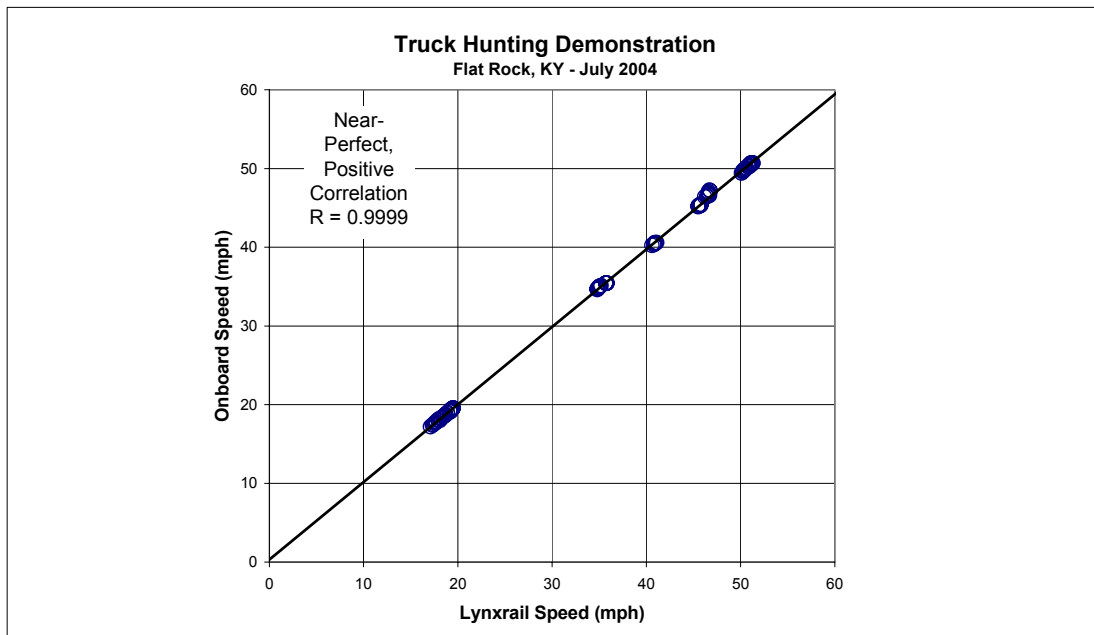
FIGURE 13 Lynxrail speed compared to onboard speed.
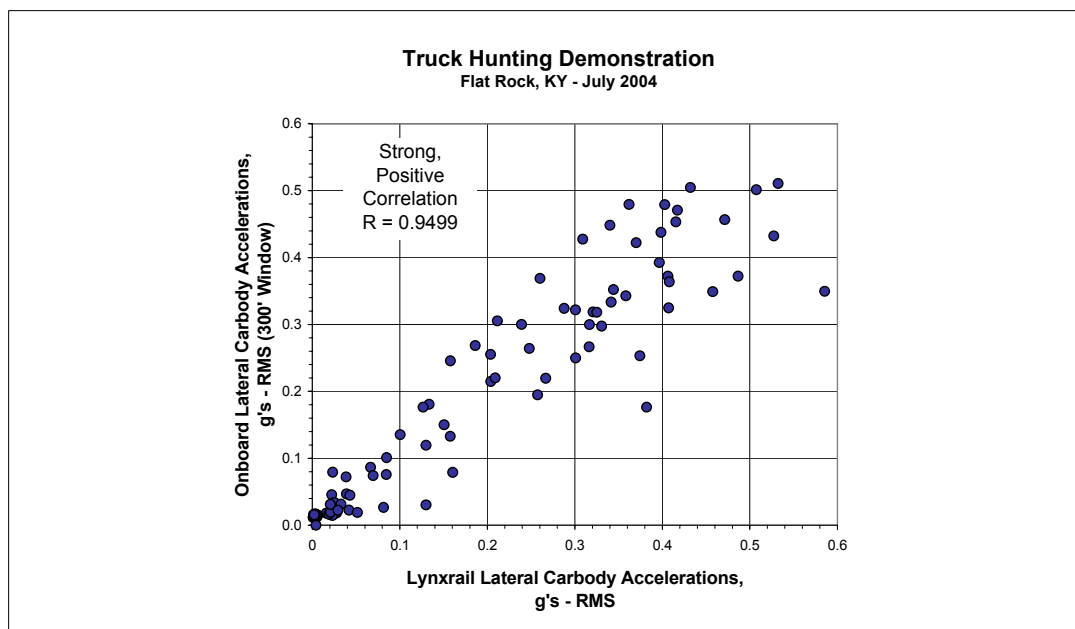
FIGURE 14 Lynxrail RMS lateral acceleration compared to onboard RMS lateral acceleration.

Graphical comparisons between the onboard and Lynxrail RMS lateral acceleration data for all tested speeds were examined for each instrumented carbody end of the test consist. For some carbody ends, the data was rather harmonious for most speeds, whereas for other carbody ends and typically for higher speeds, there was considerable overestimation or underestimation of several

21

onboard RMS lateral accelerations by Lynxrail RMS lateral acceleration estimates. Figures 15 and 16 provided examples of these mainly congruous and incongruous observations, respectively.
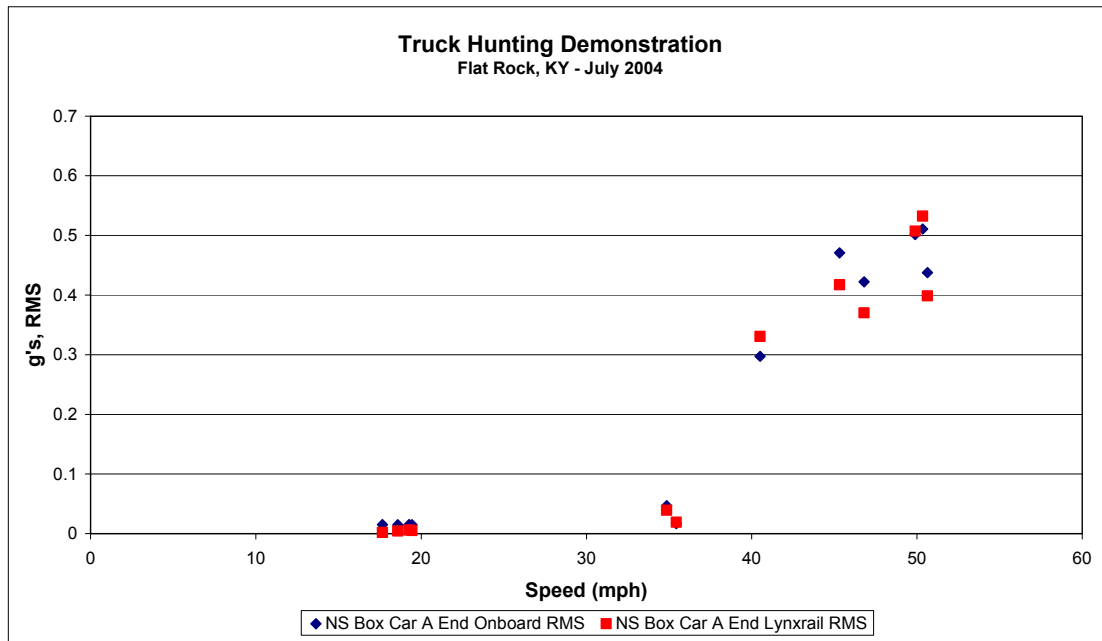
FIGURE 15 Reasonable agreement between most RMS lateral acceleration data.

In all cases, it was noted that the more substantial discrepancies between RMS lateral acceleration data appeared at higher speeds. Furthermore, increasing variability between RMS lateral acceleration data was observed with increasing speed, as depicted in Figure 17 via a scatter plot of differences between RMS lateral acceleration data against their corresponding operating speeds.
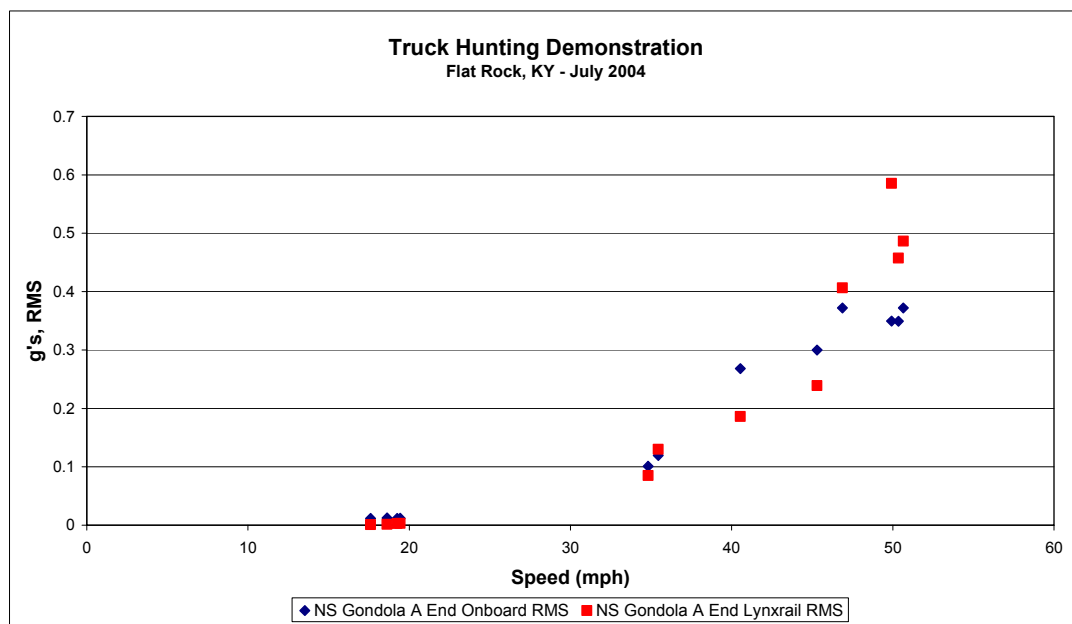
FIGURE 16 Considerable disagreement between several RMS lateral acceleration data.
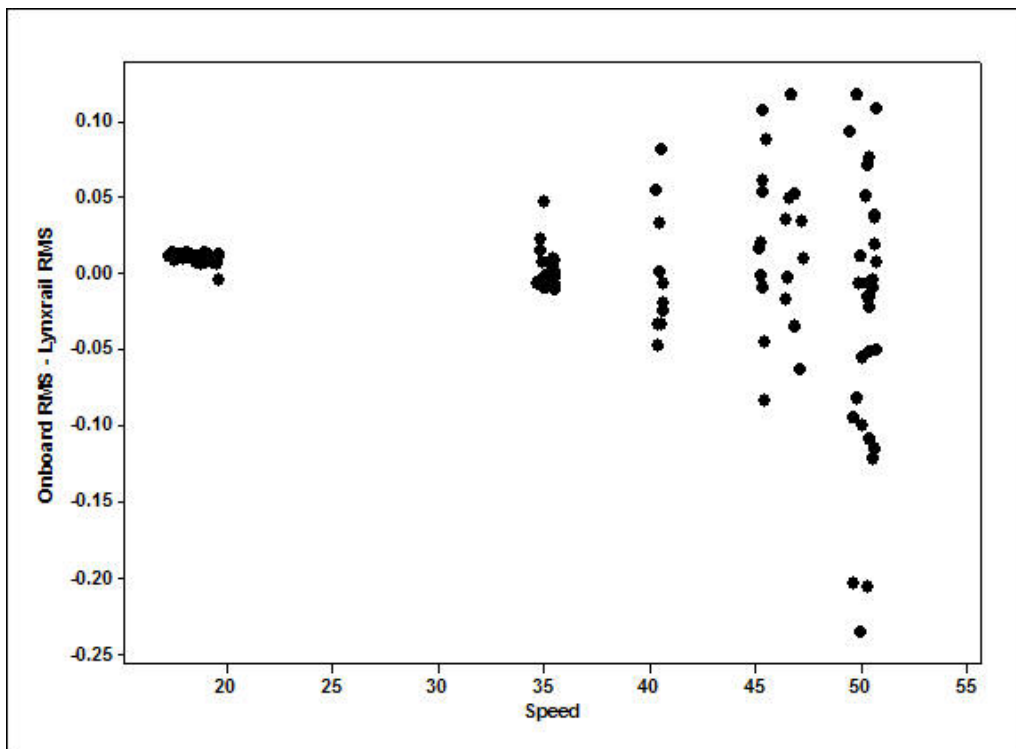
FIGURE 17 Scatter plot of RMS lateral acceleration difference versus speed.

5.4 EXPERT REVIEW OF STAGE 2

The expert panel review of Stage 2 activities of the System to Detect Truck Hunting on Freight Railroads project was held on February 3, 2005. Members of the expert panel included Scott Keegan, Senior Engineering Specialist within the Research and Tests Department of NS, as well as Curtis Urban and Scott Cummings, two of TTCI's most knowledgeable senior engineers concerning railroad vehicle dynamics including truck hunting. Darrell Iler, another knowledgeable senior engineer at TTCI, also sat in as an observer.

The meeting consisted of a review of the project objectives and proposed system, descriptive summaries of the investigative approach used and of the work completed during Stage 2, and a discussion of ideas and recommendations for the final stage of the project.

Richard Morgan, the Principal Investigator of the project, gave a presentation which recapped the overall project goals and recounted Stage 1 efforts and conclusions, bringing the understanding of the expert panel to the onset of Stage 2. A summary of Stage 2 test details was given, and also highlighted was the fact that the Lynxrail prototype utilized data from approximately 65-feet worth of rail for derivation of its estimates while the smallest rail window used for onboard data was 300-feet.

Figures 13, 14, 15, 16, and 17 were examined. Figures 13 and 14 revealed high, positive correlations between onboard and Lynxrail speed as well as between onboard and Lynxrail RMS

lateral acceleration data. Figures 15 and 16 illustrated for specific carbody ends how onboard and Lynxrail RMS lateral acceleration data compared at the different tested speeds. Figure 17 depicted how the variability between onboard and Lynxrail RMS lateral acceleration data increased with increasing speed.

Several topics were discussed following the presentation, namely:

- An unanswered question of how the Lynxrail prototype addressed hard-flanging of the wheelsets against the rails, and a recommendation that it should have done so if it did not already

- Concerns about the safety and adaptability of the Lynxrail prototype as a worthwhile product for the railroad industry, to which Richard Morgan answered that he would address these reinforcement issues with Lynxrail in the near future

- Concerns about Lynxrail's RMS lateral acceleration under and overestimates, and their implications

- A counter perspective that RMS lateral acceleration discrepancies might be based largely on the disparity between the onboard and Lynxrail data windows

- Identification of two, not necessarily corresponding, thresholds that railroads consider when reviewing hunting detection data – i.e., safety and lading damage

- A comment that it would be desirable, but not absolutely necessary, to see and compare the raw data from the different data windows

- A general consensus that the Lynxrail prototype appeared to validate the DMS-based hunting detection concept

Overall, the expert panel was comfortable with the results obtained from the Stage 2 efforts, and it did not require that further testing be conducted. The panel recognized the inherent difficulties associated with a comparison between onboard and wayside carbody end measurements, especially given the disparity between the data windows. Despite these difficulties, the panel thought the Lynxrail prototype performed reasonably well. Curt Urban did, however, recommend that Lynxrail remedy its RMS lateral acceleration overestimation. After the expert panel review had concluded, Scott Cummings remarked that it would be interesting to observe the performance of the Lynxrail prototype at speeds higher than those tested, even up to the 79-mph limit.

TTCI submitted a Stage 2 Report to the Safety IDEA Program of the TRB in March of 2005.

6.0 PLANS FOR IMPLEMENTATION

The Lynxrail prototype performed reasonably well when compared with onboard data. Additionally, the prototype performed comparably to the other systems evaluated at the NS/FRA hunting test in July of 2004, according to an NS presentation at the Wheel/Rail Interaction Conference at Chicago in May of 2005.

In the interim between the end of testing and the production of this report, Lynxrail completed several prototype enhancements needed to better support the operations of the North American railroad industry. These enhancements include: incorporation of Automatic Equipment Identification (AEI) interface capabilities, ruggedization of track-mounted system components, and protection of all system components so they can successfully function in all North American climates. Furthermore, the data from this evaluation was provided to Lynxrail, who was encouraged to continue optimizing its algorithms for improved detector performance at higher vehicle speeds. The Lynxrail system, now sufficiently mature, has been offered in several proposals to North American freight railroads. If desired, the Lynxrail system could equally serve to detect hunting for passenger railroads as well.

7.0 CONCLUSIONS

7.1 STAGE 1 RESULTS AND FINDINGS

The Stage 1 tests discussed in this report were conducted to determine the feasibility of using fiber-optic DMS in a wayside environment for detecting railroad car truck hunting.

The two tests revealed the likelihood of the fiber-optic DMS accurately determining distances from rail and wheel steel typically seen in the railroad environment. Results of the first test demonstrated that the sensors could be calibrated for nearly any surface, with corresponding sensor gain adjustments made by the manufacturer for less reflective surfaces. However, with such adjustments, the modified gain became too high for the sensors to calibrate correctly off of highly reflective materials. Since highly reflective surfaces are unlikely to consistently occur in a wayside environment, these gain adjustment limitations were judged not to be critical to successful system operation.

Results of the second test showed that the sensors were overly sensitive to surface reflectivity variations. Because many wheels passing through the measurement zone would likely have a different reflectivity than that of the rail (due to oil, grease, track induced wear, and rust), these sensors would not accurately measure lateral displacements of all passing wheels. According to the manufacturer, the possibility existed that a compensation scheme could be developed to improve the performance of the sensor. However, the level of development effort was not quantified, and the difficulty and associated costs were unknown.

The results of the Stage 1 experiments cast doubt upon the utility of a fiber-optic DMS array for railroad car truck hunting detection. However, earlier and successful testing by TTCI of an alternative, Lynxrail developed, DMS-based truck hunting detection prototype provided confidence that the underlying DMS methodology was, in fact, a valid one for determining truck hunting in a wayside environment.

An expert review panel considered the existing maturity level and tested performance of the Lynxrail prototype, in combination with the fact that it was based on the same underlying DMS methodology as originally planned for Stage 2 investigation, and recommended that it would be more effective for TTCI to concentrate Stage 2 efforts on testing this prototype at a revenue service site, rather than continue the investigation of the fiber-optic DMS approach.

7.2 STAGE 2 RESULTS AND FINDINGS

The Stage 2 field tests discussed in this report were conducted to determine the feasibility of using an array of paired DMS in a wayside environment to detect railroad car truck hunting. The Stage 2 efforts were guided by the recommendation of an expert review panel, made during the review of

Stage 1 findings, and resulted in an evaluation of Lynxrail's DMS-based truck hunting detection prototype.

The Stage 2 test results indicated that the Lynxrail prototype provided estimates of speed and RMS of carbody end lateral accelerations that were highly, positively correlated with those measured by onboard instrumentation. These results validated the concept of truck hunting detection via an array of paired DMS; however, variability in the Lynxrail prototype estimates of RMS lateral accelerations, especially at higher vehicle operating speeds, was observed in the test data.

7.3 IMPLEMENTATION

The Lynxrail prototype performed reasonably well when compared with onboard data. Additionally, the prototype performed comparably to the other systems evaluated at the NS/FRA hunting test in July of 2004, according to an NS presentation at the Wheel/Rail Interaction Conference at Chicago in May of 2005.

In the interim between the end of testing and the production of this report, Lynxrail completed several prototype enhancements needed to better support the operations of the North American railroad industry. These enhancements include: incorporation of AEI interface capabilities, ruggedization of track-mounted system components, and protection of all system components so they can successfully function in all North American climates. Furthermore, the data from this evaluation was provided to Lynxrail, who was encouraged to continue optimizing its algorithms for improved detector performance at higher vehicle speeds. The Lynxrail system, now sufficiently mature, has been offered in several proposals to North American freight railroads. If desired, the Lynxrail system could equally serve to detect hunting for passenger railroads as well.

8.0 INVESTIGATOR PROFILE

Richard Morgan
Principal Investigator
Transportation Technology Center, Inc.
55500 D.O.T. Road
P.O. Box 11130
Pueblo, Colorado 81001
Ph: (719) 584-0654
Fax: (719) 584-0770
richard_morgan@ttci.aar.com

FIBER OPTIC TRUCK HUNTING DETECTION STAGE 1 TEST PLAN

PURPOSE:

To determine the feasibility of using selected fiber-optic displacement measurement sensors (DMS) to detect railroad car truck hunting. The following tests are to be completed on a single pair of sensors prior to Stage 2 on-track testing.

CONSTANT REFLECTIVITY MEASUREMENT TEST:

PURPOSE:

To determine the ability of the fiber-optic DMS to accurately detect distances from rails of varying reflectivity

TEST SETUP:

Set up one fiber-optic sensor to collect measurements from the gage side of a rail sample. Attach a voltmeter to the OG output of the sensor. A reflecting mirror and three rail samples with reflectivity ranging from brand new to very rusty will be used during the test.

TEST PROCEDURE:

1.   Calibrate one fiber-optic sensor

     a.   Place the mirror at a 4-inch gap from the sensor and adjust the OFFSET until the output reads 0.0 Volts (V)

     b.   Move the mirror to a 2-inch gap from the sensor and adjust the CAL until the output reads 5.0 V

2.   Move the fiber-optic sensor from a 2-inch gap to a 4-inch gap in 0.25-inch increments and collect data over this range to determine a calibration curve for the sensor

3.   Repeat (1) and (2) with the three rail samples

4.   Repeat (1), (2), and (3) with the other fiber-optic sensor

5.   Create calibration curves from the data collected

VARYING REFLECTIVITY MEASUREMENT TEST:

PURPOSE:

To determine the accuracy of the fiber-optic DMS when measuring distances to wheels with different reflectivity than that of the rail to which the sensors are calibrated.

TEST SETUP:\

Set up one fiber-optic DMS to collect measurements from the gage side of a rail sample. Attach a voltmeter to the OG output of the sensor. Setup a piece of wheel steel to be placed between the sensor and the rail sample.

TEST PROCEDURE:

1. Calibrate one fiber-optic sensor

   a. Place the sensor at a 4-inch gap from the rusty rail sample and adjust the OFFSET until the output reads 0.0 V

   b. Move the sensor to a 2-inch gap from the rusty rail sample and adjust the CAL until the output reads 5.0 V

2. Place the sensor at a 2-inch gap from the wheel steel sample

3. Move the fiber-optic sensor from a 2-inch gap to a 4-inch gap in 0.25-inch increments and collect data over this range

4. Repeat (1), (2), and (3) for the other rail samples

5. Repeat (1), (2), (3), and (4) for the other fiber-optic sensor

6. Create curves from the data collected, and compare with the calibration curves to determine accuracy of measurements

LYNXRAIL TRUCK HUNTING DETECTION TEST RESULTS
(On-track Testing at TTC in December of 2003)

Lynxrail of Perth, Australia, has developed a wayside prototype that uses an array of inductive proximity displacement measurement sensors (DMS) to establish wheel position through a designated zone in an attempt to determine truck hunting tendencies. A test was conducted to evaluate the effectiveness of the Lynxrail wayside prototype in identifying a car that is in an active hunting mode.

TTCI conducted the test of the Lynxrail prototype on the Railroad Test Track (RTT) in December of 2003. The RTT is a 13.5 mile closed loop of Class VIII track on concrete ties. The test was conducted in a tangent section of the loop. A car with known hunting tendencies was instrumented and run at various speeds through a test zone. Data from the instrumented car was collected and compared to data from the Lynxrail wayside prototype.

The data from the instrumented car includes the lateral wheel displacement amplitude of each axle as well as the frequency of motion at various speeds. Data from the instrumented car is displayed in Figures B1 and B2. The data shows high amplitude lateral wheel displacement combined with typical truck hunting frequencies at speeds greater than 30 mph.
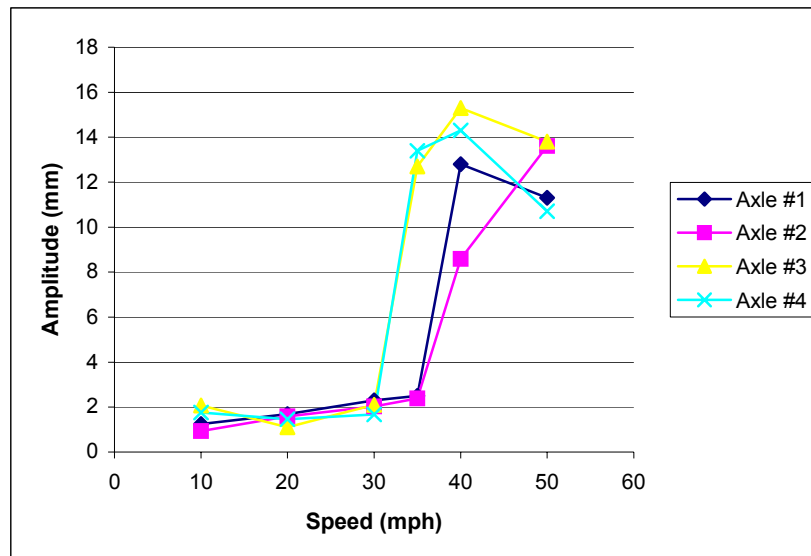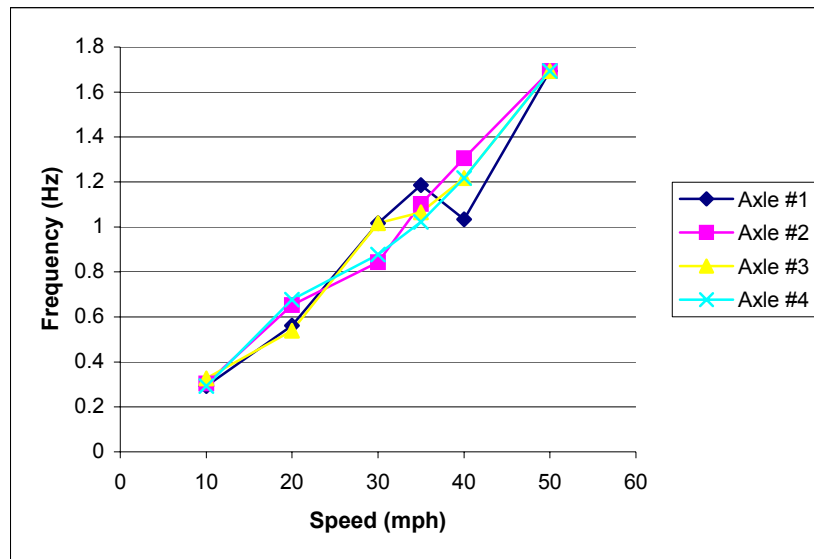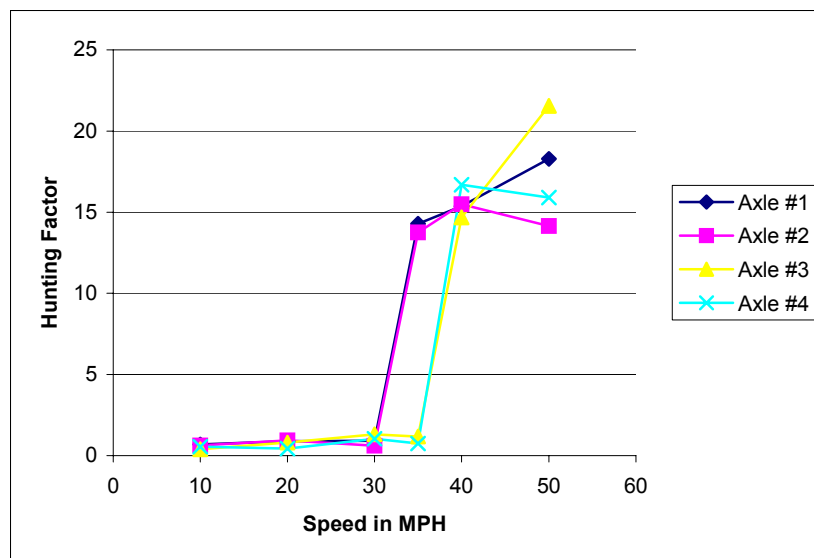

FIGURE B1 Instrumented railroad car lateral wheel displacement.

FIGURE B2 Instrumented railroad car frequency for each axle at varying speeds.

One way that data from the Lynxrail prototype is presented is as a "Hunting Factor," which is a calculated value based on a truck's hunting characteristics. A Hunting Factor between 5 and 10 indicates a truck with mild hunting tendencies. A Hunting Factor between 10 and 15 indicates a truck with moderate to severe hunting. A Hunting Factor above 15 describes a vehicle exhibiting extreme truck hunting tendencies. The data from the Lynxrail prototype, shown in Figure B3, reveals the railroad car experiencing truck hunting at speeds above 30 mph, in agreement with the onboard results above.

FIGURE B3 Instrumented railroad car Hunting Factor for each axle at varying speeds.