ENSCO PUB. NO. DOT-FR-99-08

EVALUATION OF A TOP-OF-RAIL LUBRICATION SYSTEM

August 1999

Sponsored by:

Federal Railroad Administration
Office of Research and Development
Washington, DC

U.S. Department of Energy
Washington, DC

CSX Transportation

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U.S. Department
of Transportation
Federal Railroad
Administration

EVALUATION OF A TOP-OF-RAIL LUBRICATION SYSTEM

Office of Research and
Development
Washington, DC 20590

DOT/FRA/ORD-__-__

August 1999
Final Report

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
August 1999

3. REPORT TYPE AND DATES COVERED
Final Report
February 1998 – August 1999

4. TITLE AND SUBTITLE
EVALUATION OF A TOP-OF-RAIL LUBRICATION SYSTEM

5. FUNDING NUMBERS
DTFR 53-96-C-00001

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ENSCO, Inc.
Applied Technology and Engineering Division
5400 Port Royal Road
Springfield, VA 22151

8. PERFORMING ORGANIZATION REPORT NUMBER
ENSCO-DOT-FR-99-08

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-__/__

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report documents the testing of a top of the rail lubricant applied in computer-controlled quantities. This system, the SENTRAEN 2000™, was developed by Tranergy. The testing was carried out over CSXT operated track between Corbin, KY and Cartersville, GA on various train runs from February 15, 1999 to March 4, 1999. These tests, sponsored by FRA, DOE, and CSXT, were conducted to assess the use of the top of rail lubrication system in normal operating conditions.

The report describes the test criteria used to evaluate the performance of the top of the rail lubricating system, the instrumentation used, the test locations, and the track conditions. Results are presented from tests conducted on CSXT's Stilesboro's 90 car coal trains. The significance of the results is discussed. Conclusions and recommendations are presented.

14. SUBJECT TERMS
Top of Rail (TOR) Lubrication, Effect of TOR Lubricant on Train Handling and Speed Control
Effect of TOR Lubricant on Braking, Stop Distance, Wheel Slip, Lateral Curving Forces
Safety, Energy Savings

15. NUMBER OF PAGES
116

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	Unclassified

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI/NISO Std. Z39-18
298-102

ENGLISH/METRIC CONVERSION FACTORS

(ENGLISH UNITS TO METRIC UNITS)

LENGTH

1 inch (in) = 2.54 centimeters (cm)
1 foot (ft)=30.48 centimeters (cm)
1 mile (mi) = 1.61 kilometers (km)

SPEED

1 mile/hour (mph) = 1.61 kilometers/hour (kph)

MASS – WEIGHT

1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds = 0.9 tonne/metric ton (t)

FORCE

1 pound (lbf) = 4.45 Newtons (N)

PRESSURE

1 pound/square inch (psi) = 6,894.8 Newtons/square meter (Pa)

VOLUME

1 gallon (gal) = 3.78 liters (l)

TEMPERATURE

[(x-32)(5/9)] °F = y °C

POWER RELATED

1 kilowatt-hour (kW-Hr) = 3.60 x 10^6 Joules (J)

EVALUATION OF A TOP OF RAIL LUBRICATION SYSTEM

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EXECUTIVE SUMMARY

Background

In pursuit of a common goal of reducing transportation energy consumption, the Federal Railroad Administration (FRA) and the United States Department of Energy (DOE) have sponsored evaluations of top-of-rail lubrication systems. These systems apply a consumable lubricant to the top of both rails behind the last locomotive axle to lower the wheel to rail friction of the following cars, thus reducing the energy needed to pull the train. To ensure that locomotive traction of following trains is not adversely affected, the lubricant is applied in controlled quantities and is designed to be used up (or consumed) as the train passes.

This report documents field tests of the SENTRAEN 2000 top-of-rail (TOR) lubrication system. The testing was jointly sponsored by the FRA's Office of Research and Development, CSX Transportation (CSXT), and Tranergy Corporation – the TOR developer. The tests were conducted in revenue service on a 243-mile segment of CSXT track containing a high percentage of moderate to steep grades and curves with a wide range of curvature. CSXT, Tranergy, and ENSCO (under contract from the FRA) designed the tests and analyzed the data.

Objectives

The objective of this investigation was to conduct further tests of the TOR lubrication system in field service under the full range of train operating conditions, and possible system operating conditions, with respect to the following issues:

- Safety Related Issues
  - The effect of the lubrication system on train handling/speed control;
  - The effect of the lubrication system on braking, including stop distance and wheel slip;
  - The distribution of lubricant under the train, including the amount of lubricant remaining on the rails following a train passage and its influence on subsequent traffic;
  - The effect of the lubrication on the lateral curving forces.

- Performance Related Issues
  - The energy savings that can be expected from the use of the system for a range of typical trains in freight service;
  - The effect of the lubricant on the critical speed for truck hunting.

Test Description

Train operation parameters were measured for both lubricated and unlubricated movements of CSXT's Stilesboro's 90 car coal trains between Corbin, KY, and Cartersville, GA. The consist traversed the test zone at typical operating speeds during the test with instructions being given to the engineers to avoid using special handling practices for the duration of the test.

The amount of fuel consumed and the electrical output of the locomotive's generators were recorded for the lubricated and unlubricated trips. Mechanical energy was determined by considering force measurements made with an instrumented drawbar. Electrical and mechanical energy requirements were assessed in order to provide a point of comparison for fuel consumption measurements. Measurement of the electrical energy is an accurate means to determine the energy requirements associated with the movement of the train. Mechanical energy measurements do not accurately capture energy expenditures during initial movements of the train where friction, gravity and slack "take-up" can contribute significantly, but do provide for data of interest in situations such as pulling a consist up an incline.

In addition to energy measurement, lateral and vertical forces were considered in one curve, of approximately 6 degrees, at locations within the body and spiral of the curve. Tribometer readings were made at several locations prior to and after train passage for comparison of coefficient of friction measurements to determine the extent of lubrication remaining after train passage. Stop distance tests were conducted under lubricated and unlubricated conditions as traffic conditions permitted. Full service and emergency brake applications were employed for these tests.

The "dry", or unlubricated, rail condition was considered as a case where the TOR lubrication was not in use. Throughout the test effort, both wayside lubrication devices and wheel flange lubricators were fully operational. Of the three locomotives within the consist, the lead and the middle locomotives were applying flange lubricant continually in all tests. The trailing locomotive was equipped with SENTRAEN 2000™ system, which applied lubricant from the trailing end only during tests designated as lubricated tests. *Differences in performance of the test train between the lubricated and unlubricated test runs were thus measured as a percentage above the levels obtained by using wayside and flange lubrication.*

The test zone was divided into twelve segments. This was done in order to aid in the analysis of the results - if results were compromised by weather conditions or train handling, the data from the affected segment could be disregarded without compromising results recorded in other segments. The end points of each of the segments were chosen such that the individual segments of the test zone had uniform terrain and similar track features.

Results and Conclusions

Observations made during the tests and analyses of the test data lead to the following conclusions:

- *Train Handling*: The use of the TOR system did not appear to negatively affect either train handling or speed control. This was evidenced by consideration of the average speeds, notch dwell times and the number of throttle position changes through comparable test zone segments. Testimonials from personnel associated with the test confirm this finding. The locomotive road foreman in charge of the tests reported that he liked the system due to improved train handling, including a smoother ride.

- *Braking Performance*: Braking performance was found to be safe for the lubricant rate employed during this series of tests. Stopping distances were approximately the same for lubricated and unlubricated rail conditions for full service and emergency braking of loaded and empty trains. This was evidenced by measured distances as well as the same distances corrected for grade and power application. Full service brake applications showed a decrease in stopping distance when employing the TOR lubrication, with average reductions on the order of 200 feet. It should be emphasized that these particular results pertain to these tests and that reductions of this magnitude are not necessarily universal. There was no occurrence of wheel slip during any of the thirteen (13) braking tests conducted.

- *Lubricant Distribution and Consumption*: Results from top of rail tribometer surveys were mixed, with some surveys showing no change in friction coefficients measured on the rail following the passage of the test train and some showing a decrease in measured friction coefficients. On a few occasions, a thin film could be felt by touch of a finger on the rail head after the test train had passed.

While several decreases of friction coefficient, ranging between 0.03 and 0.30, were measured during the surveys, friction coefficient measurements made at the designated curve location revealed no significant difference between the changes in friction due to the passage of normal revenue trains and changes in friction corresponding to the passage of the test train employing the lubrication system. Based on measurements made at the curve site that focused on normal revenue service trains, average friction coefficient measurements ranged between 0.37 and 0.56 before the train passage and between 0.21 and 0.48 after train passage. In comparison, measurements made at the same location for trains employing TOR lubricant ranged between 0.31 and 0.51 before the passage of the trains and between 0.27 and 0.45 after the passage of the trains. Engineers operating pusher locomotives used for the fifteen mile 1% grade found the operation of the locomotives to be quite normal when assisting the test trains using the TOR lubricant. Subsequent trains did not report anything unusual throughout the test zone; however, systematic reports from subsequent trains were not gathered.

- *Energy Savings*: Performance related issues focused largely on energy expenditures with savings being determined using a variety of methods. Energy savings for a round trip of the test train ranged from 4.20 % to 11.11 %, depending on the method of evaluation used. The average energy savings for a round trip, found by averaging the results from different methods, was determined to be 7.83 %. There was a 7.74 % savings in fuel consumption realized when results from comparable test segments were combined for a round trip (i.e. by disregarding results from segments where the train was operated in significantly different manners). It should be kept in mind that electrical energy results were based upon two locomotives. It must be emphasized that differences in performance of the test train between the lubricated and unlubricated test runs were determined as a percentage above the levels obtained by using wayside and flange lubrication.

EVALUATION OF A TOP-OF-RAIL LUBRICATION SYSTEM

1.0 INTRODUCTION

The Federal Railroad Administration (FRA), in conjunction with the United States Department of Energy (DOE), has been investigating a new product for use in rail lubrication. The system applies a new consumable lubrication on top of both rails behind the last axle of the last locomotive. The lubricant is applied in computer-controlled quantities with the intent that no lubricant is left on the rail after the train has passed.

The railroad industry has expressed interest in the aforementioned system. The lubricant system, SENTRAEN 2000™, has been developed to date by the Tranergy Corporation, in collaboration with Norfolk Southern Railroad (NS) and the Texaco Corporation. Proprietary tests of the system have been conducted in conjunction with NS in revenue coal train service during the last three years. CSX Transportation (CSXT), in a continuing effort to explore a variety of lubrication practices, has recently expressed interest in a lubrication system of this nature.

The present field demonstration represents the investigation of the use of the SENTRAEN 2000™ top-of-rail (TOR) lubrication system in typical revenue service. This investigation represents a collaborative effort between the FRA, CSXT, ENSCO, Inc. (under sponsorship of the FRA) and the Tranergy Corporation.

1.1 TEST OBJECTIVES

The objective of this investigation was to conduct further tests of the TOR lubrication system in field service under the full range of train operating conditions, and possible system operating conditions, with respect to the following issues:

- Safety Related Issues
  - The effect of the lubrication system on train handling/speed control;
  - The effect of the lubrication system on braking, including stop distance and wheel slip;
  - The distribution of lubricant under the train, including the amount of lubricant remaining on the rails following a train passage and its influence on subsequent traffic;
  - The effect of the lubrication on the lateral curving forces.

- Performance Related Issues
  - The energy savings that can be expected from the use of the system for a range of typical trains in freight service;
  - The effect of the lubricant on the critical speed for truck hunting.

1.2 LUBRICATION SYSTEM DESCRIPTION

The SENTRAEN 2000™ lubrication system described in a prior section has been developed over the last ten years by Tranergy. The system provides an alternative to current on-board wheel lubrication systems, which apply grease to the locomotive wheel flange to reduce wheel flange friction. The current wheel flange lubrication systems reduce the friction coefficient between the flange and the rail but not the force exerted by the flange on the rail. This system was designed to reduce this force exerted laterally on the rail while reducing the friction between the head of the rail and the wheel tread. Reduction in the lateral forces exerted on the rail should have additional benefits for the track.

The lubrication system applies a consumable, and environmentally safe, lubricant on top of both rails after the last locomotive axle. The amount of lubricant dispensed on the rails is computer controlled so that the lubricant is consumed by the time the entire train has passed. The rate of application of the lubricant is computed in real time by an on-board computer, and is based on the following instantaneous train and track parameters:

- Train speed
- Train tonnage
- Degree of track curvature
- Ambient temperature
- Brake application
- Direction of travel
- Locomotive position and orientation

A functional block diagram of the system is shown in Figure 1-1. The input of the parameters listed above to the controlling computer determines the duration over which the solenoid valves are in the open position, allowing the lubricant to flow from the pressurized storage tank. The solenoid valves revert to the closed condition upon power interruption to the system.

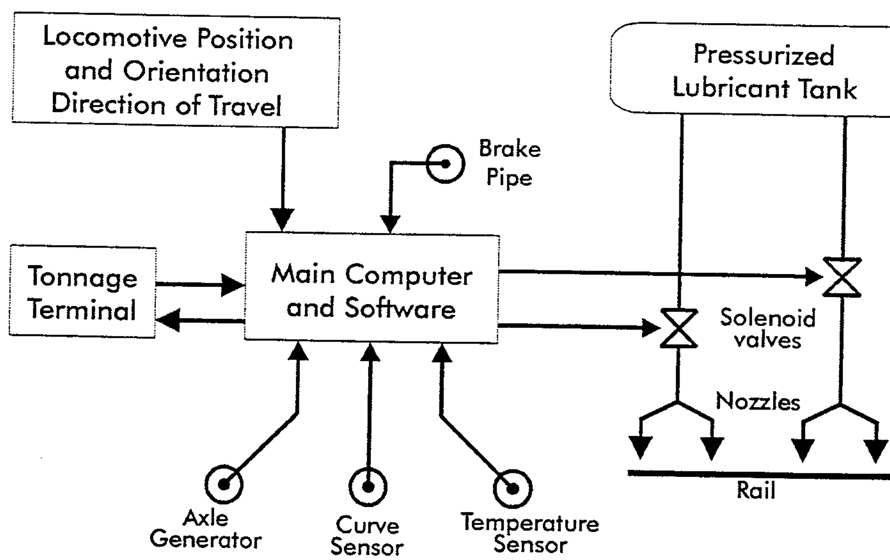

Figure 1-1. Functional Block Diagram of TOR Lubrication System

The system utilizes an environmentally safe, biodegradable, non-toxic liquid lubricant developed by Tranergy, in collaboration with Texaco. The lubricant is water-based, containing no solids commonly used in current lubrication practices such as graphite or molybdenum disulfide, and is designed to function over a wide range of temperatures. The material can be described as a friction modifier, providing a reduction in friction under normal rolling wheel conditions but resulting in an increase in friction under braking conditions. The lubricant is produced and sold by Equilon Enterprises LLC, a joint venture of Texaco and Shell.

1.3 PREVIOUS TEST RESULTS

Proprietary tests have been conducted in conjunction with NS in revenue coal train service during the last three years. Limited information reported from these tests indicates promising results.

Under the sponsorship of the FRA and the DOE, the system was further tested in June, 1997 at the Transportation Technology Center (TTC) in Pueblo, CO, on the Wheel-Rail Mechanism Loop (3.2 miles). These tests were supported by Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads (AAR/TTCI) and NS. The results showed electrical energy savings of up to 30% and mechanical energy savings of up to 44% (Note: Measurement of the electrical energy is an accurate means to determine the energy required to move the train; measurement of mechanical energy, though not as accurate, does provide for data of interest in situations such as pulling a consist up an incline while also providing a point of comparison for electrical energy measurements). It also showed significant reduction of lateral forces on curves. The average of the maximum lateral force developed on a 7.5 degree curve was reduced from 16.5 kips (1 kip = 1000 lbs.) to 5.2 kips on the inside (low) rail and from 13.3 kips to 6.9 kips on the outside (high) rail. During these tests, the level of applied lubrication was higher than the level needed; lubricant residue was left on the rail after the train passed. Consequently, in the fourth lap, enough residue build up occurred to cause wheel slip on a 2% downward grade in dynamic braking mode. Evidence of wheel slip under tractive effort was also reported. Since the time of these tests, Tranergy has lowered the level of lubrication dispensed by the system. Tests of the system using reduced lubrication levels were conducted on the same track by AAR/TTCI in the summer of 1998. No instances of wheel slip were observed over the fifteen (15) laps tested.

Recently, further tests have been conducted by NS with lowered levels of lubrication in order to confirm consumption of the lubricant towards the end of the train, however detailed results from these tests are not yet available.

1.4 TEST OVERVIEW

Train operation parameters were measured for both lubricated and unlubricated movements of CSXT's Stilesboro's 90 car coal trains between Corbin, KY, and Cartersville, GA. The consist traversed the test zone at typical operating speeds during the test. Instructions were given to the engineers to avoid using special handling practices for the duration of the test. These measures were taken in order to evaluate the use of the system under normal operating conditions.

Various energy measurements were made for the sake of comparison and validation. The amount of fuel consumed and the electrical output of the locomotive's generators were recorded for the lubricated and unlubricated trips. Mechanical energy was determined by considering force measurements made with an instrumented drawbar. In addition to energy measurement, lateral and vertical forces were measured in one curve, of approximately 6 degrees, at locations within the body and spiral of the curve. Tribometer readings were made at several locations prior to and after train passage for comparison of coefficient of friction measurements to determine the extent of lubrication remaining after train passage. Stop distance tests were conducted under lubricated and unlubricated conditions as traffic conditions permitted. Full service and emergency brake applications were employed for these tests. Information related to each measurement will be presented in Chapters 2 and 3.

Lubricant was applied from the trailing end of the trailing locomotive to the top of the rail at a rate determined by the Tranergy system. Lubrication was halted during application of the automatic brake but not during dynamic or independent braking. The amount of lubricant consumed was measured visually by marking and recording lubricant levels on the sight glass at the start and end of each trip and at designated locations within the trip.

The "dry", or unlubricated, rail condition was considered as a case where the TOR lubrication was not in use. Throughout the test effort, both wayside lubrication devices and wheel flange lubricators were fully operational. Of the three locomotives within the consist, the lead and the middle locomotives were applying flange lubricant continually in all tests. The trailing locomotive was equipped with SENTRAEN 2000™ system, which was operational only for tests designated as lubricated tests. *Differences in performance of the test train between the lubricated and unlubricated test runs were thus measured as a percentage above the levels obtained by using wayside and flange lubrication.*

1.4.1 Test Zone

The choice of the test zone was dictated by the desire to monitor the test train in a variety of terrain and track features. Candidate test zones were evaluated based on overall distance, prominence of curves, and the inclusion of geographic features such as mountainous terrain and level grade territory.

A zone over CSXT operated track between Corbin, KY, and the Stilesboro Power Plant in Cartersville, GA, was chosen for the test. Each trip to the power plant started at MP 178, south of the terminal at Corbin. The test consist proceeded to MP 421, via Etowah, TN, where it left CSXT operated track near the Stilesboro Power Plant. The consist operated through the dumping site at the plant and the empty return movement was made via the reverse route. Figure 1-2 illustrates the test zone used for the test.

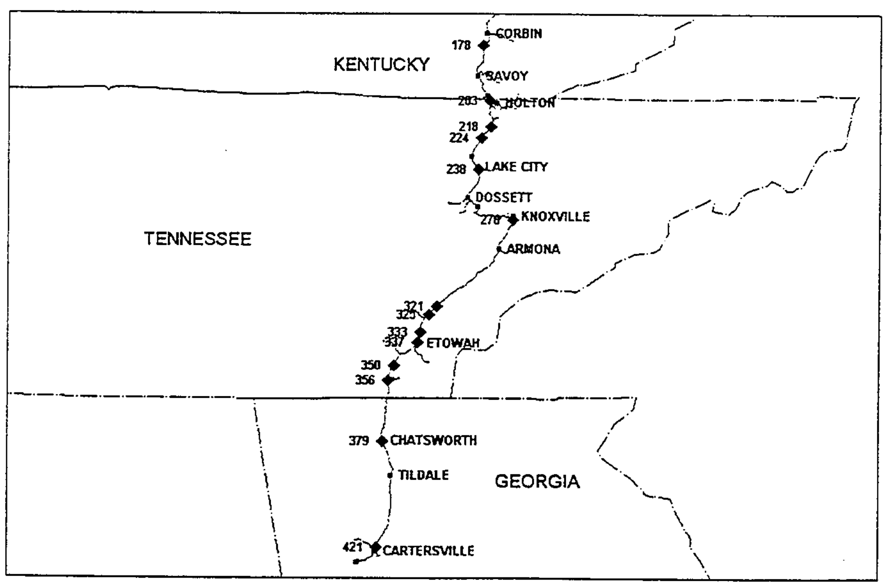

Figure 1-2. Map of Test Zone Used in TOR Lubrication Evaluation Test

The test zone was divided into twelve segments. This was done in order to aid in the analysis of the results - if results were compromised by weather conditions or train handling, the data from the affected segment could be disregarded without compromising results recorded in other segments. The end points of each of the segments, chosen such that the individual segments of the test zone had uniform terrain and similar track features, are illustrated in Figure 1-2 and detailed in Tables 1-1 and 1-2. Table 1-1 lists the beginning and ending locations of each test segment considered in test runs employing the loaded test train. Table 1-2 lists the same information for tests conducted on the empty train. The designation of the test segments based upon the loading condition of the test train was used in the data analysis phase of this effort to identify comparable cases.

Table 1-1. Segments of Test Zone Used in TOR Lubrication Evaluation Test with Loaded Test Trains

Segment Number	Starting Location	Starting MP	Ending Location	Ending MP	Number of Curves	Notes
1	Corbin, KY	178	High Cliff, TN	203	51	-
2	High Cliff, TN	203	Duff, TN	218	61	Ascent of Duff Mt.
3	Duff, TN	218	La Follette, TN	224	25	Descent of Duff Mt.
4	La Follette, TN	224	Lake City, TN	238	40	-
5	Lake City, TN	238	Knoxville, TN	276	77	-
6	Knoxville, TN	276	-	321	36	-
7	-	321	-	325	2	Stop Distance Test Zone
8	-	325	Etowah, TN	334	12	-
9	Etowah, TN	337	-	350	22	-
10	-	350	-	356	5	Stop Distance Test Zone
11	-	356	Chatsworth, GA	379	26	-
12	Chatsworth, GA	379	Junta, GA	421	41	-

Table 1-2. Segments of Test Zone Used in TOR Lubrication Evaluation Test with Empty Test Trains

Segment Number	Starting Location	Starting MP	Ending Location	Ending MP	Number of Curves	Notes
13	Junta, GA	421	Chatsworth, GA	379	41	-
14	Chatsworth, GA	379	-	356	26	-
15	-	356	-	350	5	Stop Distance Test Zone
16		350	Etowah, TN	337	22	-
17	Etowah, TN	334	-	325	12	-
18	-	325	-	321	2	Stop Distance Test Zone
19	-	321	Knoxville, TN	276	36	
20	Knoxville, TN	276	Lake City, TN	238	77	-
21	Lake City, TN	238	La Follette, TN	224	40	-
22	La Follette, TN	224	Duff, TN	218	25	Ascent of Duff Mt.
23	Duff, TN	218	High Cliff, TN	203	61	Descent of Duff Mt.
24	High Cliff, TN	203	Corbin, KY	178	51	-

Please note that the test zone segment bounded by MP 321 and MP 325 and the segment bounded by MP 350 and MP 356 were designated as areas for stop distance tests to be conducted. This was due to the prominence of tangent track within these vicinities.

1.4.2 Wayside Measurements

In order to investigate the effect of the lubricant on curving forces, forces were measured in a curve of approximately 6 degrees.

The test curve, located near MP 234.7, was instrumented with strain gage based Wheatstone bridges installed on the high and low rails. The arrangement of the gages were such that the bridges would measure lateral (L) and vertical (V) forces on the rails as each axle of a trainset passed over the instrumented sites. The test curve was instrumented at two locations, one location being in the spiral of the curve and the other being in the body of the curve. The test curve and the locations of the instrumented sites within the curve are shown in Figure 1-3.

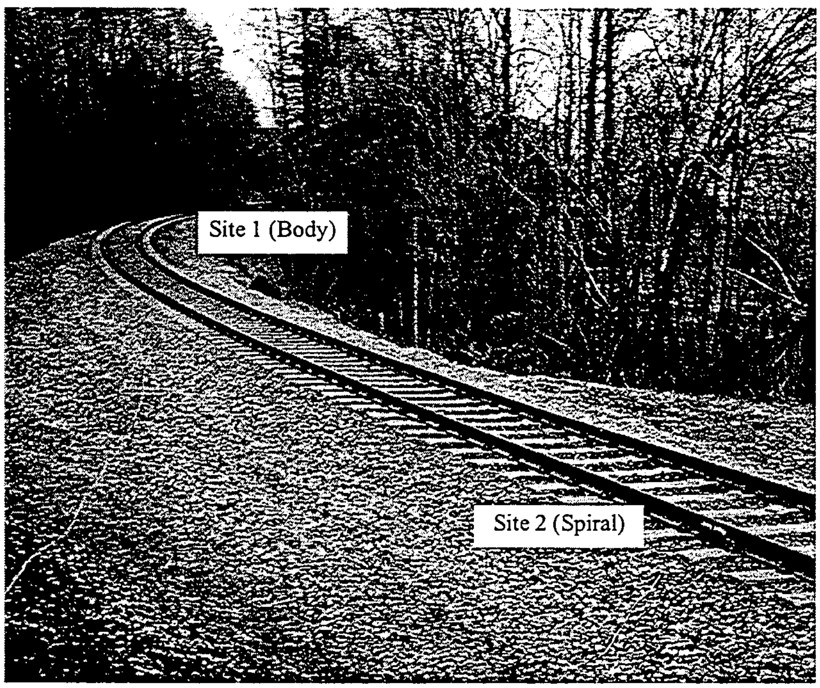

Figure 1-3. Instrumented Curve Site

During the monitoring of the test train, tribometer readings were taken on top of the two rails. This was done in order to determine the extent of lubricant remaining on the rail by making comparisons of friction coefficient measurements made prior to and following the passage of the test train. The tribometer was configured such that friction coefficients were measured at a location one (1) inch from the gage side of the rail head. This location corresponded to the region influenced by the lubricant. Tribometer readings were made at the instrumented curve site and three (3) tangent locations within the test zone.

1.4.3 Test Consist

Each test train consisted of two (2) EMD Class SD60 locomotives, one (1) EMD Class SD40-2 locomotive, CSXT's Technical Research Car, CSXT 994501, and 90 Stilesboro coal hopper cars. The configuration of the test consist used throughout the series of tests is depicted in Figure 1-4.

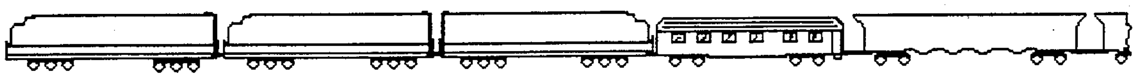

Figure 1-4. Test Consist Used for TOR Lubrication Evaluation Test

The lubrication system was installed on the SD60 locomotive designated as CSXT 8709 such that the lubricant was dispensed at the short hood end of the locomotive. CSXT 8709 was operated as the trail locomotive for all test runs. The SD40-2 locomotive, designated as CSXT 8328, was the lead locomotive for all tests. Arranging the locomotives in this manner allowed lubricant to be dispensed on the rails such that the locomotives were not affected by the lubricant. All locomotives were used for supplying power for test runs where coal was being carried. CSXT 8702 was taken off-line for the trips in which no coal was carried.

A 90-car consist comprised of Stilesboro coal hopper cars was used for each trip of the testing effort. The same set of cars and locomotives was used on each trip of the testing effort. Car numbers and corresponding car lightweights of each car used in the test were recorded. Each loaded car was weighed on track scales before beginning each trip south from Corbin.

1.4.4 Test Schedule

Data was gathered for both lubricated runs and "dry" runs. Three (3) round trip runs were made for each case.

The following is a chronological sequence of the events surrounding the test.

- TOR lubrication system installed on SD60 locomotive, CSXT 8709, during week of 12 Jan., 1998.
- Instrumentation was installed on test curve during weeks of 19 January and 2 Feb., 1998.
- Test consist assembled and instrumentation implemented at Corbin between 12 Feb. and 15 Feb., 1998.
- Test runs conducted between 16 Feb. and 4 Mar., 1998 (summarized in Table 1-3).

Table 1-3. Summary of Test Runs Used in TOR Evaluation

Test Run	Starting Date	Ending Date	Lubrication Condition
1	15 February, 1998	18 February, 1998	No Lubricant
2	19 February, 1998	21 February, 1998	No Lubricant
3	22 February, 1998	23 February, 1998	Lubricant
4	24 February, 1998	26 February, 1998	No Lubricant
5	27 February, 1998	1 March, 1998	Lubricant
6	2 March, 1998	4 March, 1998	Lubricant

Run 1 was primarily used as "shakedown" run in order to check system operations and to establish data collection procedures. A complete summary of each test run, including trip times, weather conditions, tonnage and any train handling or data gathering issues is included in Appendix A.

1.5 TEST RESPONSIBILITIES/PERSONNEL

Test personnel included responsible parties from CSXT, the Tranergy Corporation and ENSCO, Inc. The personnel and their responsibilities are included below.

Test Director	Kenneth Davis	CSXT
Instrumentation/ Data Reduction	Wain Strickland	CSXT
Test Execution/ Data Analysis/ Support Team	Dr. Sudhir Kumar	Tranergy Corp.
	Vennie Dyavanapalli	Tranergy Corp.
	Suneet Cherian	Tranergy Corp.
	Kevin Kostelny-Vogts	Tranergy Corp.
	Eric Sherrock	ENSCO, Inc.
	Jasen Bellomy	ENSCO, Inc.
	Eric Brown	ENSCO, Inc.
	Anthony Burton	ENSCO, Inc.
	William Jordan	ENSCO, Inc.
	Quan Ha	ENSCO, Inc.
	Edward Wulin	ENSCO, Inc.
Technical Monitor	Dr. Magdy EI-Sibaie	FRA Office of R&D

CSXT was responsible for provision of all equipment and train movement. ENSCO, under contract with the FRA Office of Research and Development, was responsible for test instrumentation, data acquisition, analysis, and reporting. Under subcontract to ENSCO, Tranergy Corporation was responsible for monitoring and maintenance of the lubricant system, and analysis of all data pertaining to the lubricant system.

1.6 ACKNOWLEDGEMENTS

The authors would like to acknowledge the efforts of those individuals not previously identified that helped to make this test effort possible. The authors are grateful to the Road Foremen and crews responsible for train movement between Corbin, KY, and Cartersville, GA. Personnel involved in the movement of the trains were asked to replicate all train handling procedures for all the test runs in order to facilitate comparisons. All crews associated with the test did a commendable job of operating the trains in a consistent fashion. Foremen from this territory also assisted in the arrangement of stop distance tests. The cooperation of all CSXT personnel was greatly appreciated.

The authors would also like to acknowledge the efforts of Instrumentation Services, Inc. in the implementation of the wayside instrumentation sites. Instrumentation Services' timely response under difficult time restrictions was also greatly appreciated.

2.0 MEASUREMENTS

CSXT provided the use of their Technical Research Car for the duration of the series of tests. This car housed the CSXT data acquisition system, a PC based system using Snap-Master ™ data acquisition software. The Research Car was equipped to measure the following parameters for the duration of the trip:

- Train speed
- Drawbar force
- Power outputs from all locomotives, including main generator voltage and current
- Notch, or throttle, settings and dwell times
- Fuel flow parameters from all locomotives
- Milepost passage
- Brake pipe pressure

Electrical signals from the locomotives were recorded by tapping into the electric cabinet on each locomotive and running cables back to the data acquisition system located on the Research Car. Fuel consumption was monitored by using flow meters installed into the fuel supply and return lines of each locomotive and routing the signals back to digital readout meters located on the Research Car. The passage of mileposts was logged by introduction of a location identification signal to the data stream being recorded. A pressure transducer located within the brake pipe provided signals related to the application of brakes throughout the test. The data acquisition system was connected to the train line prior to the test, allowing for the recording of locomotive signals. The test took advantage of the speed sensors located on the Research Car.

Tranergy personnel monitored the performance of the lubrication system with a laptop PC based data acquisition system. Although the lubrication delivery system, and controlling SENTRAEN 2000™ computer, were located on the trailing locomotive, Tranergy's data collection system was located on the Technical Research Car. Tranergy personnel monitored the following parameters:

- %PWM, a parameter related to lubricant's flow rate
- Amount of lubricant consumed during each trip
- Train speed
- Rail curvature
- Lubricant temperature
- Brake pipe pressure
- Tonnage

The sampling speed of the CSXT data acquisition system was set to be 1 sample/sec while the sampling rate of Tranergy's data collection system was 2 samples/sec. Synchronization of the two data acquisition systems was achieved by monitoring GPS signals in conjunction with both systems. GPS signals were recorded directly by Tranergy's data collection system. GPS time was recorded by hand at the time of milepost passage. Since the passage of mileposts was recorded with the location identification signal by CSXT's data acquisition system, the data recorded by the two systems could be related to each other.

Upon processing of the data, it was determined that the sampling rate of the CSXT data acquisition system was actually .914 Hz. (1 sample taken every 1.09 seconds). The discrepancy between the desired sampling speed, 1 Hz, and the actual sampling speed resulted from a timing incompatibility issue arising from the computer's operating system. Information pertaining to the actual sampling rate was used in the analysis of the data.

Trip monitors located in the SD60 locomotives provided information regarding travel distances, kilowatt-hours used and notch dwell times, including use of dynamic brake and idle time, corresponding to a particular test run. The trip monitors were zeroed prior to each trip. Tranergy personnel recorded readings from the monitors following each trip between the end points of the test zone. Trip monitors readings were recorded from the middle and trailing locomotive following test runs made with the loaded test trains and from the trailing locomotive for the runs made with the empty test train. Readings were made in this manner due to the fact that the middle locomotive was taken off-line for the trips made when no coal was carried.

A log book was maintained in the Research Car to record all events which may have an effect on the test results. Train orders, car weights and information pertaining to data files were made part of the test log for each test conducted.

A two-man crew monitored all wayside activity throughout the series of tests. Signals from the instrumented six (6) degree curve were monitored and recorded at times of test train passage for both "dry" and lubricated trips. Tribometer readings were made prior to and following the passage of the test train and normal revenue service trains. The readings were made in the vicinity of the instrumented curve and at selected tangent locations throughout the test zone.

Descriptions of the manner in which each measurement was made are given in the following sections. Section 2.1 will address on board measurements made of train performance parameters. All data collected by Tranergy's data collection system is described in Section 2.2. Wayside measurements are detailed in Section 2.3.

2.1 TRAIN PERFORMANCE MEASUREMENTS

Train parameters recorded for the duration of the test, locations of sensors, and the channel assignments used for the different data acquisition systems are indicated in Figure 2-1.

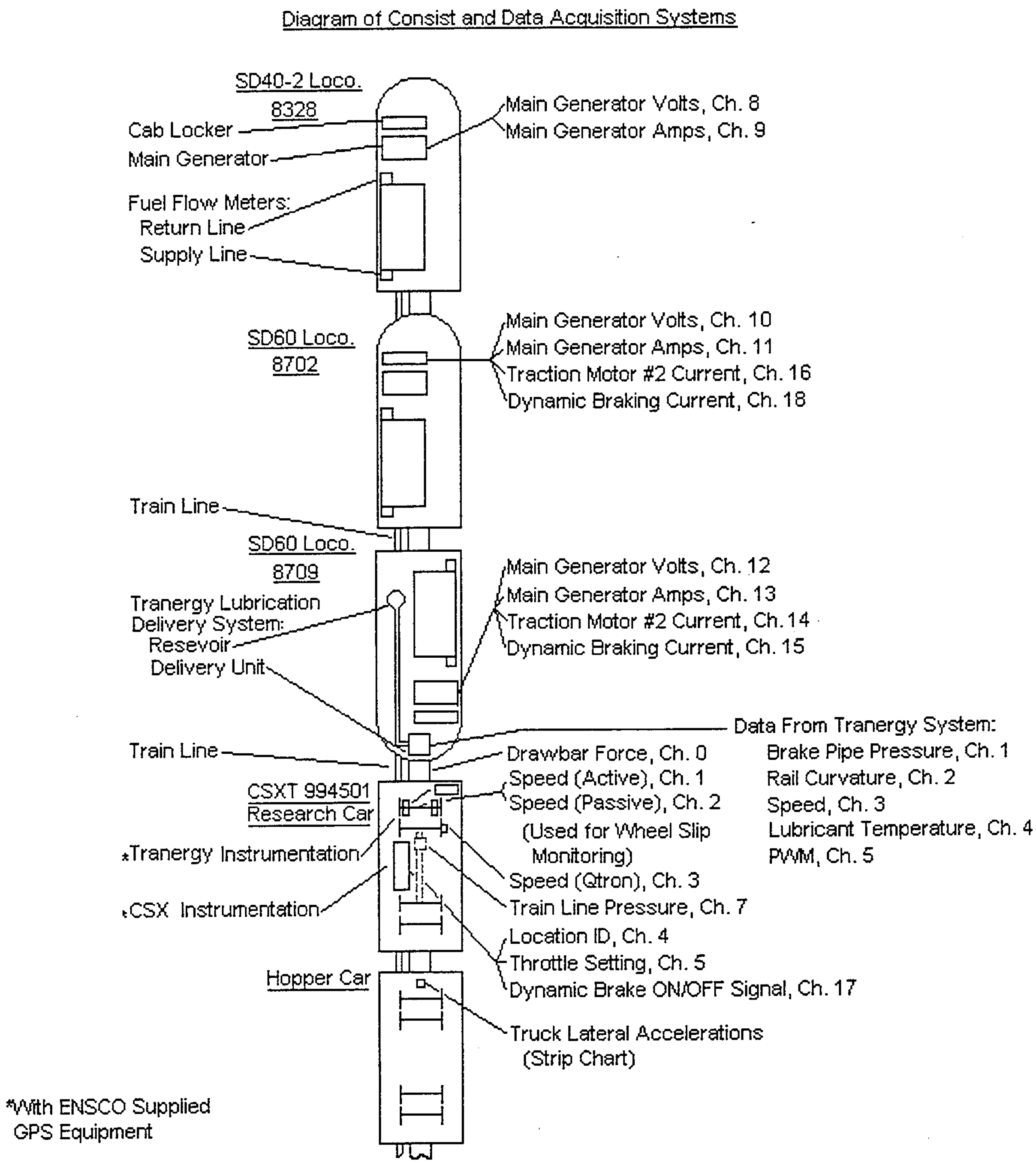

Figure 2-1. Data Acquisition System Assignments and Sensor Locations For TOR Lubrication Evaluation Test

2.1.1 Speed

Speed was measured and recorded using three (3) independent sensors located on the Research Car. All sensors utilized magnetic pickups to detect "teeth" located on the axle end caps. Rotation of the axle results in the "teeth" passing through the fields of magnetic pickups, causing a pulse to be generated.

A "Qtron" brand speed sensor was used as the main measure of speed. Located on the trailing axle of the lead truck, the Qtron sensor utilized 60 teeth and an "active" pick-up to measure speed. The term "active" refers to the fact that the magnetic pick-ups were powered, resulting in a "square wave" style pulse. This style sensor is contrasted to a "passive" pick-up speed sensor that employs unpowered magnetic pick-ups within the sensor, resulting in an induced fluctuation in current being read by the sensor.

Similar sensors were used to provide secondary measurements of speed and to detect wheel slip. An "active" speed sensor utilizing 100 teeth, referred to in Figure 2-1 as the "active speed", was used as a back-up to the Qtron speed sensor. A "passive" style speed sensor, employing 100 teeth to measure speed was used primarily as a wheel slip indicator. The signal from this sensor, referred to in Figure 2-1 as the "passive speed", would drop to zero if the train experienced wheel slip while moving.

Speed was also measured using the GPS transmission. This speed resulting from the GPS signal was used to confirm the readings taken with the sensors described above.

2.1.2 Drawbar Force

Drawbar force was measured and recorded continuously with the use of the instrumented coupler on the Research Car. The coupler, used to join the car to locomotive 8709, had a range of 500,000 pounds and could measure both draft and buff (tension or compression). The bridges on the coupler were zeroed and "shunt calibrated" at the beginning of each test run.

Drawbar force, in combination with instantaneous speed, was used in the analysis phase of this study to determine mechanical power expenditures throughout the series of tests.

2.1.3 Locomotive Electrical Power

Voltage and current produced by the main generator of each locomotive were monitored throughout the test. Signals were picked up from available low voltage check points and recorded continuously by the CSXT data acquisition system.

This data was intended to determine electrical power expenditures of the power units throughout the series of tests.

2.1.4 Notch Dwell Times

Throttle position information was available from the locomotive's electrical control circuit. Signals from the control circuit were recorded by the data acquisition system on board the Research Car on a continuous basis, resulting in a time history of the throttle settings. The notch dwell time information was also available and recorded from the locomotive trip monitors.

2.1.5 Fuel Consumption

Turbine type fuel flow meters (Halliburton Company's ½" Fuel Flow Meters) were used to determine the amount of fuel used by each of the three (3) locomotives. Two meters were employed on each locomotive – one applied in the engine fuel supply line and one applied in the fuel return line. The difference between simultaneous readings of these meters indicated the amount of fuel used by the engine.

Data from the six (6) meters were recorded manually by observing digital readout devices (Halliburton Company's LO-II Fuel Analyzers) located on board the Research Car. Readings were made as the test train entered and exited each of the specified test zone segments. Readings were also made before and after the train was stopped in order to account for fuel consumed during times when the power units were idling.

2.1.6 Trainline Pressure

Train line air pressure was continuously monitored throughout the test. Dial gages indicating the pressure of the brake system were observed during stop distance tests in order to ascertain the start of the braking procedure.

Brake system pressure was also recorded by the CSXT and Tranergy data acquisition systems. A pressure transducer was installed into the air brake line of the Research Car. Changes in pressure of the brake system were indicative of the application of brakes to the Research Car and the rest of the consist.

2.1.7 Location Identification

As a means of recording the location of the test train within the data stream, a location identification signal was utilized throughout the test. A circuit introduced a 7 volt signal when an event marker was depressed. Throughout the duration of the test, a forward observer searched and depressed the event marker upon passage of the milepost. The location of the test train could be arrived at within the data stream by noting the number of location identification pulses from the start of data collection.

As noted in Section 2.0, GPS time was recorded by hand at the time of milepost passage. This was done in order to synchronize the data stream collected by CSXT's data acquisition system with that collected by Tranergy's data collection system. GPS signals were being recorded by Tranergy's data collection system on a continuous basis.

2.1.8 Dynamic Braking

The use of dynamic brake was monitored via the train line electrical signal. A dynamic brake ON/OFF signal was continuously monitored and recorded by the data collection system in order to have a record of the time history of dynamic brake usage.

The current used in dynamic braking was monitored in order to observe the difference in demand for dynamic braking for lubricated and unlubricated conditions. Dynamic braking current and the current from traction motor #2 were recorded on a continuous basis from both the SD60 locomotives. The SD40-2 locomotive was not equipped with a system that readily provided for the direct measurement of the current associated with dynamic braking. As a result of this deficiency, current used in dynamic braking on the SD40-2 locomotive was not recorded.

2.1.9 Truck Hunting

In order to observe any occurrence of truck hunting, a triaxial accelerometer (Crossbow Model No. CXL04M3, + /- 4g) was mounted on the leading edge of the center sill of the lead coal hopper immediately behind the Research Car. Accelerometer output was monitored and recorded using a strip chart recorder during empty runs in an attempt to determine the effect of lubrication on truck hunting.

2.1.10 Global Positioning Information

ENSCO provided two GPS systems for use with the separate data collection systems. GPS information served as a synchronizing signal between the separate data systems. The GPS also provided means to measure train speed independent of the systems present on the Research Car.

One GPS system was installed to provide information for use with the CSXT data acquisition system. GPS time was recorded by hand at the time of milepost passage for use with data files recorded with the data collection system. The other GPS system was installed to interface with Tranergy's data acquisition system. GPS signals were recorded with the data stream normally collected by Tranergy's data collection system.

2.2 LUBRICATION SYSTEM MEASUREMENTS

Tranergy monitored the performance of the lubrication system through a link between the SENTRAENJ computer, the controlling device within the lubrication system, and a laptop PC based data acquisition system utilizing Test Point™ data collection software. Although the lubrication delivery system was located on the trailing locomotive, the Tranergy data collection system was located on the Technical Research Car throughout the test.

Tranergy's data acquisition system recorded train speed, track curvature, airbrake pressure, direction of travel, lubricant temperature, lubricant consumption and the tonnage of train on a continuous basis. In addition to the recorded parameters, Tranergy made observations of the headlight conditions and monitored the manner in which the lubricant was dispensed onto the rails by use of a video camera. The camera was directed at the lubricant delivery nozzle, with signals being viewed and recorded for future study. The system monitoring showed that the system worked according to design throughout the testing period.

Tranergy personnel also documented the readings of the trip monitor data made from the locomotive computer. This information included notch dwell times (100s of hours), kilowatt-hours (kW-Hrs.) in each notch settings and total trip kW-Hrs. The details of the trip monitor readings are discussed in Sections 3.1 and 3.6.

2.3 WAYSIDE MEASUREMENTS

2.3.1 Instrumented Curve

The test curve was instrumented, using wayside mounted lateral and vertical force instrumentation to measure lateral force (L) and vertical force (V), as each axle of the trainset passed by. The test curve was instrumented at two locations, one location being in the spiral of the curve and the other being in the body of the curve, to measure L and V on both the high and low rails. For the cited test curve, the following instrumentation was used:

- Lateral force strain gage measurement arrays; 1 array mounted on each rail in both the spiral and the body of the curve for a total of 4 arrays
- Vertical force strain gage measurement arrays; 1 array mounted on each rail in both the spiral and the body of the curve for a total of 4 arrays
- Datronics 9178 signal conditioning unit with bridge excitation, signal amplifier and filter
- IOTech's DAQBook 100 analog/digital data acquisition system
- PC computer digital recording, data storage and display
- 12 V deep cycle car battery.

The instrumented rail site located within the body of the curve is shown in Figure 2-2. Instrumentation used to record the bridge output signals is depicted in Figure 2-3.

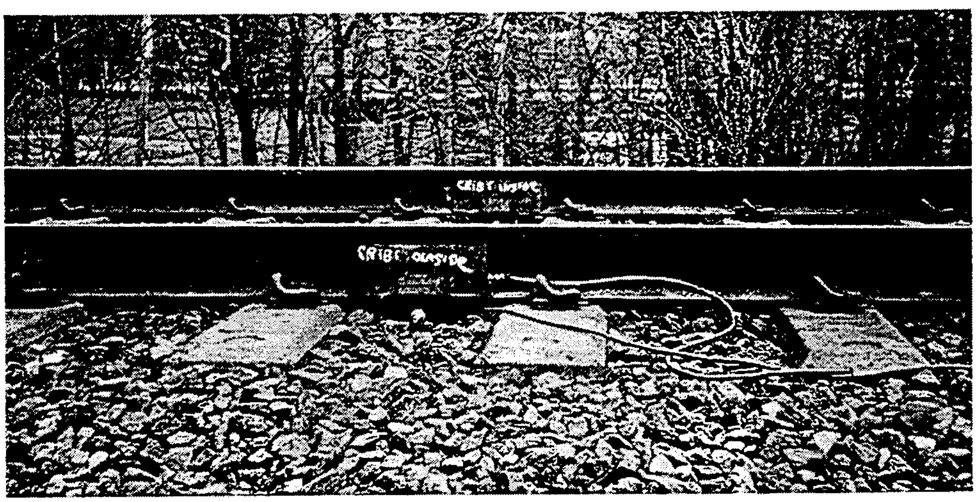

Figure 2-2. Instrumented Rail Site Within Curve Body

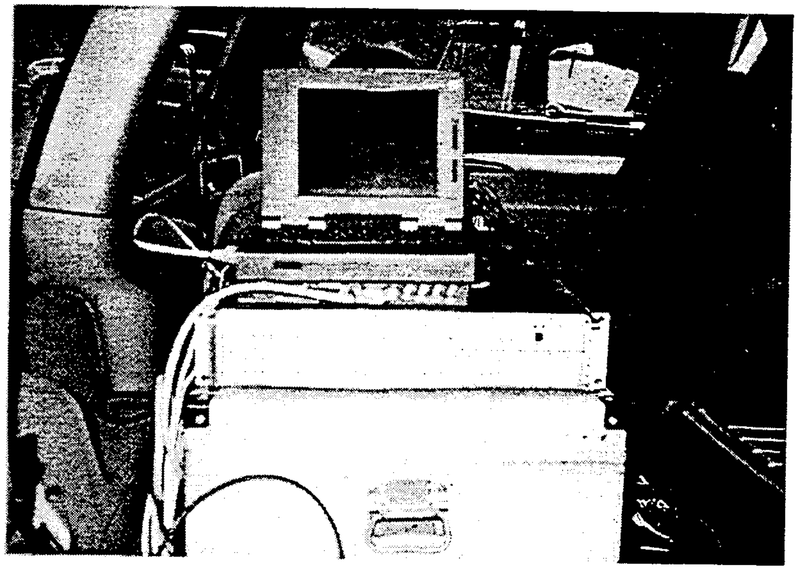

Figure 2-3. Instrumentation Employed at Curve Site

2.3.2 Tribometer Measurements

Tribometer readings were taken on the top of the rails prior to and after train passage in order to determine the extent of lubricant remaining on the rail by making comparisons of resulting friction coefficient measurements. The tribometer was configured such that friction coefficients were measured on the top of the rail within a region located one (1) inch from the gage side of the rail head. This location corresponded to the region influenced by the lubricant. Tribometer readings were made at the instrumented curve site and three (3) tangent locations within the test zone.

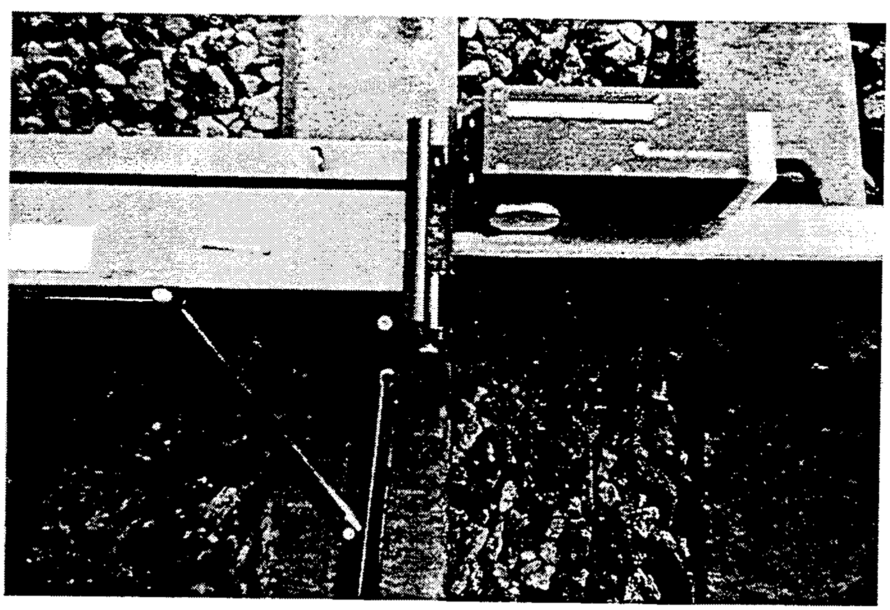

Figure 2-4. Tribometer Used for Determination of Friction Coefficients

Use of the tribometer resulted in a single value of friction coefficient for a sampled length of rail measuring approximately ten (10) to twelve (12) feet. Four (4) to five (5) measurements were made at each test location in order to record the spatial variation in friction. Figure 2-5 illustrates CSXT personnel employing the tribometer at the instrumented curve site.

Figure 2-5. CSXT Personnel Using Tribometer

3.0 TEST RESULTS

Material presented within this chapter pertains to results of the series of tests. Information is organized by areas of interest - namely notch dwell times, braking distance, tribometer measurements, curving forces, fuel consumption, electrical energy, mechanical energy and truck hunting. Considerations of the data made throughout analysis and any areas of concern with the testing or analysis will be highlighted. A compilation of results and related discussions will be presented in Chapter 4.

3.1 NOTCH DWELL TIMES

Notch dwell time is a measure of throttle position and time in throttle. Dwell time was evaluated in order to quantify the handling procedures used to control the train over the entire test zone. The dwell time was also used in the evaluation of energy savings by considering the time spent in the higher notch settings, settings that result in relatively higher fuel consumption.

Measurements of notch dwell time were obtained from the trip monitors and compared to values measured with the data acquisition system on the Research Car. Many of the newer locomotives are equipped with a computerized trip monitoring system. The system monitors the total kW-Hrs. of energy used for the trip, throttle (or notch) position, time in throttle, kW-Hrs. used in each throttle position for the trip, and the trip time. Readings of notch dwell time made from the monitors throughout the series of tests were in agreement with those obtained with the data acquisition system. Results from the trip monitors will therefore be presented in the assessment. Readings made from the monitors are documented in Appendix E.

The average dwell times for each notch position, as well as for idle and dynamic brake settings, were calculated for the lubricated test runs and compared to those determined for the unlubricated, or "dry", runs. Summaries of the average dwell times are given in the following tables and figures - Table 3-1 presents results pertinent to tests with loaded test trains with the results illustrated in Figure 3-1 while Table 3-2 and Figure 3-2 present the corresponding information for the tests made with empty test trains.

When compared to the "dry-baseline" runs, the notch dwell times for the higher throttle positions, specifically positions 7 and 8, were lower for the lubricated runs. For the loaded trips, six of the eight throttle positions showed reduction in notch dwell times, and for the empty trips, five of the eight throttle positions showed reductions in notch dwell times. The idle and dynamic brake times were found to be longer for the lubricated runs than these times were for the "dry" runs. The differences in idle time reflect differences in operations due to traffic conditions and other scenarios affecting the movement of the train. The increase in time spent in dynamic braking mode can be attributed to the decreased rolling resistance of the train during lubrication.

Table 3-1. Summary of Notch Dwell Times Obtained from Trip Monitor, Loaded Test Trains

Throttle Position	Unlubricated Tests			Lubricated Tests				% Reduction From Dry Runs
	100s of Hours Run 2	100s of Hours Run 4	Avg.	100s of Hours Run 3	100s of Hours Run 5	100s of Hours Run 6	Avg.	
8	0.030	0.037	0.0335	0.033	0.034	0.029	0.0320	4.48
7	0.006	0.003	0.0045	0.004	0.004	0.004	0.0040	11.11
6	0.005	0.003	0.0040	0.004	0.004	0.005	0.0043	-8.33
5	0.006	0.002	0.0040	0.004	0.004	0.005	0.0043	-8.33
4	0.009	0.004	0.0063	0.003	0.004	0.006	0.0043	30.67
3	0.008	0.005	0.0065	0.004	0.005	0.008	0.0055	15.38
2	0.012	0.006	0.0088	0.005	0.006	0.006	0.0057	35.24
1	0.011	0.006	0.0080	0.007	0.009	0.005	0.0070	12.50
IDLE	0.083	0.041	0.0618	0.047	0.090	0.134	0.0900	-45.75
Dyn Brk	0.042	0.037	0.0395	0.041	0.046	0.045	0.0438	-10.97

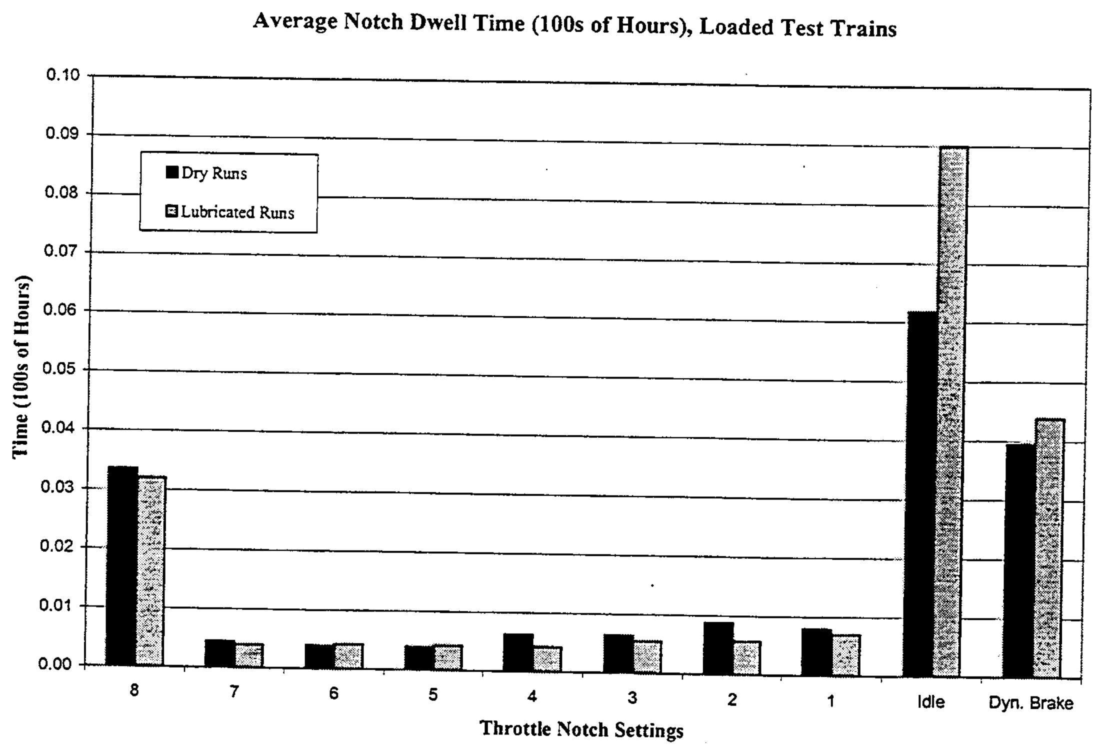

Figure 3-1. Average Notch Dwell Times Recorded from Trip Monitors, Loaded Test Trains

Table 3-2. Summary of Notch Dwell Times Obtained from Trip Monitor, Empty Test Trains*

Throttle Position	Unlubricated Tests			Lubricated Tests			% Reduction From Dry Runs
	100s of Hours Run 2	100s of Hours Run 4	Avg.	100s of Hours Run 3	100s of Hours Run 6	Avg.	
8	0.019	0.017	0.0180	0.017	0.014	0.0155	13.89
7	0.005	0.004	0.0045	0.004	0.004	0.0040	11.11
6	0.004	0.005	0.0045	0.004	0.005	0.0045	0.00
5	0.005	0.007	0.0060	0.005	0.008	0.0065	-8.33
4	0.007	0.008	0.0075	0.005	0.010	0.0075	0.00
3	0.007	0.012	0.0095	0.008	0.009	0.0085	10.53
2	0.010	0.021	0.0155	0.010	0.013	0.0115	25.81
1	0.005	0.009	0.0070	0.002	0.010	0.0060	14.29
IDLE	0.066	0.068	0.0670	0.055	0.122	0.0885	-32.09
Dyn Brk	0.017	0.021	0.0190	0.018	0.021	0.0195	-2.63

*Empty trip readings for Run 5 were not taken, thereby eliminating this case from consideration when looking at notch dwell times.

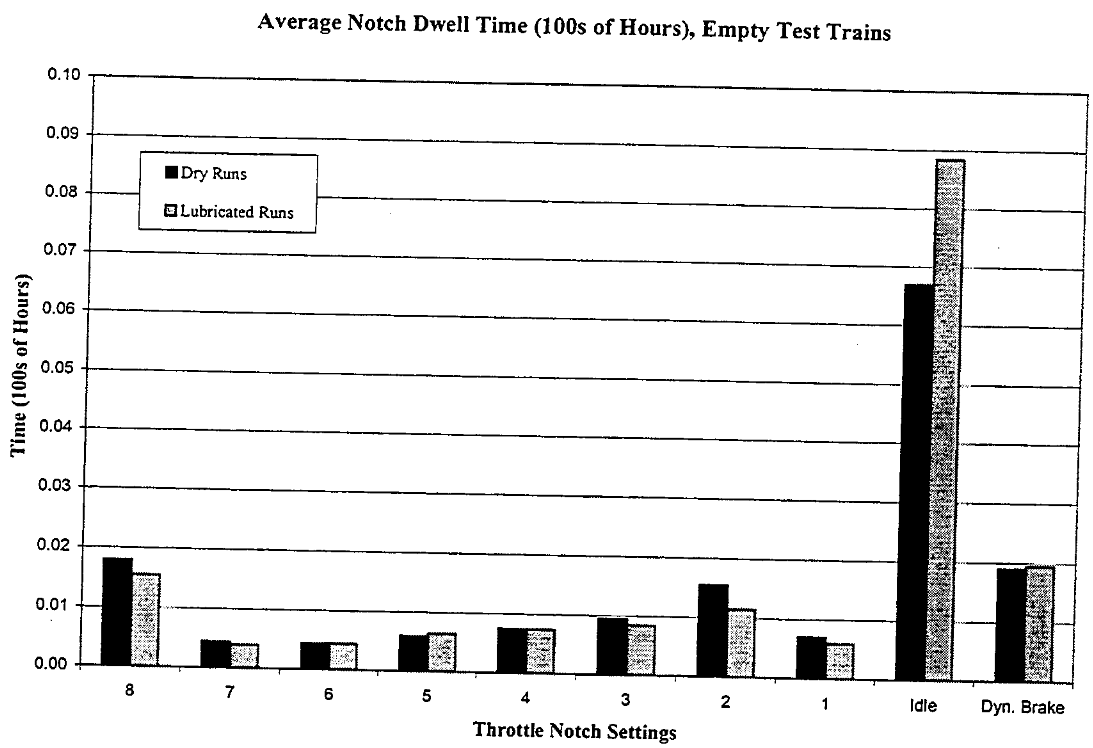

Figure 3-2. Average Notch Dwell Times Recorded from Trip Monitors, Empty Test Trains

Energy consumption is generally greater in the higher throttle positions. Considering Tables 3-1 and 3-2, it can be seen that dwell time for throttle position 8 was decreased 4.48 % when considering the loaded test train and 13.89 % when considering the movement of the empty test trains. The dwell time for throttle position 7 experienced a 11.11 % reduction when considering movements of both loaded and empty test trains. Considering a round trip by averaging the results from the loaded and empty test trains, the average reduction in dwell time for notch 8 was 9.19 % and 11.11 % for notch 7. These results are illustrated in Figure 3-3.

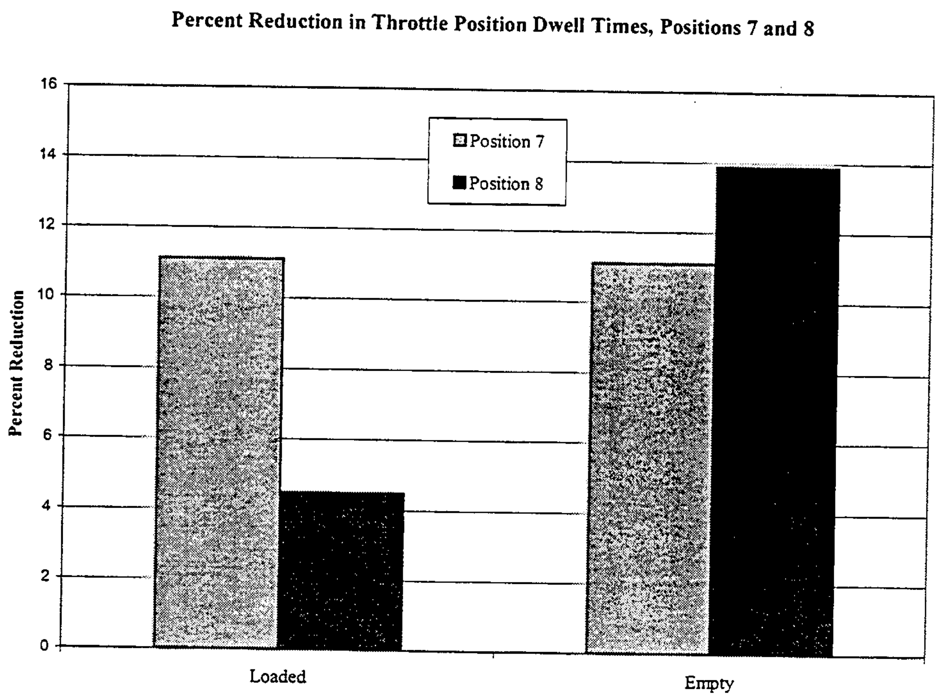

Figure 3-3. Illustration of Reduction of Dwell Time in Throttle Positions 7 and 8

3.2 BRAKING DISTANCE MEASUREMENTS

Braking tests were conducted to ascertain the influence of the TOR lubricant on the ability to stop the train. Two sections of track – one located between MP 321 and MP 325 and the other between MP 352 and MP 351 - were selected as sites for these tests due to the prevalence of tangent track at these locations, accessibility of the sites to the wayside crew, and traffic logistics.

Thirteen (13) braking tests were conducted over the six (6) test runs. Of the thirteen (13) braking tests, eight (8) employed full service brake applications and five (5) tests employed emergency brake applications. Dynamic braking was used prior to brake application in order to control the speed of the train. The stopping distance was measured using the distance counter located on the lead locomotive. Target speeds were reached prior to entering the vicinity of the stop distance test and the brakes were applied at predetermined mileposts with the distance counter being reset at the point of brake application. After each braking test, Research Car personnel exited the car placed a "marker" on a nearby tie, indicating the location at which the train had stopped. The stop distance recorded on board the lead locomotive was later validated when the wayside crew measured the distance from the milepost to the "marker" left after each test. Of the thirteen (13) tests, seven (7) tests were conducted with loaded test trains, four (4) of which were employing TOR lubrication and three (3) of which were "dry." Of the six

(6) tests conducted with empty test trains, three (3) were run with TOR lubrication, leaving three (3) tests to serve as baseline cases.

Track grade, a factor that has a significant effect on measured braking distance, was considered in the analysis of the stop distances. The effect of grade can be determined and a correction to the stop distance can be made so that comparisons can be made between various brake tests. The theory and method of calculating the grade corrected stopping distance is presented in Appendix B.

Upon review of the data, it was determined that the full service brake application made during Stop Distance Test 7, for a lubricated, empty train, was conducted while the throttle setting was gradually decreased until the train came to rest. This resulted in powered braking, a situation that was atypical for the test program. An attempt was made to correct for this in a manner similar to the one used for corrections made in order to account for grades. The details of this method are also presented in Appendix B.

A summary of braking tests conducted with loaded test trains is shown in Table 3-3. The comparable information for tests conducted with empty test trains is provided in Table 3-4.

Table 3-3. Summary of Braking Distance Tests, Loaded Test Trains (Train Weight ~12,700 Tons)

Location (MP)	Grade (%)	Braking Distance Test No.	Test Run	Rail Conditions	Speed (MPH)	TOR Lubricant Status	Uncorrected Stopping Distance (ft.)	Corrected Stopping Distance (ft.)
Full Service Brake Applications								
322-323	-0.55	2	2	Dry	30	"Dry"	3251	2074
	-0.57	5	3	Damp	30	Lube	2634	1784
352-353	-0.11	3	2	Dry	30	"Dry"	2303	2132
	-0.118	6	3	Damp	30	Lube	2047	1901
Emergency Brake Applications								
322-323	-0.52	9	4	Dry	30	"Dry"	1136	957
	-0.54	11	5	Dry	30	Lube	1303	1065
	-0.51	13	6	Damp	29	Lube	1095	920

Table 3-4. Summary of Braking Distance Tests, Empty Test Trains (Train Weight ~2,400 Tons)

Location (MP)	Grade (%)	Braking Distance Test No.	Test Run	Rail Conditions	Speed (MPH)	TOR Lubricant Status	Uncorrected Stopping Distance (ft.)	Corrected Stopping Distance (ft.)
Full Service Brake Applications								
324-323	0.117	1	1	Dry	40	"Dry"	1891	1969
	0.117	4	2	Dry	40	"Dry"	1835	1908
	0.117	8	3	Wet	40	Lube	1914	1994
352-351	0.14	7*	3	Wet	40	Lube	2376	1613
Emergency Brake Applications								
324-323	0.44	10	4	Dry	38	"Dry"	971	1061
	0.38	12	5	Dry	39	Lube	1201	1314

*Results corrected for the application of brakes with throttle set at Postion 8.

The braking distance results listed in Tables 3-3 and 3-4 are illustrated in Figure 3-4. *It should be noted that no slippage of the wheels was observed throughout any of the braking tests.*

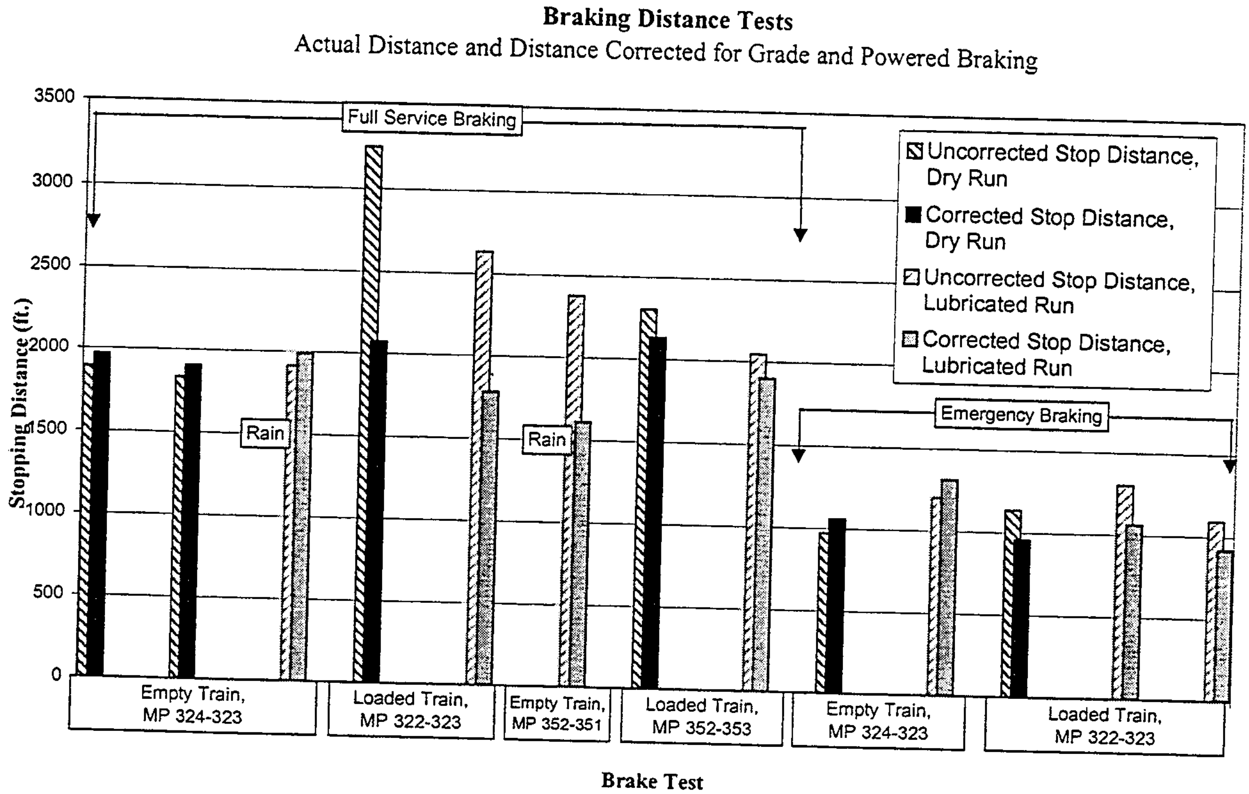

Figure 3-4. Stop Distance Test Results Conducted on Loaded and Empty Test Trains

Some notes should be made regarding the accuracy of these results:

- The manner in the brakes were applied in conjunction with the resetting of the distance counter introduces the possibility that brake application did not occur precisely at the milepost listed coincident with the zeroing of the counter. If the brakes were applied at 40 MPH within a range of ± 4 seconds about the time the distance counter was reset, an error of close to ± 235 feet could result. It was felt that the possibilities of these discrepancies were minimized due to our coordination with the crew throughout the series of tests.

- Results presented here indicate that the use of the TOR lubricant *at the delivery rate used in this test* did not impact the ability of the crew to bring the train to a stop within approximately the same distance as in normal operation.

3.3 TRIBOMETER MEASUREMENTS

Tribometer measurements were made on the top of the rails (at a location one (1) inch from the gage side of the head of the rail) before and after train passage. Use of the tribometer resulted in a single value of friction coefficient for a sampled length of rail approximately ten (10) to twelve (12) feet long. Four (4) to five (5) measurements were made at each test location in order to record the spatial variation in friction.

Measurements were made at the instrumented curve site and three (3) tangent track locations. A wayside lubrication device employed at the instrumented curve site, located approximately three hundred (300) feet south of the curve, introduced excessive amounts of grease which resulted in large variations in the measured friction coefficients in that region. The influence of wayside lubricators was not present at the tangent track locations. Records of all measurements are presented in Appendix C.

Figure 3-5 shows the spatial variation in the friction coefficient measurements made on the high and low rails of the instrumented curve before and after the empty test train passed through the wayside lubrication device during Run 4. For this case, the TOR lubrication was not utilized and the weather conditions were such that the rails were dry.

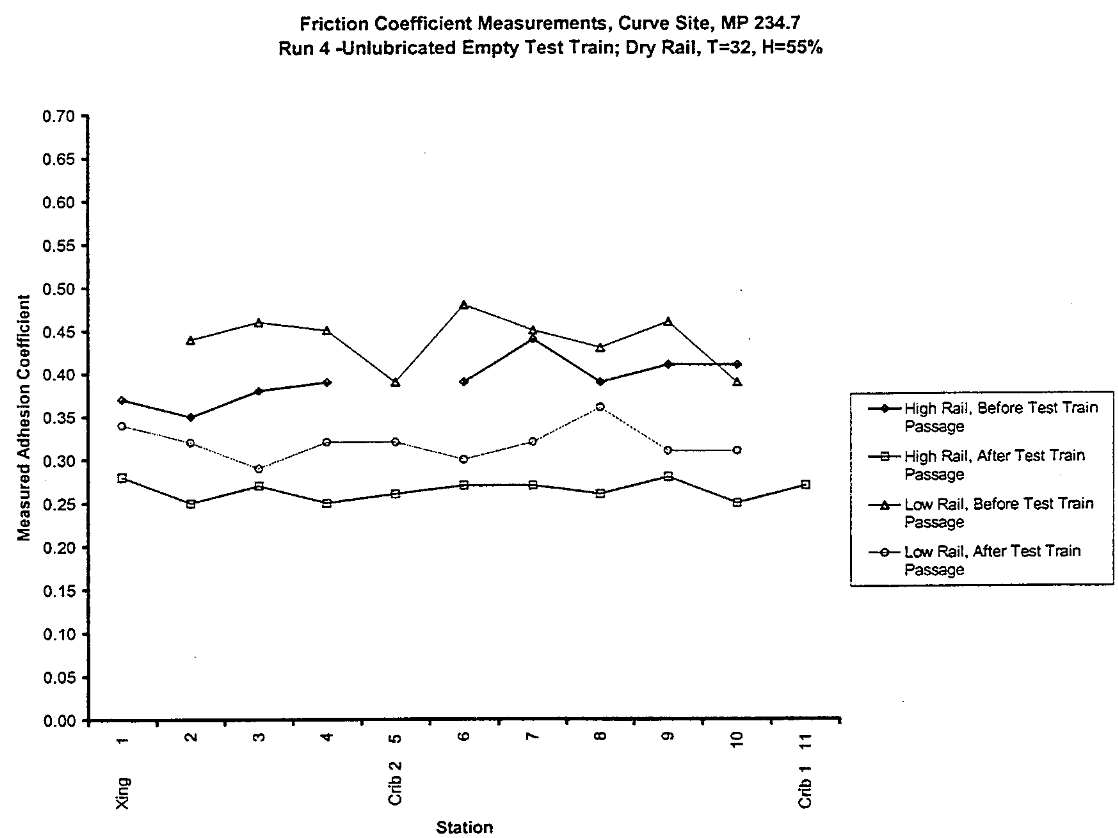

Figure 3-5. Friction Coefficient Measurements Made at Instrumented Curve Site, MP 234.7, Results from Run 4 for Passage of Unlubricated, Empty Test Train

Since the test train was not making use of the TOR lubricant, this figure illustrates the change in friction characteristics in the vicinity of the wayside lubricators due to normal traffic conditions. It can be seen that the friction coefficient on both rails decreased at each station by approximately 0.10. Due to the amount of lubricant dispensed on the south side of the instrumented curve, conclusions related to the amount of TOR lubricant remaining on the rail could not be reliably drawn from data collected prior to and following the passage of trains through the curve from the south.

Figure 3-6 presents the results from tribometer measurements made within the instrumented curve during Run 4 for the test train passing from the north, thereby avoiding the wayside lubricators. In this case, the test train was loaded but was not employing the TOR lubricant . It can be seen that friction coefficient values on both rails increased from values near 0.40 to values close to 0.50. This increase may be caused by the train "consuming" any lubrication present on the rail due to a train passing by the wayside lubricator and through the site prior to sampling.

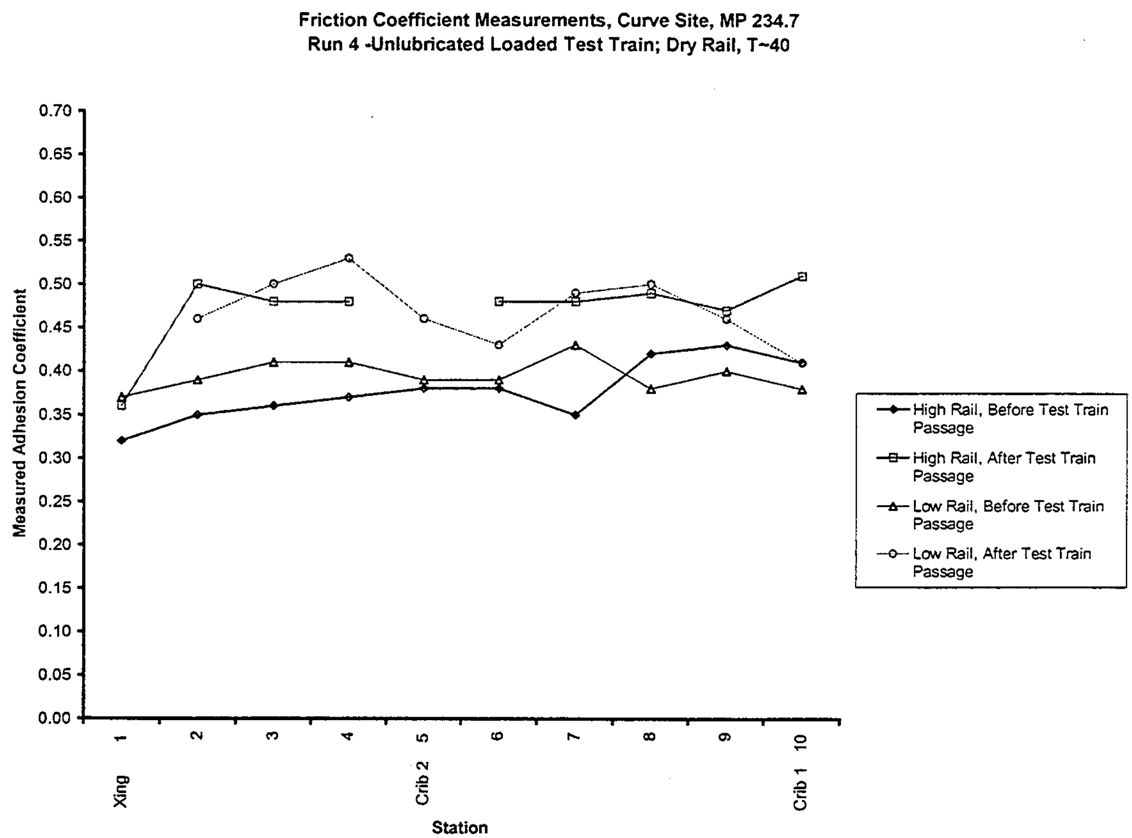

Figure 3-6. Friction Coefficient Measurements Made at Instrumented Curve Site, MP 234.7, Results from Run 4 for Passage of Unlubricated, Loaded Test Train

Results depicted in Figure 3.6 should be compared to those presented in Figures 3-7a and 3-7b. Figure 3-7a is a plot of the measurements made during Run 3 before and after the passage of a loaded test train employing the TOR lubricant. Figure 3-7b displays measurements made on the high rail during Run 6 for a test train operating under the same conditions. It should be noted that the rails were dry during Run 3 and damp during Run 6. Traffic conditions prohibited measurements to be made on the low rail during Run 6.

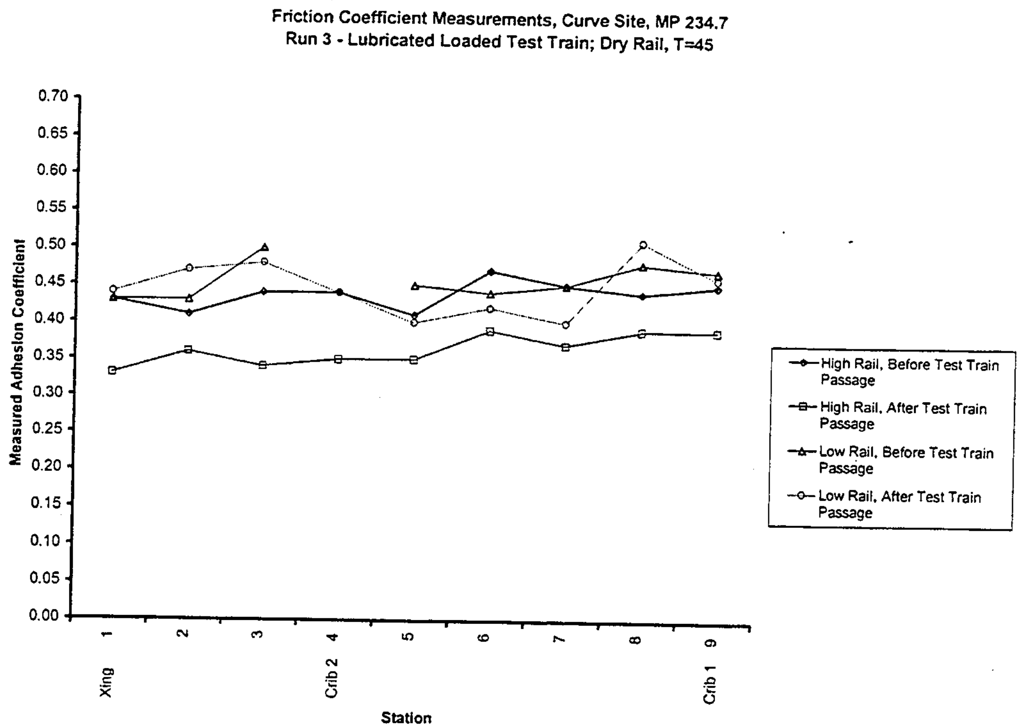

Figure 3-7a. Friction Coefficient Measurements Made at Instrumented Curve Site, MP 234.7, Results from Run 3 for Passage of Lubricated, Loaded Test Train

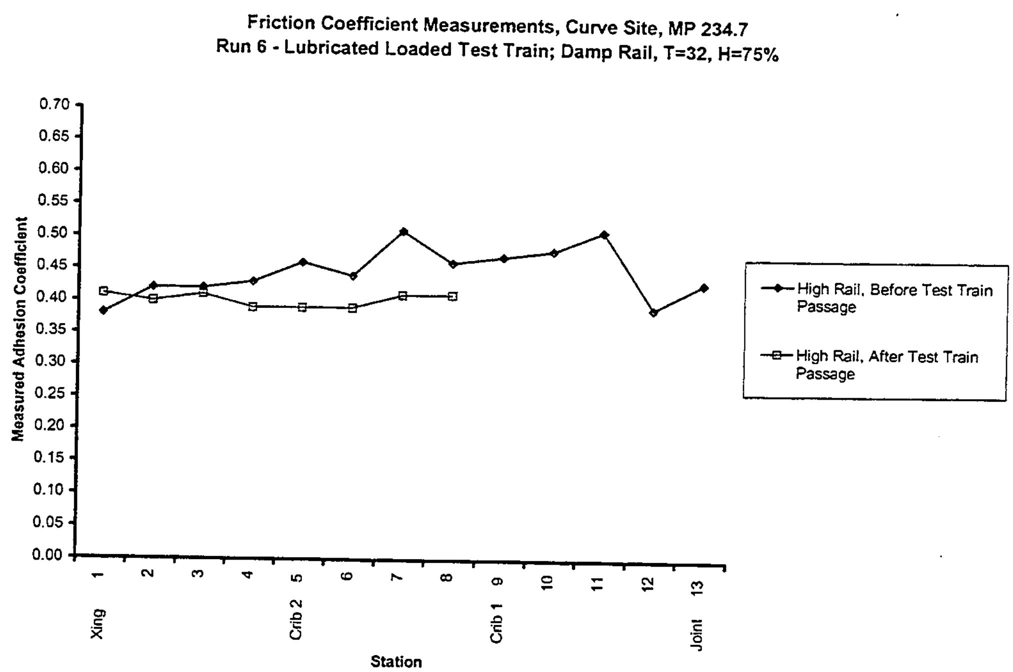

Figure 3-7b. Friction Coefficient Measurements Made at Instrumented Curve Site, MP 234.7, Results from Run 6 for Passage of Lubricated, Loaded Test Train

Results from the survey prior to and following the loaded test train utilizing the TOR lubricant exhibit an overall decrease in the measured friction coefficient. Considering Figure 3-7a, it can be seen that the most change can be seen in measurements made on the high rail, where friction coefficients measured before train passage ranged from 0.41 to 0.47 and friction coefficients measured after train passage varied between 0.33 and 0.39. Measurements made on the low rail ranged between 0.51 and 0.43 both before and after test train passage. Similar results are evident in Figure 3-7b, where it can be seen that there was a decrease in the friction coefficient measured after test train passage. These results may indicate that there was TOR lubricant remaining on the high rail of the curve. It should be noted that the minimum values found on the high rail after the lubricated test train were close to those shown in Figure 3-5 for the measurements made before and after the passage of the test train through the test zone and the wayside lubricators.

Due to the influence of the wayside lubricators, results of tribometer surveys conducted at the instrumented curve should be considered only in the sense that they provide insight into typical friction coefficients found within this route.

In order to judge the ability of the lubricant to be completely consumed by the consist, several tribometer surveys were made on tangent track, thereby avoiding the influence of wayside lubrication. Results of these tests varied, showing relatively no change in rail friction after train passage in some surveys and decreases in rail friction after train passage in other surveys. Figure 3-8 shows the results of tribometer measurements made at a tangent site for the loaded test train making a lubricated run. It can be seen that there was virtually no change in the friction coefficient measured on the top of the rails due to the passage of the test train. These results can be contrasted with those shown in Figure 3-9, where the friction coefficient values on both rails decreased from values near 0.5 to values close to 0.3.

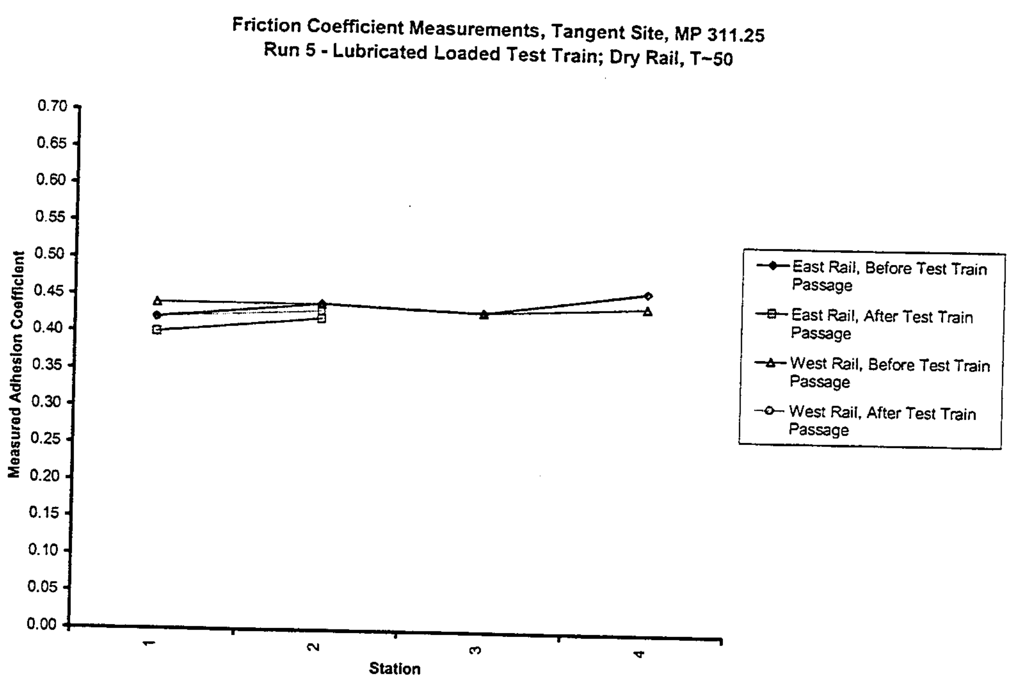

Figure 3-8. Friction Coefficient Measurements Made at Tangent Site, MP 311.25, Results from Run 5 for Passage of Lubricated, Loaded Test Train

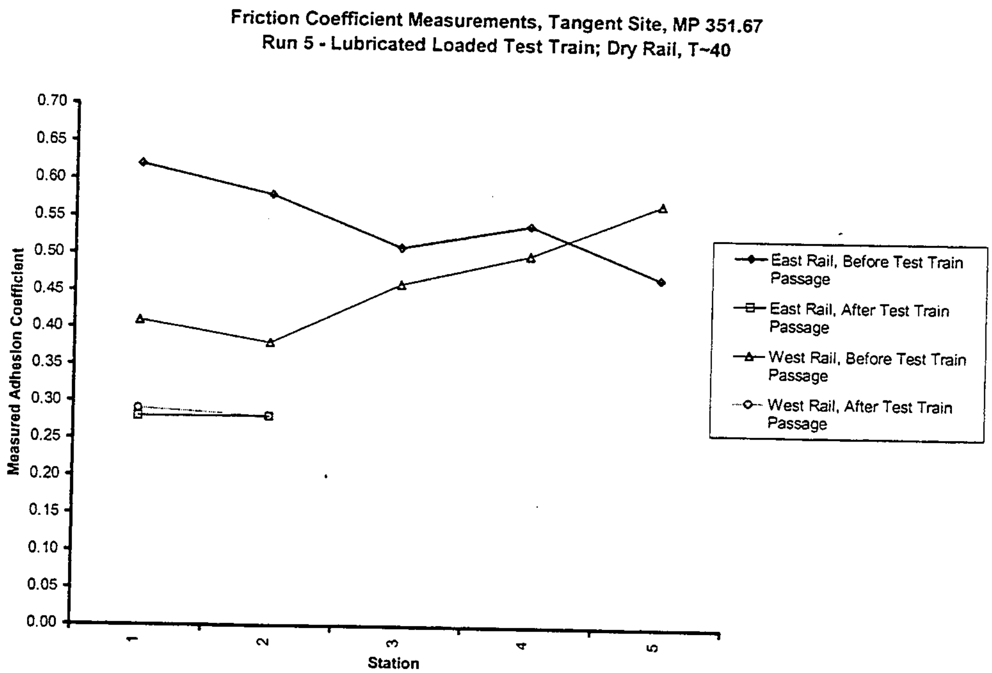

Figure 3-9. Friction Coefficient Measurements Made at Tangent Site, MP 351.67, Results from Run 5 for Passage of Lubricated, Loaded Test Train

Average values of measured friction coefficients were calculated for all surveys. These values are indicated in the Tables 3-5 and 3-6. Values reported in Table 3-5 were calculated based upon surveys taken at the various tangent sites. Average friction coefficients indicated in Table 3-6 pertain to data collected at the instrumented curve site.

Table 3-5. Average Friction Coefficient Measurements Before and After Train Passage, Tangent Sites

Run	TOR Lubricant Status	Train Condition	Location	Weather/ Rail Conditions	Avg. Coef., Rail 1 Before Train Passage	Avg. Coef., Rail 1 After Train Passage	Avg. Coef., Rail 2 Before Train Passage	Avg. Coef., Rail 2 After Train Passage	Comments
5	Yes	Loaded	Fagin Xing MP 311.25	Dry Rail, T~50	0.44	0.41	0.44	0.43	
5	Yes	Loaded	MP 351.67	Dry Rail, T~40	0.54	0.28	0.46	0.29	
5	Yes	Empty	MP 348.67	Dry Rail, T=68,H=52%	0.65	0.32	0.62	0.30	
6	Yes	Loaded	Fagin Xing MP 311.25	Slightly Damp Rail T=38, H=77%	0.57	0.32	0.61	0.31	
6	Yes	Empty	MP 351.67	Dry Rail, T=37,H=65%	0.37	0.38	0.37	0.40	

Table 3-6. Average Friction Coefficient Measurements Before and After Train Passage, Instrumented Curve Site

Run	TOR Lubricant Status	Train Condition	Direction	Weather/ Rail Conditions	Avg. Coef., High Rail Before Train Passage	Avg. Coef., High Rail After Train Passage	Avg. Coef., Low Rail Before Train Passage	Avg. Coef., Low Rail After Train Passage	Comments
-	No	Loaded/ Empty	N'bound	Drizzle, T~40	0.56*	0.21*	0.48*	0.38*	Revenue service trains; Samples taken at random times
3	Yes	Loaded	S'bound	Dry Rail, T=45	0.44	0.36	0.46	0.45	Wayside lube present.
4	No	Loaded	S'bound	Dry Rail, T~40	0.37	0.47	0.40	0.48	Wayside lube present.
4	No	Empty	N'bound	Dry Rail, T=32, H=55%	0.39	0.27	0.45	0.32	Wayside lube present.
5	Yes	Loaded	S'bound	Dry Rail, T=60, H=76%	0.40	0.34	0.31	0.37	Wayside lube present.
5	Yes	Empty	N'bound	Dry Rail, T=59, H=36%	0.39	0.27	-	-	No time to do low rail; Heavy lube on rail
6	Yes	Loaded	S'bound	Flurries, T=32, H=75%	0.45	0.40	0.50	-	No time to do low rail after train.
6	Yes	Empty	N'bound	Dry Rail, T=54, H=55%	0.51	0.28	0.49	0.35	No excessive lube.

* Values correspond to samples taken randomly during passage of revenue trains (do not pertain to passage of particular train).

It should be noted that the measurements made near the wayside lubricators during normal revenue service (presented in the first line of Table 3-6) indicate a wide range of friction coefficient values that can be found under normal operating conditions. Values ranging between 0.21 and 0.56 were found at the curve site due to the passage of normal traffic. The entries in the table for this particular survey do not correspond to the passage of a single train. Results are presented in this manner to illustrate the range of friction environments that can be encountered.

3.4 LATERAL CURVING FORCES

The objectives that were to be addressed by the measurements made at the instrumented curve site were the assessment of the consumption of TOR lubricant under the train and the effect on curving forces attributable to the use of the TOR lubricant. Due to two (2) difficulties that presented themselves throughout the test, these objectives were not met.

As described in the previous section, a wayside lubrication device was located approximately three hundred (300) feet south of the instrumented curve site. This lubricator introduced excessive amounts of grease which resulted in large variations in the measured friction coefficients. The excessive grease also introduced a large amount of uncertainty in the ability to discern the effect on curving forces attributable to the TOR lubricant.

The development of a problem with the data collection system employed at the instrumented curve site introduced a large amount of uncertainty into the force data at the site. The system would terminate data collection after the passage of fifteen (15) to twenty cars (20). In order to collect data pertaining to the entire test train, the system had to be restarted a number of times, with each restart resulting in a "gap" of the force time history. This made the task of comparing loads for the same cars of the train under different conditions difficult.

Due to the combination of events surrounding the collection of wayside force data, results stemming from these measurements will not be presented within this document and no substantial conclusions regarding the the extent of lubricant under the train and the reduction in curving forces can be drawn from wayside force data. A number of studies have been conducted to quantify curving force reduction attributable to the use of TOR lubricant[1,2]. The reader is encouraged to consult these studies for information related to this issue.

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[1] Reiff, Richard P., Scott Gage & Sudhir Kumar. TOP-OF-RAIL LUBRICATION ENERGY TEST. U.S. Department of Transportation Report Number DOT/FRA/ORD-98/01, February 1998.

[2] Runyon, Robert S. & Sudhir Kumar. TOP-OF-RAIL LUBRICATION. Presented at the 1996 Annual Meeting of the Locomotive Maintenance Officers Association, September 16, 1996.

3.5 FUEL CONSUMPTION

3.5.1 Comparable Runs

In revenue service, it is generally not possible to have two complete runs of the same train on the same track be very similar. The speed profiles and the number of stops vary depending on traffic and track conditions. This makes comparisons of parameters, such as fuel consumption, difficult. It was with these difficulties in mind that the test zone was divided into segments, as described in Section 1.3.1.

As a matter of convention, segments referred to by numbers 1 through 12 contain information for loaded trains and segments referred to 13 through 24 provided information on the empty train (see Tables 1-1 and 1-2). All train performance related data gathered was plotted for each segment from Runs 2 through 6. The average speed, speed profile and the number of stops were then compared for "dry" and lubricated runs for each segment. It was found that ten (10) paired run segments out of a total sixty (60) were comparable for empty trains. For the loaded trains, fourteen (14) pairs of comparable segments were found. Tables 3-7 and 3-8 summarize all comparable test runs. The tabulation of parameters used to judge the comparability of all segments is given in Appendix D.

Table 3-7. Comparable Test Segments, Loaded Test Trains

Segment	Comparable Run From Unlubricated Tests	Comparable Run From Lubricated Tests
1	2	6
2	2	6
	4	3
3	2	3
	4	6
4	2	3
	4	5
5	4	3
	2	6
8	4	6
9	2 4	3 5 6
12	2 4	5 6

Table 3-8. Comparable Test Segments, Empty Test Trains

Segment	Comparable Run From Unlubricated Tests	Comparable Run From Lubricated Tests
13	2	5
14	4	5
16	2	5
17	4	5
19	2	5
	4	3
20	2	3
22	4	3
23	4	6
24	2	6

3.5.2 Comparison of Fuel Meter Readings

As described in Section 2.1.5, turbine type fuel flow meters were used to determine the amount of fuel used by each of the three (3) locomotives. Two meters were employed on each locomotive – one applied in the engine fuel supply line and one applied in the fuel return line. The difference between simultaneous readings of these meters indicated the amount of fuel used by the engine. Data from the six (6) meters were recorded manually by observing digital readout devices located on board the Research Car. Readings were made as the test train entered and exited each of the specified test zone segments. Readings were also made before and after the train was stopped in order to account for fuel consumed during times when the power units were idling.

Fuel meter readings were considered for the comparable cases listed in Tables 3-7 and 3-8. Fuel consumption was calculated for each of the appropriate test segments. The details of these calculations are included in Appendix D. Values of fuel consumption applying to unlubricated test cases were compared to the corresponding cases for the lubricated tests. Fuel savings were determined for each of the comparable segments. These are shown in Tables 3-9 and 3-10. As indicated below each table, the average fuel savings observed with loaded trains was 10.13 % and that corresponding to the empty trains was 5.35 %.

Table 3-9. Fuel Savings for Comparable Segments in Different Runs, Loaded Test Trains

Segment	Unlubricated Tests		Lubricated Tests		% Savings	Average % Savings
	Run	Fuel Consumed (gallons)	Run	Fuel Consumed (gallons)		
1	2	252	6	204	19.05	19.05
2	2	562	6	522	7.18	4.56
	4	500	3	490	2.00	
3	2	17	3	9	47.06	32.79
	4	27	6	22	18.52	
4	2	64	3	69	-7.81	5.77
	4	62	5	50	19.36	
5	4	588	3	554	5.78	2.80
	2	556	6	557	-0.18	
8	4	111	6	109	1.80	1.80
9	2 4	135 143 Avg. – 139	3 5 6	125 125 135 Avg. – 128	7.91	7.91
12	2 4	547 548 Avg. – 547.5	5 6	511 514 Avg. – 512.5	6.39	6.39

Overall Average From All Segments 10.13

Table 3-10. Fuel Savings for Comparable Segments in Different Runs, Empty Test Trains

Segment	Unlubricated Tests		Lubricated Tests		% Savings	Average % Savings
	Run	Fuel Consumed (gallons)	Run	Fuel Consumed (gallons)		
13	2	317	5	284	10.41	10.41
14	4	173	5	168	2.89	2.89
16	2	85	5	70	17.65	17.65
17	4	94	5	87	7.45	7.45
19	2	297	5	251	15.49	14.91
	4	258	3	221	14.34	
20	2	250	3	231	7.60	7.60
22	4	91	3	88	3.29	3.29
23	4	29	6	36	-24.14	-24.14
24	2	174	6	160	8.05	8.05

Overall Average From All Segments 5.35

3.6 ELECTRICAL ENERGY

Measurement of the electrical energy is an accurate means to determine the energy requirements associated with the movement the train. This measurement, as well as the determination of mechanical energy, was made to serve as a compliment to results determined with fuel consumption measurements. Fuel consumption over a distance is dependent on the manner in which the train was operated. Compensation for this fact was made by considering only comaprable segments (see Section 3.5.1). Direct measurements and determination of energy expenditures reflect the manner in which the train was operated, thereby providing an accurate assessment of energy requirements.

As was done with assessment of notch dwell time, values of electrical energy expenditure were obtained from the trip monitors and compared to measurements made with the data acquisition system on the Research Car. Upon analysis of the signals originating on the lead locomotive, CSXT 8328, it was decided that the electical energy outputs measured using the data acquisition system would not be considered in the analysis. The signal to noise ratio from the main generator voltage and current pertaining to the lead locomotive was not acceptable. Considering the fact that the trip monitor readings served as a redundant measurement of the electrical signals from the remaining locomotives, it was decided that attention be focused on trip monitor results.

Energy readings were recorded from the trip monitors located on the middle and trailing SD60 locomotives (units 8702 and 8709, respectively) throughout the series of tests. Measurements were not recorded from the lead locomotive, SD40 unit 8328, due to the SD40's computer lack of capability to measure the kW-Hrs. and notch dwell time information. Data was recorded from the middle and trail locomotives for the loaded trips and the trail locomotive for the empty trips. The middle locomotive was "taken off-line", or not used for power, during the return trips of the empty trains in keeping with standard operating procedures of CSXT.

Data was gathered from the trip monitors for loaded and empty trips during Runs 2, 3, 4, 5 and 6. All recorded data is provided in Appendix E.

Electrical energy data recorded from the trip monitors is shown in Table 3-11. The average electrical energy outputs of locomotives pulling lubricated and unlubricated loaded trains are compared to those of the locomotives pulling the lubricated and unlubricated empty trains. These comparisons are presented in Table 3-12. It should be noted that data pertaining to the trip of the empty train conducted during Run 5 was not recorded. This was inadvertent.

Table 3-11. Electrical Energy Readings Made From Trip Monitor

Trip Number	kW-Hrs. From Unlubricated (Dry) Tests				kW-Hrs. From Lubricated Tests			
	Locomotive 8709 Loaded	Locomotive 8702 Loaded	Locomotive 8709 Empty	Total For Roundtrip	Locomotive 8709 Loaded	Locomotive 8702 Loaded	Locomotive 8709 Empty	Total For Roundtrip
2	12751	11561	9297	33609				
3					11691	10377	8239	30307
4	12387	10386	9157	31930				
5					12099	10412	*	-
6					11359	10188	8503	30050
Average	12569	10974	9227	32770	11716	10326	8371	30179

*Empty trip readings for Run 5 were not taken, thereby eliminating this case from consideration when looking at kW-Hr. expenditures for round trips.

Table 3-12. Summary of Average Electrical Energy Outputs Based on Trip Monitor Readings

	Average kW-Hrs. From Unlubricated (Dry) Tests			Average kW-Hrs. From Lubricated Tests		
	Locomotive 8709 Loaded	Locomotive 8702 Loaded	Locomotive 8709 Empty	Locomotive 8709 Loaded	Locomotive 8702 Loaded	Locomotive 8709 Empty
Average of Individual Cases	12569	10974	9227	11716	10326	8371
Average for Locomotives Pulling Loaded Test Train	11771		-	11021		-
Average for Locomotives Pulling Empty Test Train	-		9227	-		8371

Average Energy Savings, Loaded Trains 6.38 %

Average Energy Savings, Empty Trains 9.28 %

As can be seen in Table 3-12, the average electrical energy expended for unlubricated, or "dry-baseline" runs was 11,771 kW-Hrs. for the trips made with the loaded train and 9227 kW-Hrs. for the trips made with the empty train. The average electrical energy expended for the lubricated runs was 11,021 kW-Hrs. for the trips made with the loaded train and 8371 kW-Hrs. for the trips made with the empty train. Comparison of these results indicates that there was 6.38 % reduction in expended electrical energy for the loaded lubricated runs and 9.28 % reduction in expended electrical energy for the empty lubricated runs. An evaluation of the reduction in expended electrical energy for a "round-trip" consisting of one movement of a loaded train and a return trip made with an empty train can be arrived at by totaling the results from the loaded and empty movements of the train under each condition of lubrication and comparing the results. Following through on this procedure will yield a 7.19 % reduction of expended electrical energy for a round trip based on average measurements.

These findings are illustrated in Figure 3-10.

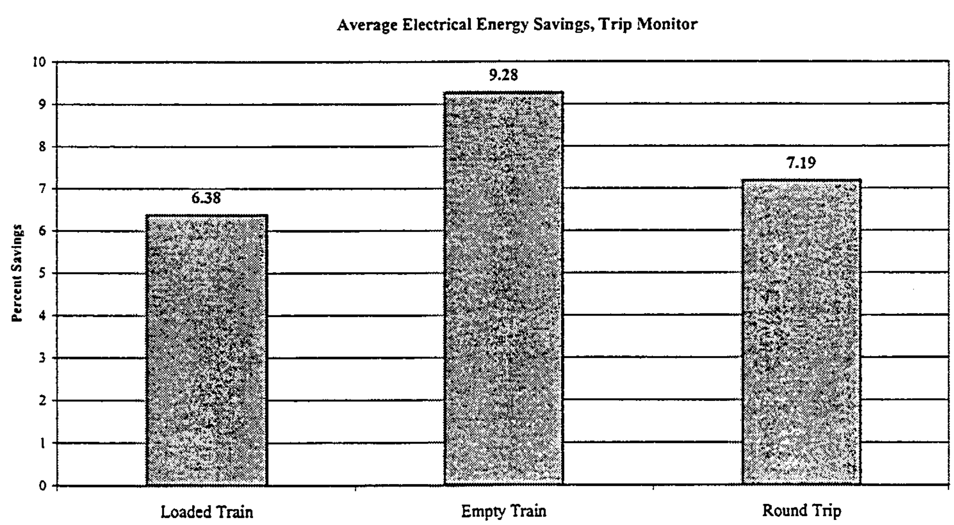

Figure 3-10. Average Electrical Energy Savings Arrived at Using Trip Monitor

Two items should be kept in mind when regarding these, as well as other, results:

- As pointed out in Section 1.3, the term "unlubricated" or a "dry" condition refers to the lack of TOR lubricant. Locomotive flange lubricators and wayside lubricators were fully operational throughout the tests. The results presented indicate the effect of the TOR lubricant over and above existing lubrication practices.

- The numbers reported in this section correspond to results from two of the three locomotives used throughout the tests. Although the results do not represent the total amount of electrical energy expended in each run (due to the lack of information from the lead locomotive), comparisons of the measurements do lend themselves to the evidence of the effect of the additional lubrication.

3.7 MECHANICAL ENERGY

Measurement of mechanical energy does not provide as accurate a measurement of energy requirements as that of electrical energy. Mechanical energy measurements do not accurately capture energy expenditures during initial movements of the train where friction, gravity and slack "take-up" can contribute significantly. Mechanical energy does provide for data of interest in situations such as pulling a consist up an incline and provides a point of comparison for electrical energy measurements. Mechanical energy was calculated for all test segments in each of the six test runs. The drawbar force, measured with the Research Car's instrumented coupler, is combined with the train speed and the duration of the drawbar force at a given speed. Since data was sampled at regular intervals, force duration was easily determined. These quantities were combined in the following manner:

Force (lbs.) x Speed (MPH) x Time (Hours) = Mechanical Energy, lb.-miles

In order to convert mechanical energy to comparable units, the following constant is applied:

1 Kilowatt-Hour of mechanical energy = 502.681 lb.- miles [2]

thus,

(Force [lbs.]/502.681) x Speed (MPH) x Time (Hours) = kW-Hrs.

Mechanical energy (in kW-Hrs.) was calculated for every segment within each trip. It should be restated at this time that segments 1 through 12 represent the trips made with the loaded train and segments 13 through 24 represent the trips made with the empty train. The mechanical energy values determined for all segments are given in Appendix F.

The average mechanical energy associated with each segment was determined for both "dry" and lubricated runs. Comparisons of the findings are illustrated in Figure 3-11.

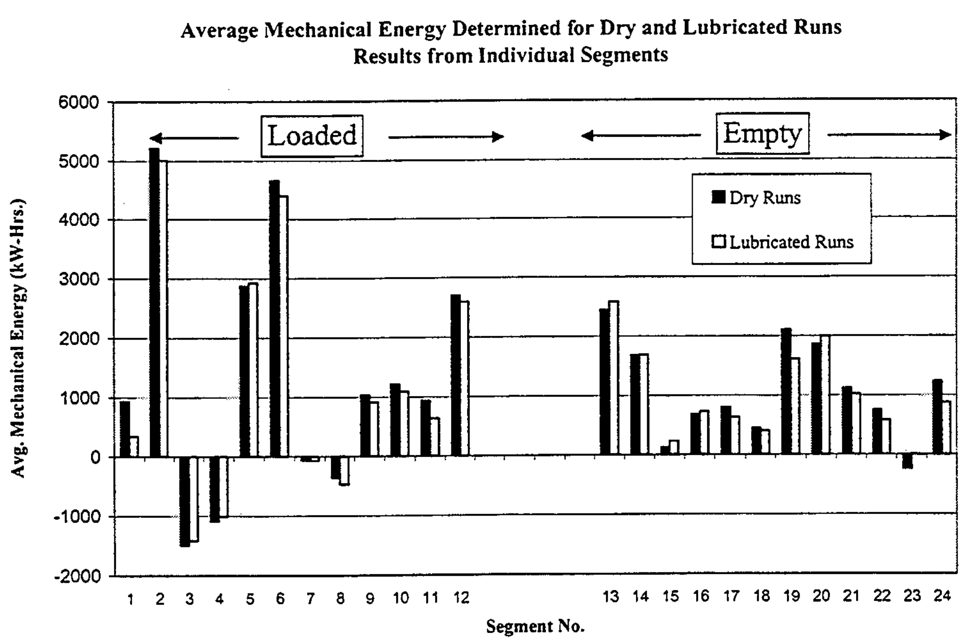

Figure 3-11. Average Mechanical Energy Values Determined for Each Segment of Test Route

[2] Reiff, Richard P., Scott Gage & Sudhir Kumar. TOP-OF-RAIL LUBRICATION ENERGY TEST. U.S. Department of Transportation Report Number DOT/FRA/ORD-98/01, February 1998.

Considering results pertaining to the loaded trains, average mechanical energy values under lubricated conditions were observed to be lower than values under "dry" conditions in nine of the twelve segments. Considering trips made with empty trains, six of the twelve segments exhibited lower values of average mechanical energy under lubricated conditions than under "dry" conditions.

The average mechanical energy calculations, summarized in Table 3-13, show 7.53% less energy used during the lubricated round trip runs than during the unlubricated, or "dry", round trip runs. The "dry," or baseline, energy values (which averaged 27002.5 kW-Hrs.) were collected during Runs 2 and 4, while the lubricated energy values (which averaged 24969.6 kW-Hrs.) were collected during Runs 3, 5 and 6.

Table 3-13. Average Mechanical Energy Calculations for Test Runs

	Unlubricated Tests			Lubricated Tests				% Savings Based on Avg. Results
	Run 2	Run 4	Average	Run 3	Run 5	Run 6	Average	
Mech. Energy (kW-Hrs.) Loaded Trains	16586.5	13646.9	15116.7	12980.6	12996.9	15028.4	13668.6	9.58
Mech. Energy (kW-Hrs.) Empty Trains	12482.9	11288.6	11885.8	12006.5	10660.5	11236.0	11301.0	4.92
Total Mech. Energy	29069.5	24935.5	27002.5	24987.1	23657.4	26264.4	24969.6	7.53

These results are illustrated in Figure 3-12.

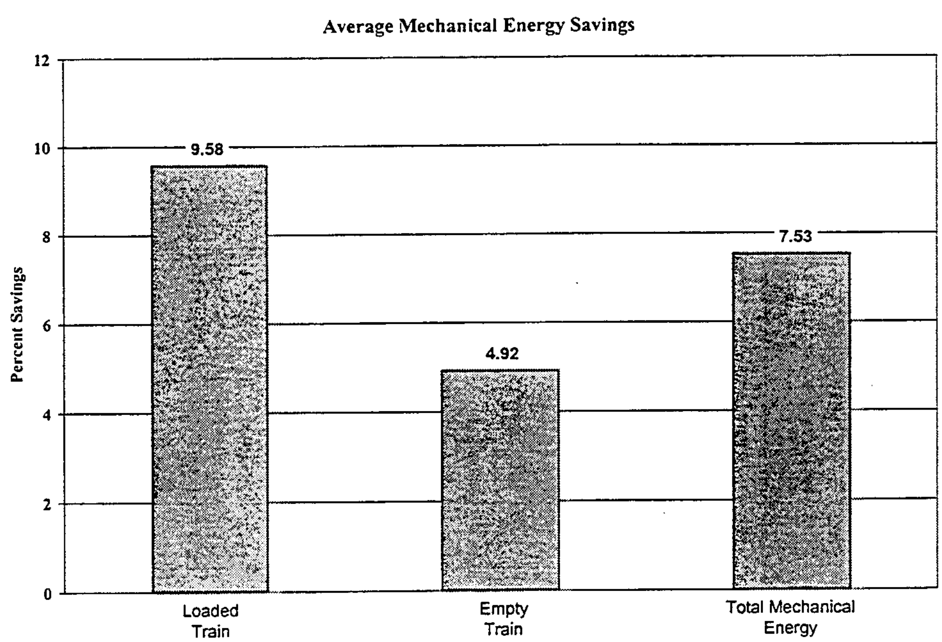

Figure 3-12. Average Mechanical Energy Savings Calculated for Test Runs

3.8 CRITICAL SPEED FOR TRUCK HUNTING

Lateral accelererations experienced on the leading hopper car were monitored for evidence of truck hunting. The accelerometer was mounted to the center sill of the car and monitored during runs made with the empty trains. Focusing on the empty, lead hopper provided an opportunity to observe a "worst case" scenario, due to the fact that the lead car was exposed to the highest level of TOR lubricant.

No evidence of truck hunting was observed in the series of tests. The critical speed for the development of unstable motion was evidently higher than 40 MPH, the top speed of the trains comprised of empty hopper cars.

4.0 FINDINGS AND DISCUSSION

Results discussed in the previous chapter are summarized and discussed within this chapter. All conclusions that can be drawn from the discussions presented here will be summarized in Chapter 5.

The present discussion of the findings is written in response to the issues identified as the test objectives (stated in Section 1.1). Results pertaining to safety related issues are discussed first and those pertaining to performance related issues are discussed subsequently.

It should be noted that the tests were conducted under the following conditions:

- The unlubricated, or "dry", rail condition was considered as one with the TOR lubrication system turned off and both wayside and wheel flange lubricators operating fully. The lubricated rail condition was one with the TOR lubrication system being employed in addition to the wayside and flange lubricators. Changes or improvement in performance were thus measured over and above the levels obtained by lubrication practices currently employed by CSXT.

- The TOR lubricant was delivered at one rate throughout the test (aside from a slight modification to the system after the initial lubricated test). Therefore, all results presented here pertain to the conditions corresponding to the single TOR lubricant delivery rate. The ramifications of dispensing excessive amounts of TOR lubricant are outside the range of study conducted for this test.

4.1 SAFETY RELATED ISSUES

The safety related concerns that served as objectives for this investigation were:

- What is the effect of the lubrication system on train handling/speed control?

- What is the effect of the lubrication system on braking, including stop distance and wheel slip?

- What is the distribution of lubricant under the train, including the amount of lubricant remaining on the rails following a train passage and its influence on subsequent traffic?

- What is the effect of the lubrication on the lateral curving forces?

The answers to these questions were sought by considering the results from the study of the notch dwell times, the conduction of the stop distance testing, the tribometer surveys and the instrumented curve site tests.

4.1.1 Effect of TOR Lubrication on Train Handling/Speed Control

The study of the notch dwell time is important to consideration of the train handling issues and the study of the energy consumption. The results of the notch dwell time with respect to the handling of the train will be addressed in this section. The impact of the notch dwell time study on the issue of energy consumption will be addressed in Section 4.2.1.

Based on average results cited in the previous chapter, the dwell time for throttle settings 8 and 7 decreased 4.48 % and 11.11 %, respectively, for loaded trains when using the TOR lubricant. The dwell time for throttle settings 8 and 7 decreased 13.89 % and 11.11 %, respectively, for the empty trains when using the TOR lubricant. This indicates that the higher throttle settings were not needed "as much" when utilizing the TOR lubricant.

The dynamic brake times were found to be longer for the lubricated runs than the times for the "dry" runs. The increase in time spent in dynamic braking mode can be attributed to the decreased rolling resistance of the train during lubrication. Readings made from the monitors are documented in Appendix E.

Speed control did not appear to be compromised with the use of the TOR lubrication. Results of notch dwell time consideration are presented in Tables 4-1 and 4-2. The dwell time in each throttle position, as well as idle time and time in dynamic braking, were determined as a percentage of the overall time in the particular segment. Results of this consideration were then compared for the segments deemed comparable in the fuel consumption study (the segments where the trains were operated in similar manners). The number of throttle position changes and average speeds of the consist in each of the test runs are also summarized in Tables 4-1 and 4-2.

As can be seen, there was little variation in the speeds when considering results from lubricated tests against those from unlubricated tests. The number of throttle position changes did vary between comparable runs, but there seems to be no pattern to this variation (i.e. lubricated test results were not consistently higher or lower than unlubricated test results). This may indicate the difficulty in operating the train in the same fashion during different test runs. The notch dwell times, as a percentage of total time within the segment, did not vary significantly between the lubricated and unlubricated runs considered. These results may indicate that the train handling was not adversely affected by the presence of the lubricant.

Table 4-1. Summary of Average Speeds, Number of Throttle Position Changes and Percentage of Dwell Times for Comparable Test Segments, Loaded Test Trains

Segment	Unlubricated Tests				Lubricated Tests			
	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)
1	2	27.1	86	Pos1 2 Pos6 5 Pos2 3 Pos7 5 Pos3 3 Pos8 23 Pos4 4 Idle 4 Pos5 7 DB 44	6	33.4	64	Pos1 2 Pos6 5 Pos2 5 Pos7 3 Pos3 3 Pos8 26 Pos4 3 Idle 3 Pos5 4 DB 45
2	2	15.6	43	Pos1 0 Pos6 8 Pos2 1 Pos7 10 Pos3 3 Pos8 61 Pos4 7 Idle 0 Pos5 8 DB 0	6	15.0	29	Pos1 0 Pos6 8 Pos2 2 Pos7 5 Pos3 1 Pos8 78 Pos4 1 Idle 0 Pos5 5 DB 0
	4	18.3	32	Pos1 1 Pos6 4 Pos2 1 Pos7 12 Pos3 2 Pos8 72 Pos4 3 Idle 0 Pos5 6 DB 0	3	18.7	44	Pos1 1 Pos6 14 Pos2 1 Pos7 8 Pos3 2 Pos8 66 Pos4 1 Idle 0 Pos5 7 DB 0

Table 4-1(cont.). Summary of Average Speeds, Number of Throttle Position Changes and Percentage of Dwell Times for Comparable Test Segments, Loaded Test Trains

Segment	Unlubricated Tests				Lubricated Tests			
	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)
3	2	20.0	8	Pos1 2 Pos6 0 Pos2 2 Pos7 0 Pos3 5 Pos8 0 Pos4 2 Idle 8 Pos5 0 DB 81	3	22.7	4	Pos1 1 Pos6 0 Pos2 1 Pos7 0 Pos3 2 Pos8 0 Pos4 0 Idle 3 Pos5 0 DB 93
3	4	17.3	11	Pos1 4 Pos6 1 Pos2 2 Pos7 2 Pos3 0 Pos8 0 Pos4 1 Idle 1 Pos5 1 DB 87	6	17.0	10	Pos1 1 Pos6 2 Pos2 3 Pos7 0 Pos3 4 Pos8 0 Pos4 3 Idle 1 Pos5 2 DB 85
4	2	29.4	23	Pos1 1 Pos6 2 Pos2 1 Pos7 2 Pos3 1 Pos8 10 Pos4 5 Idle 5 Pos5 3 DB 71	3	30.3	31	Pos1 1 Pos6 4 Pos2 2 Pos7 4 Pos3 6 Pos8 8 Pos4 2 Idle 3 Pos5 4 DB 66
4	4	22.9	30	Pos1 13 Pos6 1 Pos2 4 Pos7 1 Pos3 11 Pos8 6 Pos4 5 Idle 3 Pos5 1 DB 56	5	19.0	28	Pos1 6 Pos6 0 Pos2 5 Pos7 0 Pos3 5 Pos8 0 Pos4 9 Idle 3 Pos5 3 DB 70
5	4	23.5	78	Pos1 4 Pos6 1 Pos2 4 Pos7 1 Pos3 3 Pos8 46 Pos4 3 Idle 4 Pos5 2 DB 32	3	24.0	91	Pos1 4 Pos6 5 Pos2 2 Pos7 5 Pos3 3 Pos8 36 Pos4 5 Idle 4 Pos5 5 DB 32
5	2	21.1	49	Pos1 3 Pos6 3 Pos2 4 Pos7 3 Pos3 10 Pos8 25 Pos4 16 Idle 1 Pos5 6 DB 29	6	22.0	158	Pos1 3 Pos6 6 Pos2 6 Pos7 2 Pos3 7 Pos8 24 Pos4 7 Idle 6 Pos5 10 DB 29
8	4	18.3	16	Pos1 1 Pos6 1 Pos2 1 Pos7 1 Pos3 1 Pos8 25 Pos4 1 Idle 2 Pos5 1 DB 66	6	18.0	16	Pos1 1 Pos6 1 Pos2 1 Pos7 1 Pos3 1 Pos8 25 Pos4 1 Idle 3 Pos5 1 DB 66

Table 4-1(cont.). Summary of Average Speeds, Number of Throttle Position Changes and Percentage of Dwell Times for Comparable Test Segments, Loaded Test Trains

Segment	Unlubricated Tests				Lubricated Tests			
	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)
9	2	30.4	38	Pos1 3 Pos6 5 Pos2 2 Pos7 7 Pos3 6 Pos8 24 Pos4 7 Idle 4 Pos5 14 DB 28	3	30.7	42	Pos1 2 Pos6 10 Pos2 3 Pos7 5 Pos3 4 Pos8 20 Pos4 13 Idle 5 Pos5 7 DB 31
					5	32.0	42	Pos1 3 Pos6 4 Pos2 2 Pos7 4 Pos3 10 Pos8 24 Pos4 8 Idle 4 Pos5 10 DB 31
	4	31.0	33	Pos1 0 Pos6 12 Pos2 4 Pos7 5 Pos3 2 Pos8 32 Pos4 7 Idle 12 Pos5 5 DB 22	6	30.0	37	Pos1 2 Pos6 4 Pos2 5 Pos7 5 Pos3 7 Pos8 29 Pos4 7 Idle 3 Pos5 5 DB 34
12	2	24.6	40	Pos1 2 Pos6 4 Pos2 3 Pos7 11 Pos3 3 Pos8 27 Pos4 3 Idle 1 Pos5 6 DB 39	5	25.0	52	Pos1 1 Pos6 4 Pos2 2 Pos7 4 Pos3 2 Pos8 37 Pos4 2 Idle 2 Pos5 2 DB 44
	4	25.2	57	Pos1 1 Pos6 3 Pos2 11 Pos7 1 Pos3 6 Pos8 41 Pos4 4 Idle 2 Pos5 2 DB 30	6	22.0	91	Pos1 3 Pos6 4 Pos2 6 Pos7 6 Pos3 4 Pos8 26 Pos4 5 Idle 8 Pos5 6 DB 31

Table 4-2. Summary of Average Speeds, Number of Throttle Position Changes and Percentage of Dwell Times for Comparable Test Segments, Empty Test Trains

Segment	Unlubricated Tests				Lubricated Tests			
	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)
13	2	34.3	82	Pos1 1 Pos6 5 Pos2 3 Pos7 10 Pos3 5 Pos8 34 Pos4 6 Idle 2 Pos5 10 DB 25	5	33.0	93	Pos1 8 Pos6 6 Pos2 7 Pos7 9 Pos3 10 Pos8 26 Pos4 6 Idle 7 Pos5 5 DB 17
14	4	44.9	53	Pos1 4 Pos6 5 Pos2 6 Pos7 5 Pos3 5 Pos8 52 Pos4 14 Idle 0 Pos5 10 DB 0	5	44.0	66	Pos1 6 Pos6 10 Pos2 6 Pos7 13 Pos3 5 Pos8 43 Pos4 4 Idle 2 Pos5 7 DB 2

Table 4-2(cont.). Summary of Average Speeds, Number of Throttle Position Changes and Percentage of Dwell Times for Comparable Test Segments, Empty Test Trains

Segment	Unlubricated Tests				Lubricated Tests			
	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)	Run	Avg. Speed (MPH)	No. of Notch Changes	Notch Dwell Time (% of Total Segment Time)
16	2	42.0	27	Pos1 2 Pos6 7 Pos2 4 Pos7 20 Pos3 7 Pos8 25 Pos4 6 Idle 2 Pos5 5 DB 22	5	40.0	24	Pos1 0 Pos6 11 Pos2 8 Pos7 11 Pos3 10 Pos8 16 Pos4 14 Idle 4 Pos5 7 DB 19
17	4	24.1	30	Pos1 0 Pos6 5 Pos2 38 Pos7 3 Pos3 13 Pos8 34 Pos4 5 Idle 0 Pos5 2 DB 0	5	24.0	33	Pos1 2 Pos6 11 Pos2 34 Pos7 9 Pos3 13 Pos8 19 Pos4 4 Idle 2 Pos5 3 DB 33
19	2	30.9	160	Pos1 5 Pos6 6 Pos2 6 Pos7 8 Pos3 10 Pos8 21 Pos4 10 Idle 5 Pos5 6 DB 22	5	27.0	110	Pos1 8 Pos6 4 Pos2 10 Pos7 5 Pos3 6 Pos8 14 Pos4 7 Idle 7 Pos5 12 DB 28
	4	33.8	194	Pos1 7 Pos6 10 Pos2 8 Pos7 6 Pos3 8 Pos8 19 Pos4 8 Idle 7 Pos5 8 DB 19	3	29.4	144	Pos1 0 Pos6 5 Pos2 13 Pos7 4 Pos3 12 Pos8 12 Pos4 7 Idle 13 Pos5 6 DB 27
20	2	33.3	68	Pos1 4 Pos6 7 Pos2 7 Pos7 10 Pos3 7 Pos8 19 Pos4 15 Idle 6 Pos5 10 DB 15	3	31.4	99	Pos1 0 Pos6 9 Pos2 6 Pos7 5 Pos3 9 Pos8 18 Pos4 6 Idle 8 Pos5 9 DB 29
22	4	25.2	11	Pos1 1 Pos6 1 Pos2 1 Pos7 1 Pos3 1 Pos8 79 Pos4 3 Idle 2 Pos5 1 DB 11	3	23.0	17	Pos1 0 Pos6 2 Pos2 2 Pos7 8 Pos3 4 Pos8 57 Pos4 9 Idle 4 Pos5 2 DB 12
23	4	19.1	23	Pos1 15 Pos6 0 Pos2 8 Pos7 0 Pos3 1 Pos8 1 Pos4 1 Idle 14 Pos5 0 DB 59	6	19.0	31	Pos1 2 Pos6 2 Pos2 3 Pos7 3 Pos3 4 Pos8 21 Pos4 3 Idle 2 Pos5 3 DB 57
24	2	23.8	94	Pos1 6 Pos6 9 Pos2 14 Pos7 5 Pos3 14 Pos8 10 Pos4 12 Idle 3 Pos5 6 DB 20	6	22.0	21	Pos1 54 Pos6 0 Pos2 23 Pos7 0 Pos3 0 Pos8 0 Pos4 0 Idle 9 Pos5 0 DB 15

Based on conversations with the locomotive engineers after the test run, train handling and speed control of the train was found to be normal for all the test runs. One road foreman served as the locomotive road foreman throughout the series of tests and as an engineer for several of the tests. During an informal interview after Run 3, he commented that the train handled better when the TOR system was running than it did when the system was off-line. He made the observation that the train seemed to pull "smoother" with the TOR lubricant being dispensed. He reported no problem in train handling.

In light of these results and observations, it is felt that introduction of the TOR lubricant into operations does not adversely affect train handling.

4.1.2 Effect of TOR Lubrication System on Braking

Thirteen (13) stop distance tests were performed – six (6) tests under unlubricated conditions and seven (7) tests under lubricated conditions. Eight (8) of the tests involved full service braking while five (5) of the tests involved emergency braking. Details and treatments are included in Appendix B.

Braking distances were measured with the distance measuring instrumentation on the lead locomotive. Inaccuracies inherent to this method are discussed in Section 3.2). Initial test results were corrected for the effects of grade and, in one case, for the occurrence of powered braking. Stop distances were approximately the same for comparable cases of lubricated and unlubricated tests. Test results are provided in Tables 3-3 and 3-4 and are summarized in Table 4-3.

Table 4-3. Summary of Stop Distance Test Results

Brake Application	Train Condition	Corrected Braking Distance (ft.)		Average Corrected Braking Distance (ft.)	
		Unlubricated Test	Lubricated Test	Unlubricated Test	Lubricated Test
Full Service	Loaded	2074	1784	2103	1843
		2132	1901		
	Empty	1969 1994	1908	1982	1761
		-	1613		
Emergency	Loaded	957	1065	957	993
			920		
	Empty	1061	1314	1061	1314

The numbers listed in Table 4-3 indicate that the average corrected stopping distances were approximately the same for "dry" and lubricated rail conditions for full service and emergency braking conditions. The same observation can be made if one considers the uncorrected distances determined (see Tables 3-3 and 3-4). The presence of the TOR lubricant does not seem to significantly increase the distance required to stop the train. A number of cases documented in Table 4-3 exhibit a decrease in stop distance when using the TOR lubricant. One possible explanation for this, offered by the *vendor* of the TOR system, lies in the design of the lubricant. As described in Section 1.2, the lubricant is described as a friction modifier, providing a reduction in friction under normal rolling wheel conditions but resulting in an increase in friction under braking conditions. Testing of the lubricant in typical freight service under a range of operating conditions wider than the one employed in this test would be necessary to identify all possible contributions to the results found in this portion of the test program.

4.1.3 Distribution of TOR Lubricant

It was not possible to measure the distribution of lubricant under the train directly. The intent of the investigators was to assess the distribution of the lubricant by considering the following:

- Tribometer measurements prior to and following the passage of the test train would identify the situation where the lubricant was not completely consumed over the length of the train.

- The comparison of the curving forces resulting from the train using the TOR lubricant to the forces generated by the train employing no TOR lubrication. *If any difference in curving forces between the two operating conditions were evident*, comparison of the forces along the length of the train *could* indicate a location at which the lubricant ceased to result in a difference in operating loads.

The results from the wayside instrumentation did not provide adequate information to assess the distribution of the lubricant. As discussed in Section 3.3, tribometer measurements made in the vicinity of the instrumented curve did not reveal detailed information regarding any remaining TOR lubricant on the rail due to the presence of the wayside lubricators. However, information collected during the tribometer surveys and wayside observations can lend insight to the issue of lubricant remaining on the rail after train passage.

It was difficult to identify the influence of TOR lubricant from tribometer measurements taken on top of the rails within the instrumented curve due to the presence of the grease from the wayside lubricator. On tangent track, however, it could be seen that the friction coefficient measured after the passage of the train was generally lowered to values between 0.30 to 0.40. Considering measurements made throughout the series of tests at several locations, including the instrumented curve, friction coefficients measured on the rails prior to the passage of the test train employing the TOR lubricant ranged from 0.19 to 0.68; the friction coefficient measured after the passage of the test train employing the TOR lubricant ranged from 0.25 to 0.53. Figure 4-1 illustrates the range of all of the friction coefficient values measured prior to and following the passage of the test train. Considering Figure 4-1, it can be seen that the use of the TOR lubricant does not introduce friction coefficients that are outside the range of values of coefficients that are found in a typical operating environment.

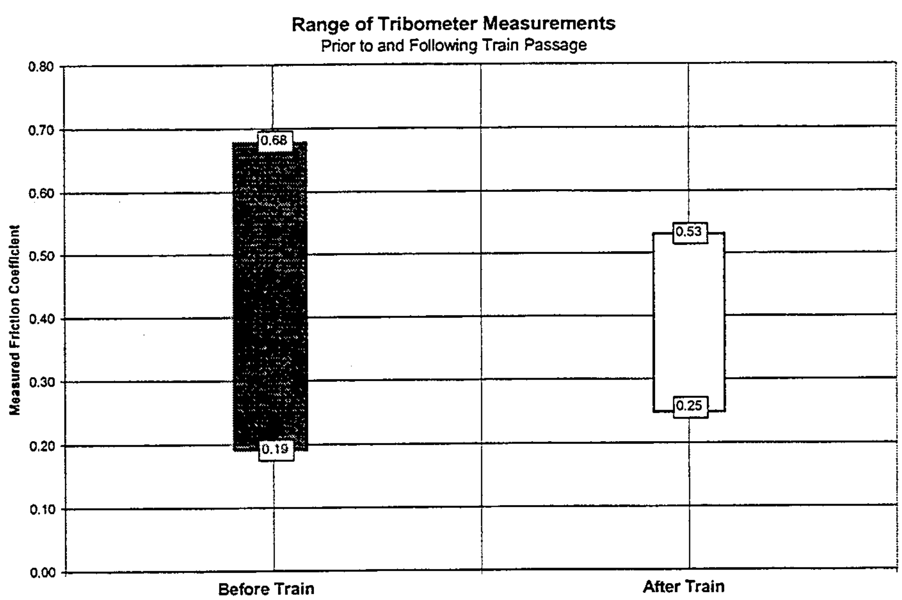

Figure 4-1. Illustration of Range of Measured Friction Coefficients

It was possible to observe the rail prior to and following train passage at the curve site and on tangent track. The rail generally looked clean to the naked eye during all the tests. At the instrumented curve site, where a large number of the top of rail surface observations were made, the wayside lubricators dispensed a significant amount of grease. Each time a train approached from the south, it traversed this wayside lubricator and introduced grease for a considerable distance. This made it difficult to observe the effect of the TOR lubricant on the curve. On tangent track the surface of the rail was also generally clean; occasionally, a very thin film of lubricant was observed when the rail surface was rubbed by hand.

Brief interviews were conducted with the engineer of the pusher locomotives used on Duff Mountain. The engineer reported normal operation of the pushers while assisting the test train employing the TOR lubricant. Subsequent trains did not report anything unusual throughout the test zone; however, systematic reports from subsequent trains were not gathered.

Results indicate that there was no appreciable loss in top of rail friction for the continued good handling of subsequent trains. Use of the TOR lubricant did not result in friction coefficients lower than those found under typical operating conditions. Brief interviews indicated that train operation seemed completely satisfactory. It should be noted that these results pertain to a given delivery rate. A slightly lower rate of TOR lubricant application would be considered an improvement in performance in terms of the friction measurements made on the rail. A slightly higher rate of TOR lubricant may have adverse effects on train operations.

Details of all measurements made with the tribometer are provided in Appendix C.

4.1.4 Effect of TOR Lubrication on Lateral Curving Forces

Lateral and vertical force measuring bridges were installed within the spiral and body of a six (6) degree curve in order to record curving forces for the lubricated and unlubricated test trains. As discussed in previous sections, there were several difficulties collecting data at the instrumented curve site. These difficulties included:

- The presence of wayside lubricators adjacent to the instrumented curve site; the lubricators dispensed an amount of grease sufficient to cover the top of rail for two to three hundred feet, making it difficult to evaluate the influence of the TOR lubricant on the curving forces generated on the rail.

- The development of a problem with the data collection system employed at the instrumented curve site; the system would terminate data collection after the passage of fifteen (15) to twenty cars (20). In order to collect data pertaining to the entire test train, the system had to be restarted a number of times, with each restart resulting in a "gap" of the force time history making it difficult to compare loads for the same cars of the train under different conditions.

A slight reduction in lateral forces was observed (by looking at numerical readouts at the site) for the northbound, empty trains. The empty trains were not affected as significantly as were the loaded test trains. This observation, combined with the earlier observations by CSXT, NS and AAR/TTCI[1,2], suggests that there was a reduction of lateral loads in these tests, but no evidence of that occurrence is available.

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[1] Reiff, Richard P., Scott Gage & Sudhir Kumar. TOP-OF-RAIL LUBRICATION ENERGY TEST. U.S. Department of Transportation Report Number DOT/FRA/ORD-98/01, February 1998.

[2] Runyon, Robert S. & Sudhir Kumar. TOP-OF-RAIL LUBRICATION. Presented at the 1996 Annual Meeting of the Locomotive Maintenance Officers Association, September 16, 1996.

4.2 PERFORMANCE RELATED ISSUES

The performance related concerns that served as objectives for this investigation were:

- What energy savings can be expected from the use of the lubricant system for a range of typical trains in freight service?
- What is the effect of the lubrication system on the critical speed for truck hunting?

The ability to judge the TOR lubricant system's impact on energy expenditures depended on the measurements of the following parameters:

- Locomotive notch dwell times, assessed using readings made from the trip monitors on two of the three locomotives;
- Fuel consumption;
- Electric energy, assessed using the readings made from the trip monitors on two of the three locomotives;
- Mechanical energy;

The results from these studies, as well as observations made during consideration of truck hunting phenomena, are discussed in the following sections.

4.2.1 Locomotive Notch Dwell Times

An important indicator of energy consumption is the duration for which the locomotives dwell in higher notches. Notch 8 and 7 use a major portion of the energy used by the locomotives. For the whole trip, the average reduction of notch 8 dwell time was found to be 9.19 % and that for notch 7 was 11.11 % as recorded in the locomotive trip monitor.

4.2.2 Fuel Consumption

Flow meters were put into the supply and return fuel lines of each locomotive. Meter readings were taken for each locomotive as the test train passed into or out of a test segment and every time the test train started and stopped. Taking readings in this matter not only allowed for the calculation of the fuel used in each test segment but accounted for fuel consumed during idle time.

There were considerable differences from trip to trip in the number of stops and the average speeds achieved within a given segment. For example, a broken rail encountered during Run 6 necessitated long slow orders and many stops. Therefore, the comparison of fuel consumption was a complicated process. The average speed, speed profiles and number of stops were analyzed and compared between "dry" and lubricated test runs throughout all test segments. Those segments deemed comparable were identified (as summarized in Tables 3-7 and 3-8) and fuel savings were calculated based upon consumption within these segments. Detailed records of the fuel monitor readings and considerations of parameters used to identify comparable segments are included in Appendix D.

The average fuel savings found while considering comparable runs of the loaded test train was 10.13%, while the average fuel savings for the empty test train was 5.35 %. The average of these two, corresponding to a round trip, was determined to be 7.74 %. These results are detailed in Tables 3-9 and 3-10.

As a second manner of assessing fuel savings, the fuel consumed over an entire trip was calculated from the flow meter readings for each test run and comparisons were made between lubricated and unlubricated trips. This manner of consideration differs from that method previously cited in that no comparable segments or test zones were identified – this is reflective of the typical operation of freight service. This method neglects the contributions of fuel consumed in stops and differences in the speed profile including average speed and number of stops. The average fuel savings found for the loaded test train was 2.60 %, while that determined for the empty train was 5.80 %. The combination of these two results yields an average percentage of savings equal to 4.20 %.

Regardless of the method used to compare fuel consumption between test cases, it is evident that savings in fuel consumption may be realized by employing the TOR lubrication.

4.2.3 Electrical Energy

Electrical energy consumption was measured using two methods. The first method was to measure the electrical voltage and current used by each locomotive, continually recording these values in the test car for all the test runs. Unfortunately, the recorded data was deemed unusable. The second method used yielded useful results. In this method, the locomotive trip monitor was used to determine electrical energy.

Using the trip monitor readings as the primary source of data, the electrical energy savings produced for the two SD60 locomotives by the SENTRAEN 2000™ system were 6.38 % for loaded trains, 9.28 % for empty trains and 7.19 % for the total trip. These savings were representative of energy reductions above those resulting from the use of flange lubrication.

4.2.4 Mechanical Energy

Mechanical energy was calculated from the drawbar force, monitored by the instrumented coupler on the research car, and speed using basic integration methods. The mechanical energy savings based upon average results from each of the test runs was 9.58 % for considerations of the loaded train and 4.92 % when considering the tests conducted with the empty trains. Mechanical energy savings based upon average results were determined to be 7.53 % when considering a round trip.

These results can be affected by the manner in which the train was operated during a particular run. The mechanical energy calculation procedure automatically eliminates the consideration of stops because no mechanical work is done when the train is not moving. It does not, however, take into account the differences due to the number of stops or the average speed of the train. For example, the mechanical energy calculated for the loaded train during run 6, a lubricated run, seems to have been affected by long slow orders, necessary due to the occurrence of a broken rail. The mechanical energy calculated for the loaded test train during run 6, 16441.07 kW-Hrs., is markedly higher than the energy determined for the corresponding case found in runs 3 and 5, the other lubricated test runs (14,200.74 and 14,218.66 kW-Hrs. respectively).

Records of the mechanical energy calculations are included in Appendix F.

4.2.5 Comparison of Energy Reductions

Energy savings were determined using several methods. Results from the different methods used are summarized in Table 4-4 and illustrated in Figure 4-2. The average savings, based upon the results using the different methods, are illustrated in Figure 4-3. The average energy savings pertaining to round trips determined by the various methods was 7.83 %.

Table 4-4. Percentage of Energy Reduction Determined by Various Methods

Basis of Comparison	Method	% Reduction, Loaded Test Train	% Reduction, Empty Test Train	% Reduction, Round Trip
Locomotive Notch Dwell Time	Dwell Time, via Trip Monitor, Notch 8	4.48	13.89	9.19
	Dwell Time, via Trip Monitor, Notch 7	11.11	11.11	11.11
Fuel Consumption	Consideration of Total Trip	2.60	5.80	4.20
	Consideration of Comparable Segments	10.13	5.35	7.74
Electrical Energy	Consideration of Trip Monitor Results	6.38	9.28	7.19
Mechanical Energy	Calculated from Time History of Train Parameters	9.60	4.90	7.53
	Overall Average, All Methods	**7.38**	**8.39**	**7.83**

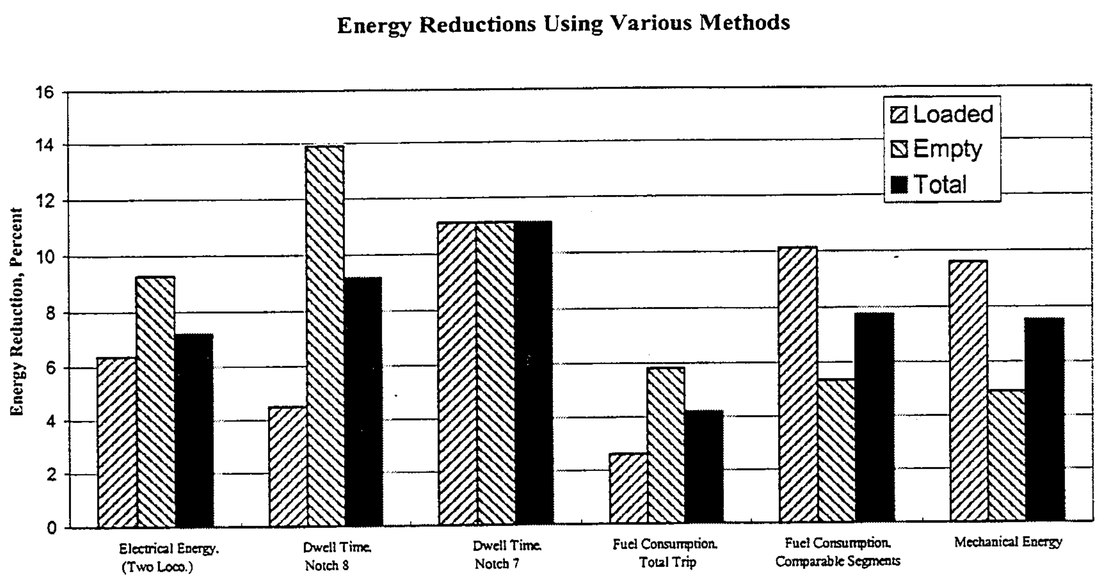

Figure 4-2. Illustration of Energy Reduction Determined by Various Methods

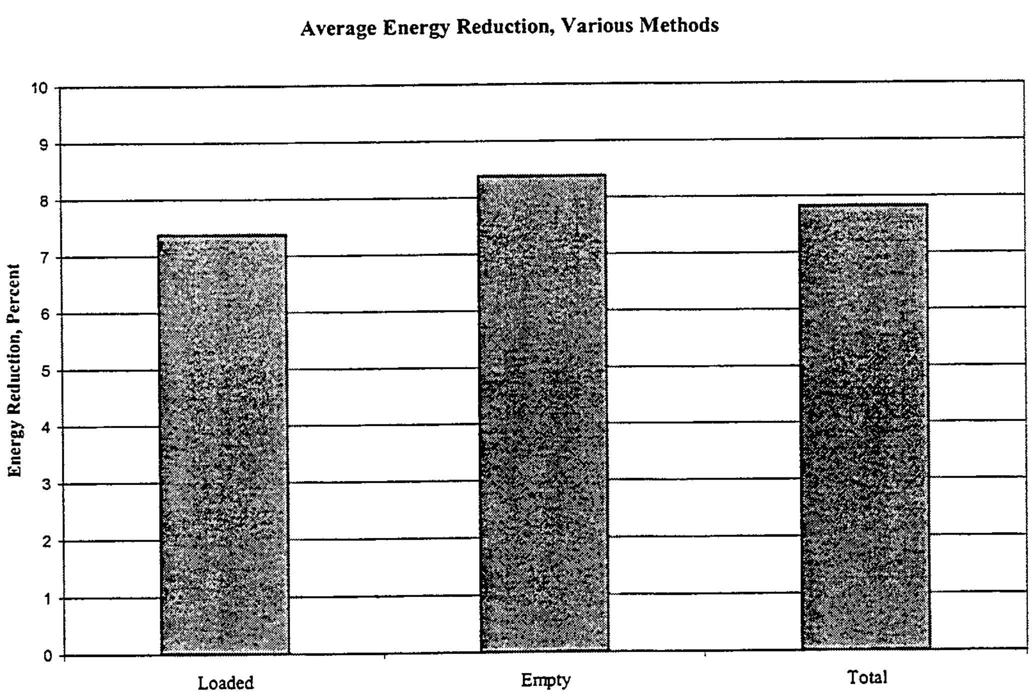

Figure 4-3. Illustration of Average Energy Reduction

4.2.6 Effect of TOR Lubrication on Truck Hunting

The center sill of the hopper car located behind the Research Car was instrumented with an accelerometer in order to assess the effect of TOR lubrication on truck hunting. Accelerometer signals were monitored using a strip chart recorder during movements of the empty cars.

During the present series of tests, speeds were not high enough for the train to develop hunting in either the "dry" or lubricated rail conditions (the speed of the empty train was restricted to 40 MPH). No evidence of truck instability was observed during the tests. Therefore, no conclusion could be drawn in this area.

5.0 CONCLUSIONS

A top-of-rail (TOR) lubrication system, the SENTRAEN 2000™ manufactured by the Tranergy Corporation, was tested in order to investigate the use of the system in typical revenue service. All lubricated and unlubricated tests were conducted while using wayside lubrication devices and flange lubricators. All results correspond to a single lubrication delivery rate. Observations made during the tests and analyses of the test data lead to the following conclusions:

- *Train Handling*: The use of the TOR system did not appear to negatively affect either train handling or speed control. This was evidenced by consideration of the average speeds, notch dwell times and the number of throttle position changes through comparable test zone segments. Testimonials from personnel associated with the test confirm this finding. The locomotive road foreman in charge of the tests reported that he liked the system due to improved train handling, including a smoother ride.

- *Braking Performance*: Braking performance was found to be safe for the lubricant rate employed during this series of tests. Stopping distances were approximately the same for lubricated and unlubricated rail conditions for full service and emergency braking of loaded and empty trains. This was evidenced by measured distances as well as the same distances corrected for grade and power application. Full service brake applications showed a decrease in stopping distance when employing the TOR lubrication, with average reductions on the order of 200 feet. It should be emphasized that these particular results pertain to these tests and that reductions of this magnitude are not necessarily universal. There was no occurrence of wheel slip during any of the thirteen (13) braking tests conducted.

- *Lubricant Distribution and Consumption*: Results from top of rail tribometer surveys were mixed, with some surveys showing no change in friction coefficients measured on the rail following the passage of the test train and some showing a decrease in measured friction coefficients. On a few occasions, a thin film could be felt by touch of a finger on the rail head after the test train had passed. While several decreases of friction coefficient, ranging between 0.03 and 0.30, were measured during the surveys, friction coefficient measurements made at the designated curve location revealed no significant difference between the changes in friction due to the passage of normal revenue trains and changes in friction corresponding to the passage of the test train employing the lubrication system. Based on measurements made at the curve site that focused on normal revenue service trains, average friction coefficient measurements ranged between 0.37 and 0.56 before the train passage and between 0.21 and 0.48 after train passage. In comparison, measurements made at the same location for trains employing TOR lubricant ranged between 0.31 and 0.51 before the passage of the trains and between 0.27 and 0.45 after the passage of the trains. Engineers operating pusher locomotives used for the fifteen mile 1% grade found the operation of the locomotives to be quite normal when assisting the test trains using the TOR lubricant. Subsequent trains did not report anything unusual throughout the test zone; however, systematic reports from subsequent trains were not gathered.

- *Energy Savings*: Performance related issues focused largely on energy expenditures with savings being determined using a variety of methods. Energy savings for a round trip of the test train ranged from 4.20 % to 11.11 %, depending on the method of evaluation used. The average energy savings for a round trip, found by averaging the results from different methods, was determined to be 7.83 %. There was a 7.74 % savings in fuel consumption realized when results from comparable test segments were combined for a round trip (i.e. by disregarding results from segments where the train was operated in significantly different manners). It should be kept in mind that electrical energy results were based upon two locomotives. It must be emphasized that differences in performance of the test train between the lubricated and unlubricated test runs were determined as a percentage above the levels obtained by using wayside and flange lubrication.

Information related to the following issue was not observed during this series of tests:

- *Wheel/Rail Interaction*: An evaluation of the effect of the TOR lubricant on curving forces based on this series of tests was not possible. This was due to the employment of wayside lubrication in the vicinity of the instrumented curve and data acquisition system problems. No evidence of truck instability was observed during the tests and, therefore, no conclusion could be drawn regarding the effect of the TOR lubricant on the critical speed for truck hunting. During the series of tests, speeds were restricted to 40 MPH, a speed below that necessary to develop hunting under either "dry" or lubricated rail conditions.

6.0 RECOMMENDATIONS FOR FURTHER TESTING

Upon completion of this series of tests, a number of recommendations were arrived at that would address issues identified in this round of testing:

- Efforts to investigate curving forces and friction coefficient changes should be done in an area that does not employ wayside lubrication. During this investigation, wayside lubrication affected the results of the test by making it difficult to "separate" the influence of the TOR lubrication from that of the lubrication employed at the wayside site.

- Efforts should be made to test the TOR lubrication on a test train that does not employ flange lubricators. Conducting a test in this manner in an area that does not employ wayside lubrication would not only eliminate the effects of other lubricants on test results, it would quantify savings realized by using the TOR lubrication system only. This would allow for direct comparison to savings that result from the use of conventional lubrication methods.

- Accommodations should be made that will allow for a test train to run on track permitting higher operating speeds so that truck hunting could be investigated. Testing of this nature may require the use of a dedicated test track. Allowance of testing at a wide range of speeds may be a reasonable means to investigate the effect of lubrication on truck dynamics.

- Interest may exist in conducting similar tests at a variety of lubrication system settings and operating conditions. Tests of this nature could employ the following:

    - *A range of lubrication delivery rates*. Employing a variety of lubrication delivery rates for similar tonnages would address issues associated with the presence of excess lubrication due to human error. An example of this situation is the input of erroneous information, such as incorrect tonnage. Tests under these conditions should investigate braking performance and truck steering characteristics.

    - *The application of lubricant to one rail only*. Dispensing lubricant on one rail addresses the situations in which a lubricant delivery line becomes severed or the case where a nozzle becomes obstructed. Tests under these conditions should investigate curving forces, braking performance and truck steering characteristics.

    - *Testing of the lubricant in cold and warm environments*. A series of tests could be conducted to determine the effect of large changes in ambient temperature on the operation of a train employing the lubricant system at a given setting. This would address the scenario of a train, employing the system dispensing lubricant at a fixed flow rate, moving from a warm climate to a cold climate (or vice-versa) without modifications to the system settings being made. Tests of this nature could be conducted with a given set of system settings in different climates over similar terrains or over the same test zone at different times of the year. Tests should determine the effect of the change in environment on train handling, braking performance, lubricant distribution and the generation of curving forces.

APPENDIX A

SUMMARY OF TESTS

Run: 1 Top of Rail Lubricant: __Yes x No

Dates: 2/16/98 to 2/17/98 Trip Time: 14:07 Train No.: N25315 Tonnage: 12639 Brake Tests: None

Test Zone Segment	Starting Milepost	Ending Milepost	No. of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
1	178	203	0	Clear	Loco. 8709 on-line, not loaded, corrected.	Research Car not connected to trainline signals.
2	203	218	1	Clear	Stopped for pusher train at base of Duff Mt.	
3	218	224	0	Clear		
4	224	238	1	Clear		
5	238	276	2	Clear		
6	276	321	4	Clear		
7	321	325	1	Clear		
8	325	334	1	Clear		
9	337	350	0	Light Rain		
10	350	356	0	Light Rain		
11	356	379	1	Clear		
12	379	421	1	Rain		

Dates: 2/17/98 to 2/18/98 Trip Time: 14:00 Train No.: N25315 Tonnage: 2389 Brake Tests: MP 324 – 323

Test Zone Segment	Starting Milepost	Ending Milepost	No. of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
13	421	379	3	Clear	Shut down Loco. 8709 for return trip.	
14	379	356	0	Clear		
15	356	350	0	Clear		
16	350	337	0	Clear		
17	334	325	0	Light Rain	Turned on Loco. 8709, isolated Loco. 8702.	
18	325	321	1	Clear	Stop Distance Test	
19	321	276	1	Rain		
20	276	238	1	Light Rain		
21	238	224	0	Clear		
22	224	218	0	Light Rain		
23	218	203	0	Clear		
24	203	178	0	Clear		

Run: 2 Top of Rail Lubricant: __Yes x No

Dates: 2/19/98 to 2/20/98 Trip Time: 16:27 Train No.: N25318 Tonnage: 12635 Brake Tests: MP 322 –323, 352–353

Test Zone Segment	Starting Milepost	Ending Milepost	No. of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
1	178	203	0	Light Rain		
2	203	218	1	Clear	Stopped for pusher train at base of Duff Mt.	
3	218	224	0	Clear		
4	224	238	0	Clear		
5	238	276	2	Clear		
6	276	321	2	Clear		
7	321	325	1	Clear	Stop Distance Test	
8	325	334	0	Clear		
9	337	350	0	Clear		
10	350	356	1	Clear	Stop Distance Test	
11	356	379	0	Clear		
12	379	421	2	Clear		

Dates: 2/20/98 to 2/20/98 Trip Time: 14:46 Train No.: N25318 Tonnage: 2389 Brake Tests: MP 324–323

Test Zone Segment	Starting Milepost	Ending Milepost	No. of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
13	421	379	2	Light Rain	Shut down Loco. 8702 for return trip.	
14	379	356	1	Clear		
15	356	350	1	Clear		
16	350	337	0	Clear		
17	334	325	0	Clear		
18	325	321	1	Clear	Stop Distance Test	
19	321	276	2	Clear		
20	276	238	0	Clear		
21	238	224	0	Clear		
22	224	218	0	Clear		
23	218	203	2	Clear		
24	203	178	1	Clear		

Run: 3 Top of Rail Lubricant: x Yes __No

Dates: 2/22/98 to 2/22/98 Trip Time: 14:18 Train No.: N25321 Tonnage: 12668 Brake Tests: MP 322–323, 352–353

Test Zone Segment	Starting Milepost	Ending Milepost	Number of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
1	178	203	0	Fog		
2	203	218	1	Clear	Stopped for pusher train at base of Duff Mt.	
3	218	224	0	Clear		
4	224	238	0	Clear		
5	238	276	1	Clear		
6	276	321	0	Clear		
7	321	325	1	Clear	Stop Distance Test	
8	325	334	1	Clear		
9	337	350	0	Clear		
10	350	356	1	Clear	Stop Distance Test	
11	356	379	0	Clear		
12	379	421	1	Light Rain		

Dates: 2/23/98 to 2/23/98 Trip Time: 13:15 Train No.: N25321 Tonnage: 2389 Brake Tests: MP 352–351, 324–323

Test Zone Segment	Starting Milepost	Ending Milepost	Number of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
13	421	379	2	Light Rain	Shut down Loco. 8702 for return trip.	
14	379	356	1	Light Rain		
15	356	350	1	Rain	Stop Distance Test	
16	350	337	0	Clear		
17	334	325	0	Rain		
18	325	321	1	Rain	Stop Distance Test	
19	321	276	0	Clear		
20	276	238	0	Clear		
21	238	224	2	Rain		
22	224	218	0	Rain		
23	218	203	1	Rain		
24	203	178	3	Rain		

Run: 4 Top of Rail Lubricant: __Yes _x_No

Dates: 2/24/98 to 2/25/98 Trip Time: 13:20 Train No.: N27223 Tonnage: 12643 Brake Tests: MP 322–323

Test Zone Segment	Starting Milepost	Ending Milepost	Number of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
1	178	203	2	Clear		
2	203	218	1	Clear	Stopped for pusher train at base of Duff Mt.	
3	218	224	1	Clear		
4	224	238	2	Clear		
5	238	276	1	Clear		
6	276	321	0	Clear		
7	321	325	1	Clear	Stop Distance Test	
8	325	334	1	Clear		
9	337	350	0	Clear		
10	350	356	0	Clear		
11	356	379	1	Clear		
12	379	421	2	Clear		

Dates: 2/25/98 to 2/26/98 Trip Time: 15:23 Train No.: N27223 Tonnage: 2390 Brake Tests: MP 324–323

Test Zone Segment	Starting Milepost	Ending Milepost	Number of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
13	421	379	0	Clear	Shut down Loco. 8702 for return trip.	
14	379	356	0	Clear		
15	356	350	1	Clear		
16	350	337	0	Clear		
17	334	325	0	Clear		
18	325	321	1	Clear	Stop Distance Test	
19	321	276	0	Clear		
20	276	238	5	Clear		
21	238	224	0	Clear		
22	224	218	0	Clear		
23	218	203	2	Clear		
24	203	178	4	Clear		

Run: _5_ Top of Rail Lubricant: _x_Yes __No

Dates: 2/27/98 to 2/27/98 Trip Time: 17:24 Train No.: N25326 Tonnage: 12816 Brake Tests: MP 322–323

Test Zone Segment	Starting Milepost	Ending Milepost	Number of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
1	178	203	3	Clear		
2	203	218	2	Clear	Stopped for pusher train at base of Duff Mt.	
3	218	224	1	Clear		
4	224	238	2	Clear		
5	238	276	2	Clear		
6	276	321	1	Clear		
7	321	325	1	Clear	Stop Distance Test	
8	325	334	0	Clear		
9	337	350	0	Clear		
10	350	356	0	Clear		
11	356	379	0	Clear		
12	379	421	1	Clear		

Dates: 2/28/98 to 2/28/98 Trip Time: 15:40 Train No.: N25326 Tonnage: 2390 Braking Tests: MP 324–323

Test Zone Segment	Starting Milepost	Ending Milepost	Number of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
13	421	379	2	Clear	Shut down Loco. 8702 for return trip.	
14	379	356	0	Clear		
15	356	350	1	Clear		
16	350	337	0	Clear		
17	334	325	0	Clear		
18	325	321	1	Clear	Stop Distance Test	
19	321	276	2	Clear		
20	276	238	1	Clear		
21	238	224	1	Clear		
22	224	218	0	Clear		
23	218	203	1	Clear		
24	203	178	1	Clear		

Run: 6 Top of Rail Lubricant: x Yes __No

Dates: 3/2/98 to 3/3/98 Trip Time: 23:34 Train No..: N25301 Tonnage: 12681 Brake Tests: MP 322–323

Test Zone Segment	Starting Milepost	Ending Milepost	Number of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
1	178	203	0	Light Rain		
2	203	218	2	Rain	Stopped for pusher train at base of Duff Mt.	
3	218	224	1	Light Snow		
4	224	238	0	Light Snow		
5	238	276	2	Clear		
6	276	321	1	Clear		
7	321	325	1	Light Snow	Stop Distance Test	
8	325	334	1	Clear		
9	337	350	0	Clear		
10	350	356	1	Clear		
11	356	379	1	Clear		
12	379	421	3	Clear		

Dates: 3/3/98 to 3/4/98 Trip Time: 19:59 Train No.: N25301 Tonnage: 2390 Brake Tests: None

Test Zone Segment	Starting Milepost	Ending Milepost	Number of Stops	Weather Conditions	Train Handling Issues	Data Gathering Issues
13	421	379	0	Clear	Shut down Loco. 8702 for return trip.	
14	379	356	0	Clear		
15	356	350	0	Clear		
16	350	337	0	Clear		
17	334	325	1	Clear		
18	325	321	0	Clear	No Stop Distance Test	
19	321	276	1	Clear		
20	276	238	5	Clear		
21	238	224	1	Clear		
22	224	218	0	Clear		
23	218	203	2	Clear		
24	203	178	0	Clear		

APPENDIX B

BRAKING DISTANCE RESULTS AND THEORETICAL TREATMENTS

Theory and Method of Braking Distance Corrections Due to Grade Effects and Powered Braking

Braking Distance

Braking distance L (ft.) of a train is given by[1]:

$$L = \frac{70 * W * V^2}{F_B} \quad (1)$$

Where

W is weight of train in tons
V is speed in MPH
F_B is the total braking force in lb.

$$F_B = F_1 + F_2 + F_G \quad (2)$$

Where

F_1 - braking force
F_2 - train resistance
F_G - grade resistance

Grade affects the braking distance significantly. Its effect can be calculated and correction on the stopping distance can be made. Such corrections in stopping distances make it possible to compare different brake tests.

Grade Resistance

Grade resistance = 20lb/ton/1%grade[1]

Grade resistance of a loaded train, F_{GL}, with load W = 12,000 tons is:

$$F_{GL} = 20 \times 12000 \times \%grade, \text{ lbs.}$$
$$= 240{,}000 \times \%grade, \text{ lbs.} \quad (3)$$

Grade resistance of empty train, F_{GE}, with load = 3000 tons is:

$$F_{GE} = 20 \times 3000 \times \%grade, \text{ lbs.}$$
$$= 60{,}000 \times \%grade, \text{ lbs.} \quad (4)$$

[1] William W. Hay. Railroad Engineering; Second Edition; John Wiley & Sons, New York 1982.

Correction for Grade Resistance

It can be assumed as a good first approximation that

$$F_1 + F_2 = \text{Braking Force} + \text{Train Resistance} = F \tag{5}$$

is nearly the same for all full service brake applications or separately for all emergency brake applications.

Stopping distance L_G, for braking on grade, from Eq. (1) can then be written as

$$L_G = \frac{70*W*V^2}{F + F_G} \tag{6}$$

or

$$F = \frac{70*W*V^2}{L_G} - F_G \tag{7}$$

W and V are known and F_G can be calculated from Eqs. (3) and (4). Thus, the value of F can be calculated. Once F is known, the corrected stopping distance for level track, L, can be determined. Corrected stopping distance L for tangent track is then given by

$$L = \frac{70*W*V^2}{F} \tag{8}$$

This approach was used for correcting the stopping distances for grade.

Track Grades During Braking

Brake tests were conducted in two locations, one north of Etowah, TN and the other was south of Etowah. The mileposts from which braking started were 324, 323, and 352. Track charts pertaining to these regions are included in this appendix. Since trains were traveling in both northbound and southbound directions, the location, with respect to milepost, and the grades over which braking was done varied between tests. These are listed in Table B-1.

Table B-1. Mileposts and Grade Distributions Estimated from Track Charts

Mile Post	Northbound	Southbound	Length (ft)	Grade (%)
324-323	√ Reverse grade sign		600	-0.65
			636	-0.11
			600	+0.41
			720	+0.41
			2760	+0.18
322-323		√ Reverse grade sign	660	-0.45
			2100	-0.61
			2040	-0.45
352-353		√ Reverse grade sign	1284	-0.14
			3717	-0.08
352-351	√ Reverse grade sign		3055	-0.14
			2216	0.65

As can be seen in Table B-1, the grade varied over the length of track where braking was done. For calculation purposes, an average grade was calculated over the length of track required in bringing the train to rest. This average grade was used in Eqs. (3) and (4) to determine the force due to grade.

As a simple illustration of the manner in which the stopping distances can be corrected for grade differences, consider brake tests #1 and 4, both of which were conducted on empty, unlubricated trains. The stopping distance from test #4 was 1835 feet. This value is used to determine the distribution of the grade over the test zone.

Length	Grade
600'	-0.65%
636'	-0.11%
600'+	0.0014%
Totals	
1835 ft+	Proportional Avg = -0.117%

The sign of the average grade is reversed due to the fact that the train is northbound in this particular case, resulting in a value of + 0.117 used as the average grade for this calculation. For the purpose of illustration, the following calculation is made for the aggregate results from tests #1 and 4 since both tests were conducted with empty trains on the same grade.

For these cases, the average stopping distance was:

$$L = \frac{1891+1835}{2} = 1863 \text{ ft.}$$

The other parameters pertaining to these tests are:

$$V = 40 \text{ mph} \qquad W = 2389 \text{ tons}$$

$$F_G = 20 \times 2389 \times 0.117 = 5590 \text{ lb.}$$

Therefore,

$$F = \frac{70*W*V^2}{L_B} - F_G = (70*2389*40^2)/1863 - 5590 = 143{,}622 - 5590 = 138{,}032 \text{ lb.}$$

And

$$\text{Corrected } L = \frac{70*W*V^2}{F} = 1938 \text{ ft.}$$

The corrected values of stopping distance for tests #1 and 4 are actually 1969 and 1908 feet, respectively, using the values pertinent to each test. The values corresponding to the braking distance tests are provided in the accompanying table.

Correction for Powered Braking

Sometimes, the brakes are applied while the locomotive is still in power mode, i.e., the locomotive brought to rest while in notch positions other than "0". In this study, this was the case for Brake Test 7. In order to facilitate comparisons with "unpowered" brake distance tests, the driving force must be accounted for. A correction for power application can be made in a manner similar to that presented in the preceding section.

Eq. (1) will remain the same as before, but Eq. (2) can be rewritten as:

$$F_B = F_1 + F_2 + F_G + F_P$$

where F_1, F_2, F_G represent the same quantities presented earlier and a new term F_P, representing the average "power forward" force, is added. For the case being considered, the average force is estimated to be half of the force that results when the control was set in notch 8. This is done for the sake of ease due to the fact that a gradual "notching down" from notch 8 to an idle position was performed (as evidenced in Figure B-1, marked "Chart 1", which shows the time history of the throttle position that resulted during powered braking). Thus, the corrected stopping distance is given by Eq. (9), where the expression for F is now given by

$$F = \frac{70*W*V^2}{L_B} \qquad \textbf{(9)}$$

For SD 60 locomotives, the tractive effort in notch 8 at 30-40 mph is estimated as approximately 30,000 lbs. per locomotive. Thus for the empty train, the total tractive effort is 60,000 lbs. due to the fact that only two locomotives are used to power the train.

Consider application of this method to the results pertaining to Brake Test 7. The value of F is determined as follows:

$$V = 40 \text{ mph} \qquad W = 2389 \text{ tons}$$

$$F_G = 20 \times 2389 \times 0.14 = 6689 \text{ lb.}$$

Therefore,

$$F = \frac{70*W*V^2}{L_B} - F_G = (70*2389*40^2)/2376 - 6{,}689 = 112613 - 6689 = 105924 \text{ lb.}$$

The actual braking force without power would be 60,000 lbs. higher than the value experienced. Thus the calculated value of $F_1 + F_2 = 105924$ will be corrected to $F = 165924$ lbs. Using this, the corrected braking distance becomes:

$$L = \frac{70*2389*40^2}{165924} = 1613 \text{ ft.}$$

Error Margin

The brake application could not be precisely at the milepost listed. If the brakes were applied ± 4 seconds apart at 40 mph, this could result in a discrepancy of ± 235 feet. This alone can create a spread of approximately 400 feet. There also could be some error in the locomotive distance counter, particularly due to a variety of humidity conditions due to different wheel creeps experienced.

Table B-2. Analysis of CSX Braking Tests

Test #	Speed (MPH)	Date	Time of Day	Dry/ Lube	Run #	Weather	Cars	Tonnage	Temp. (deg. F)	Wheel Slip (yes/no)	Location (N/S of Etowah)	Avg. Grade	Mile Post	Type of Braking (Emer. or Full Ser.)	Distance (Feet)	Force due to Grade (lb)	Total Force(lb)	Corrected Length(Feet)
1	40	2/17	8:00 PM	Dry	1	cloudy dryrail	Empty	2389		No	N-Northbound	0.117	324-323	Fullservice	1891	5590.26	135905	1969
2	30	2/19	7:20 PM	Dry	2	cloudy dryrail	Loaded	12635	52	No	N-Southbound	-0.55	322-323	Fullservice	3251	-138985	383834	2074
3	30	2/19	9:30 PM	Dry	2	cloudy dryrail	Loaded	12635	46	No	S-Southbound	-0.11	352-353	Fullservice	2303	-27797	373435	2132
4	40	2/20	12:30 PM	Dry	2	cloudy dryrail	Empty	2389		No	N-Northbound	0.117	324-323	Fullservice	1835	5590.26	140223	1908
5	30	2/22	12:20 PM	Lube	3	cloudy damp	Loaded	12668	45	No	N-Southbound	-0.57	322-323	Fullservice	2634	-144415.2	447408	1784
6	30	2/22	5:15 PM	Lube	3	cloudy damp	Loaded	12668		No	S-Southbound	-0.118	352-353	Fullservice	2047	-29896.48	419776	1901
7	40	2/23	3:45 AM	Lube	3	cloudy rain	Empty	2389	45	No	S-Northbound	0.14	352-351	Fullservice	2376	6689.2	165924	1613
8	40	2/23	6:00 AM	Lube	3	cloudy rain	Empty	2389	45	No	N-Northbound	0.117	324-323	Fullservice	1914	5590.26	134205	1994
9	30	2/25	1:00 AM	Dry	4	Clear dryrail	Loaded	12643	45	No	N-Southbound	-0.52	322-323	Emergency	1136	-131487.2	832639	957
10	38	2/26		Dry	4	Clear dryrail	Empty	2390		No	S-Northbound	0.44	324-323	Emergency	971	21032	227764	1061
11	30	2/27		Lube	5		Loaded	12816		No	N-Southbound	-0.54	322-323	Emergency	1303	-138412.8	758066	1065
12	39	2/28	1:00 PM	Lube	5	Clear dryrail	Empty	2390	60	No	N-Northbound	0.38	324-323	Emergency	1201	18164	193712	1314
13	29	3/3	3:00 AM	Lube	6	cloudy snow	Loaded	12681	45	No	N-Southbound	-0.51	322-323	Emergency	1095	-129346.2	811109	920

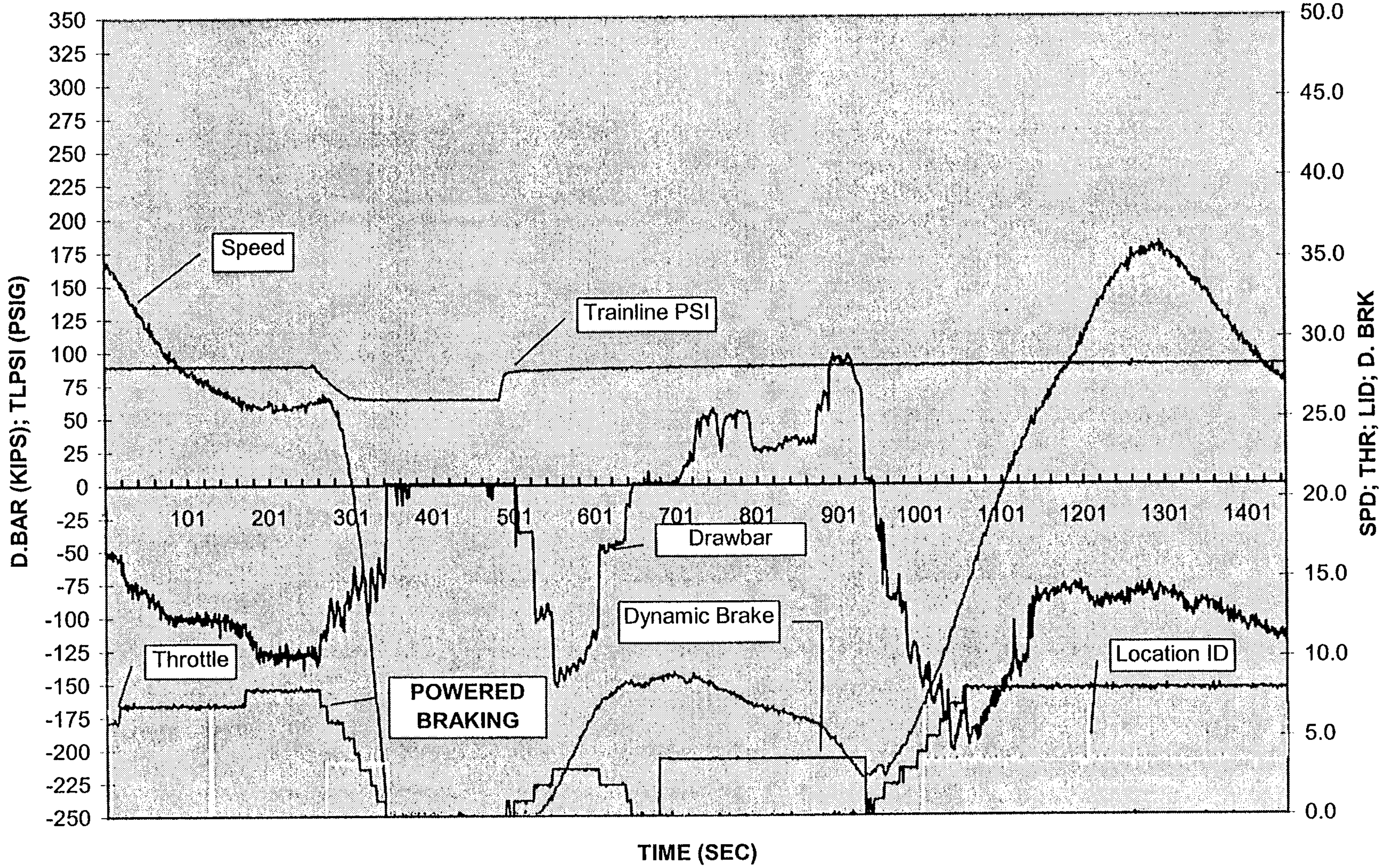

Figure B-1. Time History of Parameters Recorded During Brake Test 7 (Run 3, MP 350 - MP 356)

APPENDIX C

TRIBOMETER MEASUREMENTS

Tribometer Measurements

The following items are provided in this appendix:

- A record of all tribometer measurements made. Measurements are reported for both rails at multiple stations. Other information provided includes train conditions, the weather associated with each test case and additional comments pertaining to operating conditions that could affect results.

- A graph, Figure C-1, illustrating the range of average tribometer measurements made over the series of tests. The results presented in this graph illustrate the range of adhesion coefficients that are found in typical operating conditions and the relative effect of the TOR lubricant. Values presented on this graph represent the average of the tribometer readings made on both rails at corresponding stations.

Friction Coefficient Measurements

Test Case 1
Run: 3
Date/Time: 2/22/98
Time: 8-9 AM
TOR Lubrication: Yes
Train Condition: Loaded
Locations: Curve Site, MP 234.7
Conditions: Dry Rail, T=45
Comments: Test train proceeding from north; did not pass through wayside lubricator

Station		High Rail, Before Test Train Passage	High Rail, After Test Train Passage	Low Rail, Before Test Train Passage	Low Rail, After Test Train Passage
Xing	1	0.43	0.33	0.43	0.44
	2	0.41	0.36	0.43	0.47
	3	0.44	0.34	0.50	0.48
Crib 2	4	0.44	0.35		0.44
	5	0.41	0.35	0.45	0.40
	6	0.47	0.39	0.44	0.42
	7	0.45	0.37	0.45	0.40
	8	0.44	0.39	0.48	0.51
Crib 1	9	0.45	0.39	0.47	0.48
Average		0.44	0.36	0.46	0.45

Test Case 2
Run: 3
Date: 2/23/98
Time: 11:30:AM - 1:00 PM
TOR Lubrication: No
Train Condition: Empty
Locations: Curve Site, MP 234.7
Conditions: Drizzle, T=45
Comments: Revenue service train proceeding from south; passed through wayside lubricator

Station		High Rail, Sample 1	High Rail, Sample 2	Low Rail, Sample 1	Low Rail, Sample 2
Xing	1	0.39	0.21	0.55	0.38
	2	0.44	0.22	0.50	0.35
	3	0.52	0.19	0.49	0.35
Crib 2	4	0.57	0.21	0.49	0.37
	5		0.20	0.49	
	6	0.58	0.22	0.49	0.39
	7	0.64	0.22	0.43	0.39
	8	0.63	0.23	0.46	0.41
Crib 1	9	0.68	0.22	0.43	0.38
Average		0.56	0.21	0.48	0.38

Test Case 3
Run: 4
Date: 2/24/98
Time: 7:00 PM
TOR Lubrication: No
Train Condition: Loaded
Locations: Curve Site, MP 234.7
Conditions: Dry Rail, T~40
Comments: Test train proceeding from north; did not pass through wayside lubricator

Station		High Rail, Before Test Train Passage	High Rail, After Test Train Passage	Low Rail, Before Test Train Passage	Low Rail, After Test Train Passage
Xing	1	0.32	0.36	0.37	
	2	0.35	0.50	0.39	0.46
	3	0.36	0.48	0.41	0.50
	4	0.37	0.48	0.41	0.53
Crib 2	5	0.38		0.39	0.46
	6	0.38	0.48	0.39	0.43
	7	0.35	0.48	0.43	0.49
	8	0.42	0.49	0.38	0.50
	9	0.43	0.47	0.40	0.46
Crib 1	10	0.41	0.51	0.38	0.41
Average		0.38	0.47	0.40	0.47

Test Case 4

Run:	4
Date:	2/26/98
Time:	8-8:30 AM
TOR Lubrication:	No
Train Condition:	Empty
Locations:	Curve Site, MP 234.7
Conditions:	Dry Rail, T=32, H=55%
Comments:	Test train proceeding from south; passed through wayside lubricator

Station		High Rail, Before Test Train Passage	High Rail, After Test Train Passage	Low Rail, Before Test Train Passage	Low Rail, After Test Train Passage
Xing	1	0.37	0.28		0.34
	2	0.35	0.25	0.44	0.32
	3	0.38	0.27	0.46	0.29
	4	0.39	0.25	0.45	0.32
Crib 2	5		0.26	0.39	0.32
	6	0.39	0.27	0.48	0.30
	7	0.44	0.27	0.45	0.32
	8	0.39	0.26	0.43	0.36
	9	0.41	0.28	0.46	0.31
	10	0.41	0.25	0.39	0.31
Crib 1	11		0.27		
Average		0.39	0.26	0.44	0.32

Test Case 5

Run:	5
Date:	2/27/98
Time:	7:45-10:30 AM
TOR Lubrication:	Yes
Train Condition:	Loaded
Locations:	Curve Site, MP 234.7
Conditions:	Dry Rail, T=60, H=76%
Comments:	Test train proceeding from north; did not pass through wayside lubricator

Station		High Rail, Before Test Train Passage	High Rail, After Test Train Passage	Low Rail, Before Test Train Passage	Low Rail, After Test Train Passage
Crib 2	1	0.36	0.31	0.33	0.36
	2	0.39	0.34	0.32	0.41
	3	0.42	0.35	0.32	0.38
	4	0.43	0.34	0.30	0.35
Crib 1	5			0.30	0.34
Average		0.40	0.34	0.31	0.37

Test Case 6

Run:	5
Date:	2/27/98
Time:	1:45 PM
TOR Lubrication:	Yes
Train Condition:	Loaded
Locations:	MP 311.25
Conditions:	Dry Rail, T~50
Comments:	Test train on tangent track

Station		East Rail, Before Test Train Passage	East Rail, After Test Train Passage	West Rail, Before Test Train Passage	West Rail, After Test Train Passage
	1	0.42	0.40	0.44	0.42
	2	0.44	0.42	0.44	0.43
	3	0.43		0.43	
	4	0.46		0.44	
Average		0.44	0.41	0.44	0.43

Test Case 7
Run: 5
Date: 2/27/98
Time: 9:30 PM
TOR Lubrication: Yes
Train Condition: Loaded
Locations: MP 351.67
Conditions: Dry Rail, T~40
Comments: Test train on tangent track

Station	East Rail, Before Test Train Passage	East Rail, After Test Train Passage	West Rail, Before Test Train Passage	West Rail, After Test Train Passage
1	0.62	0.28	0.41	0.29
2	0.58	0.28	0.38	0.28
3	0.51		0.46	
4	0.54		0.50	
5	0.47		0.57	
Average	0.54	0.28	0.46	0.29

Test Case 8
Run: 5
Date: 2/28/98
Time: 9:15-10:30 AM
TOR Lubrication: Yes
Train Condition: Empty
Locations: MP 348.67
Conditions: Dry Rail, T=68, H=52%
Comments: Test train on tangent track; surveys conducted to determine effect of time on adhesion coefficient

Station	West Rail, Before Test Train Passage	West Rail, After Test Train Passage	West Rail, 15 Minutes After Test Train Passage	West Rail, 30 Minutes After Test Train Passage	East Rail, Before Test Train Passage	East Rail, After Test Train Passage	East Rail, 15 Minutes After Test Train Passage	East Rail, 30 Minutes After Test Train Passage
1	0.66		0.34	0.30	0.64	0.29	0.31	0.31
2	0.67	0.31	0.32	0.32	0.64	0.31	0.33	0.32
3	0.62	0.33	0.34	0.35	0.59	0.30	0.30	0.31
4		0.32	0.33	0.31		0.31	0.32	0.32
Average	0.65	0.32	0.33	0.32	0.62	0.30	0.32	0.32

Test Case 9
Run: 5
Date: 2/28/98
Time: 5:00 PM
TOR Lubrication: Yes
Train Condition: Empty
Locations: Curve Site, MP 234.7
Conditions: Dry Rail, T=59, H=36%
Comments: Test train proceeding from south; passed through wayside lubricator
no time to measure on low rail; heavy lube on rail after test train pass

Station		High Rail, Before Test Train Passage	High Rail, After Test Train Passage	Low Rail, Before Test Train Passage	Low Rail, After Test Train Passage
Xing	1	0.38	0.29		
	2	0.38	0.28		
	3	0.41	0.27		
	4	0.43	0.27		
	5	0.40	0.28		
Crib 2	6	0.40	0.27		
	7	0.40	0.26		
	8	0.43	0.28		
	9	0.39	0.29		
Crib 1	10	0.38	0.25		
	11	0.36	0.27		
	12	0.37	0.27		
	13	0.35	0.32		
Joint	14	0.36	0.29		
Average		0.39	0.28		

Test Case 10
Run: 6
Date: 3/2/98
Time: 6:00 PM
TOR Lubrication: Yes
Train Condition: Loaded
Locations: Curve Site, MP 234.7
Conditions: Snow Flurries, T=32, H=75%
Comments: Test train proceeding from north; did not pass through wayside lubricator
no time to measure on low rail after test train passage

Station		High Rail, Before Test Train Passage	High Rail, After Test Train Passage	Low Rail, Before Test Train Passage	Low Rail, After Test Train Passage
Xing	1	0.38	0.41	0.45	
	2	0.42	0.40	0.46	
	3	0.42	0.41	0.48	
	4	0.43	0.39	0.51	
Crib 2	5	0.46	0.39	0.47	
	6	0.44	0.39	0.51	
	7	0.51	0.41	0.54	
	8	0.46	0.41	0.52	
Crib 1	9	0.47		0.50	
	10	0.48		0.52	
	11	0.51		0.55	
	12	0.39		0.48	
Joint	13	0.43		0.47	
Average		0.45	0.40	0.50	

Test Case 11
Run: 6
Date: 3/3/98
Time: 12:20 AM
TOR Lubrication: Yes
Train Condition: Loaded
Locations: Fagin Xing, MP 311.25
Conditions: Slight Condensation, T=38, H=77%
Comments: Test train on tangent track

Station	East Rail, Before Test Train Passage	East Rail, After Test Train Passage	West Rail, Before Test Train Passage	West Rail, After Test Train Passage
1	0.53	0.31	0.58	0.32
2	0.56	0.32	0.64	0.30
3	0.58	0.33	0.59	0.33
4	0.60	0.32	0.62	0.31
5	0.56	0.32	0.62	0.31
Average	0.57	0.32	0.61	0.31

Test Case 12
Run: 6
Date: 3/3/98
Time: 11:00 PM
TOR Lubrication: Yes
Train Condition: Empty
Locations: MP 351.67
Conditions: Dry Rail, T=37, H=65%
Comments: Test train on tangent track

Station	East Rail, Before Test Train Passage	East Rail, After Test Train Passage	West Rail, Before Test Train Passage	West Rail, After Test Train Passage
1	0.37	0.37	0.38	0.40
2	0.38	0.34	0.38	0.41
3	0.35	0.40	0.38	0.41
4	0.37	0.38	0.37	0.40
5	0.38	0.39	0.36	0.38
Average	0.37	0.38	0.37	0.40

Test Case 13
Run: 6
Date: 3/4/98
Time: 11:35 AM
TOR Lubrication: Yes
Train Condition: Empty
Locations: Curve Site, MP 234.7
Conditions: Dry Rail, T=54, H=55%
Comments: Test train proceeding from south; passed through wayside lubricator; no excessive wayside lube

Station		High Rail, Before Test Train Passage	High Rail, After Test Train Passage	Low Rail, Before Test Train Passage	Low Rail, After Test Train Passage
Xing	1	0.42	0.27		
	2	0.45	0.28	0.51	
	3	0.53	0.29	0.51	0.35
	4	0.52		0.53	0.36
Crib 2	5	0.43	0.27	0.52	0.35
	6	0.58	0.29	0.47	0.37
	7	0.58	0.27	0.47	0.35
Crib 1	8	0.55		0.42	0.34
Average		0.51	0.28	0.49	0.35

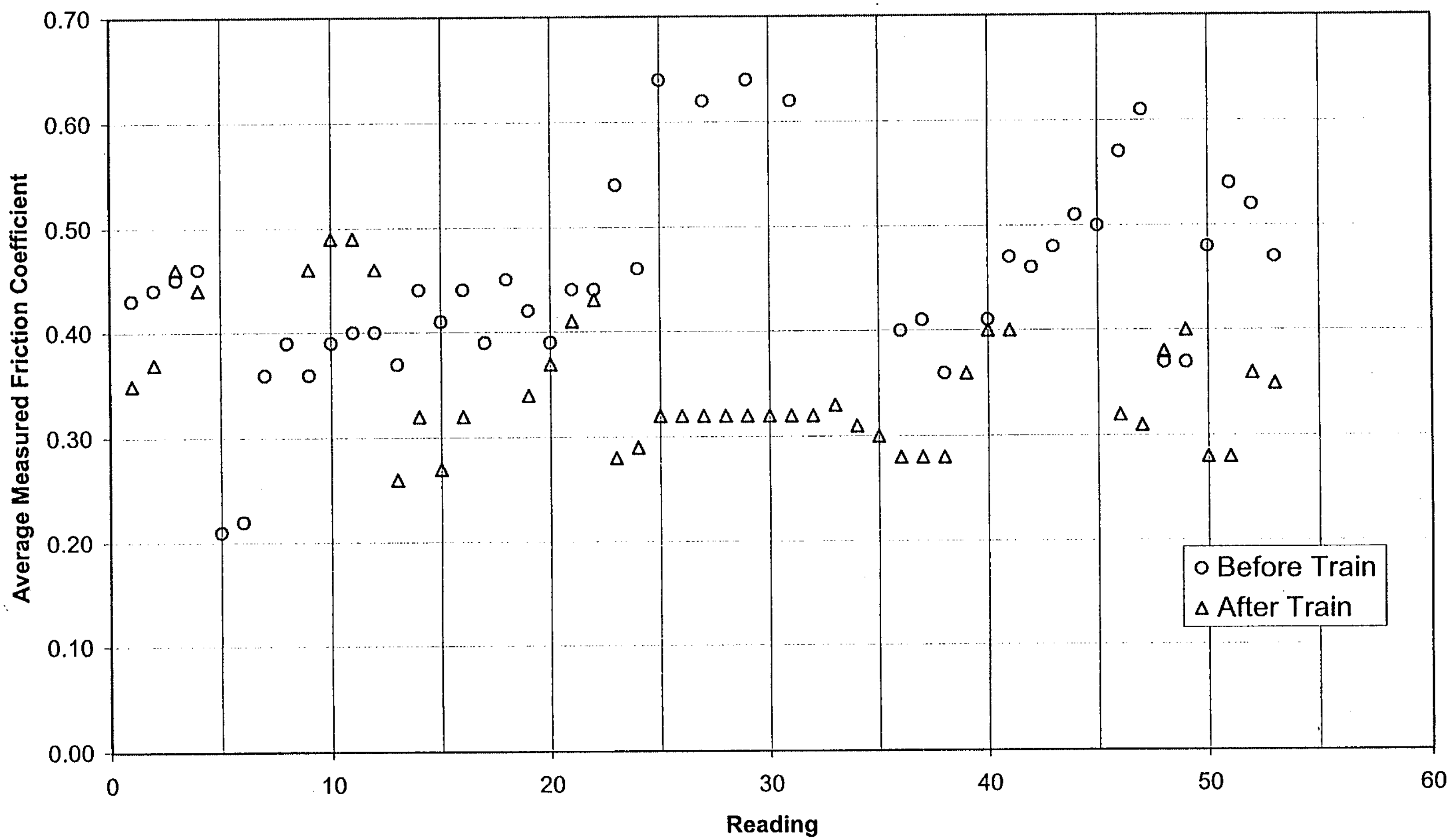

Figure C-1. Average Tribometer Readings, Before and After Test Train Passage

APPENDIX D

FUEL CONSUMPTION MEASUREMENTS

Fuel Consumption Results, Runs with Loaded Test Train

Fuel Consumption for CSXT 8328 (L1), CSXT 8702 (L2) and CSXT 8709 (L3) Presented in Gallons

Segment 1	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
25 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	70	85	97	252	7	5	9	21	69	70	94	233	3	2	6	11	57	68	79	204
Stop 1				0	0	0	0	0				0	2	2	2	6				0
Stop 2				0	75	81	100	256				0	53	63	71	187				0
Stop 3				0				0				0	19	21	24	64				0
Stop 4				0				0				0				0				0
Fuel in segment	70	85	97	252	82	86	109	277	69	70	94	233	77	88	103	268	57	68	79	204

Segment 2	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
15 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	95	116	130	341	65	61	86	212	58	73	79	210	66	58	88	212	70	65	92	227
Stop 1	63	76	82	221	80	99	109	288	79	95	106	280	23	27	31	81	85	98	112	295
Stop 2				0				0				0	66	75	86	227				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	158	192	212	562	145	160	195	500	137	168	185	490	155	160	205	520	155	163	204	522

Segment 3	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
6 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	5	5	7	17	1	2	2	5	2	3	4	9	6	8	11	25	1	1	2	4
Stop 1				0	5	8	9	22				0				0	5	6	7	18
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	5	5	7	17	6	10	11	27	2	3	4	9	6	8	11	25	6	7	9	22

Segment 4	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
14 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	17	22	25	64	7	6	5	18	19	22	28	69	8	8	10	26	16	20	24	60
Stop 1				0	2	5	1	8				0	2	3	3	8				0
Stop 2				0	11	8	17	36				0	5	5	6	16				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	17	22	25	64	20	19	23	62	19	22	28	69	15	16	19	50	16	20	24	60

Fuel Consumption Results, Runs with Loaded Test Train

Fuel Consumption for CSXT 8328 (L1), CSXT 8702 (L2) and CSXT 8709 (L3) Presented in Gallons

Segment 5	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
38 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	27	33	35	95	167	180	225	572	139	161	187	487	44	52	61	157	24	28	32	84
Stop 1	112	139	149	400	5	5	6	16	18	23	26	67	122	129	165	416	115	142	158	415
Stop 2	16	21	24	61				0				0	4	4	6	14	16	19	23	58
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	155	193	208	556	172	185	231	588	157	184	213	554	170	185	232	587	155	189	213	557

Segment 6	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
45 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	23	27	31	81	187	219	258	664	182	220	245	647	101	106	133	340	157	188	214	559
Stop 1	73	75	101	249				0				0	104	125	134	363	28	33	39	100
Stop 2	99	118	134	351				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	195	220	266	681	187	219	258	664	182	220	245	647	205	231	267	703	185	221	253	659

Segment 7	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
4 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	10	12	13	35	12	9	17	38	12	13	15	40	13	12	23	48	9	7	13	29
Stop 1				0				0				0				0				0
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	10	12	13	35	12	9	17	38	12	13	15	40	13	12	23	48	9	7	13	29

Segment 8	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
9 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	24	30	34	88	1	2	3	6	2	3	5	10	24	30	32	86	2	3	4	9
Stop 1				0	29	36	40	105	29	32	41	102				0	29	31	40	100
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	24	30	34	88	30	38	43	111	31	35	46	112	24	30	32	86	31	34	44	109

Fuel Consumption Results, Runs with Loaded Test Train

Fuel Consumption for CSXT 8328 (L1), CSXT 8702 (L2) and CSXT 8709 (L3) Presented in Gallons

Segment 9, 13 Miles

	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	39	42	54	135	43	46	54	143	36	40	49	125	36	39	49	124	38	44	53	135
Stop 1				0				0				0				0				0
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	39	42	54	135	43	46	54	143	36	40	49	125	36	39	49	124	38	44	53	135

Segment 10, 6 Miles

	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	40	49	53	142	27	34	34	95	38	45	52	135	28	36	38	102	10	12	14	36
Stop 1				0				0				0				0	23	24	32	79
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	40	49	53	142	27	34	34	95	38	45	52	135	28	36	38	102	33	36	46	115

Segment 11, 23 Miles

	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	65	83	89	237	43	46	49	138	64	73	86	223	67	81	89	237	44	56	59	159
Stop 1				0	34	41	40	115				0				0	1	1	0	2
Stop 2				0				0				0				0	31	41	43	115
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	65	83	89	237	77	87	89	253	64	73	86	223	67	81	89	237	76	98	102	276

Segment 12, 42 Miles

	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	98	105	132	335	158	167	191	516	167	176	229	572	19	26	29	74	0	4	1	5
Stop 1	53	56	74	183	1	3	2	6	2	1	1	4	127	136	174	437	56	70	79	205
Stop 2	8	10	11	29	8	9	9	26				0				0	34	39	42	115
Stop 3				0				0				0				0	57	52	80	189
Stop 4				0				0				0				0				0
Fuel in segment	159	171	217	547	167	179	202	548	169	177	230	576	146	162	203	511	147	165	202	514

Total Fuel Used

Run 2	3316	Run 4	3306	Run 3	3213	Run 5	3261	Run 6	3202

Fuel Consumption Results, Runs with Empty Test Train

Fuel Consumption for CSXT 8328 (L1), CSXT 8702 (L2) and CSXT 8709 (L3) Presented in Gallons

Segment 13	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
42 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	6	1	7	14	117	5	160	282	49	3	67	119	3	4	4	11	127	6	174	307
Stop 1	91	4	122	217				0	43	4	59	106	110	5	82	197				0
Stop 2	35	1	50	86				0	32	1	44	77	31	2	43	76				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	132	6	179	317	117	5	160	282	124	8	170	302	144	11	129	284	127	6	174	307

Segment 14	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
23 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	18	2	18	88	73	3	97	173	30	1	41	72	71	3	94	168	77	2	104	183
Stop 1	46	2	61	109				0	47	2	63	112				0				0
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	84	4	109	197	73	3	97	173	77	3	104	184	71	3	94	168	77	2	104	183

Segment 15	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
6 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	2	0	2	4				0	16	1	21	38	3	0	3	6	12	1	14	27
Stop 1	9	0	13	22				0				0	10	1	12	23				0
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	11	0	15	26	0	0	0	26	16	1	21	38	13	1	15	29	12	1	14	27

Segment 16	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
13 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	35	3	47	85				0	33	2	44	79	28	2	40	70	34	1	49	84
Stop 1				0				0				0				0				0
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	35	3	47	85	0	0	0	96	33	2	44	79	28	2	40	70	34	1	49	84

Fuel Consumption Results, Runs with Empty Test Train

Fuel Consumption for CSXT 8328 (L1), CSXT 8702 (L2) and CSXT 8709 (L3) Presented in Gallons

Segment 17	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
9 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	38	3	53	94	38	3	53	94	34	1	47	82	36	1	50	87				0
Stop 1				0				0				0				0				0
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	38	3	53	94	38	3	53	94	34	1	47	82	36	1	50	87	0	0	0	80

Segment 18	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
4 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	22	0	28	50	22	1	30	53	21	1	29	51	15	3	20	38				0
Stop 1				0				0				0				0				0
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	22	0	28	50	22	1	30	53	21	1	29	51	15	3	20	38	0	0	0	40

Segment 19	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
45 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	16	1	21	38	107	7	144	258	92	8	121	221	86	4	111	201	54	4	74	132
Stop 1	88	6	118	212				0				0	2	0	1	3	46	4	61	111
Stop 2	20	1	26	47				0				0	19	2	26	47				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	124	8	165	297	107	7	144	258	92	8	121	221	107	6	138	251	100	8	135	243

Segment 20	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
38 Miles	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	105	7	138	250	2	1	3	6	96	7	128	231	2	0	2	4	76	7	100	183
Stop 1				0	37	2	51	90				0	100	5	134	239	2	1	3	6
Stop 2				0	18	3	22	43				0				0	8	0	9	17
Stop 3				0	24	2	34	60				0				0	11	3	14	28
Stop 4				0	6	1	8	15				0				0	0	1	1	2
Fuel in					15	1	21	37												
segment	105	7	138	250	102	10	139	251	96	7	128	231	102	5	136	243	97	12	127	236

Fuel Consumption Results, Runs with Empty Test Train

Fuel Consumption for CSXT 8328 (L1), CSXT 8702 (L2) and CSXT 8709 (L3) Presented in Gallons

Segment 21 14 Miles	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	55	3	72	130	55	2	73	130	32	1	44	77	49	1	63	113	42	3	57	102
Stop 1				0				0	8	1	11	20	5	0	7	12	12	2	15	29
Stop 2				0				0	13	1	18	32				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	55	3	72	130	55	2	73	130	53	3	73	129	54	1	70	125	54	5	72	131

Segment 22 6 Miles	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	39	1	51	91	41	2	48	91	37	2	49	88	41	2	55	98	38	0	51	89
Stop 1				0				0				0				0				0
Stop 2				0				0				0				0				0
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	39	1	51	91	41	2	48	91	37	2	49	88	41	2	55	98	38	0	51	89

Segment 23 15 Miles	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	0	1	0	1	3	1	13	17	11	2	16	29	5	1	7	13	8	3	10	21
Stop 1	8	2	9	19	4	2	4	10	4	1	4	9	3	1	4	8	2	0	1	3
Stop 2	5	3	4	12	1	0	1	2				0				0	5	2	5	12
Stop 3				0				0				0				0				0
Stop 4				0				0				0				0				0
Fuel in segment	13	6	13	32	8	3	18	29	15	3	20	38	8	2	11	21	15	5	16	36

Segment 24 25 Miles	Run 2, Unlubricated				Run 4, Unlubricated				Run 3, Lubricated				Run 5, Lubricated				Run 6, Lubricated			
	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total	L1	L2	L3	Total
Stop 0	7	1	8	16	7	1	8	16	7	1	9	17	6	1	5	12	66	4	90	160
Stop 1	65	4	89	158	17	2	22	41	30	3	38	71	55	2	82	139				0
Stop 2				0	9	0	12	21	3	1	4	8				0				0
Stop 3				0	9	1	11	21	34	2	46	82				0				0
Stop 4				0	31	0	43	74				0				0				0
Fuel in segment	72	5	97	174	73	4	96	173	74	7	97	178	61	3	87	151	66	4	90	160

Total Fuel Used					
	Run 2 1743	Run 4 1656	Run 3 1621	Run 5 1565	Run 6 1616

Identification of Comparable Segments from Tests Conducted with Loaded Train

			Run 2, Unlubricated			Run 4, Unlubricated			Run 3, Lubricated			Run 5, Lubricated			Run 6, Lubricated		
Segment	MP	Miles	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops
1	178-203	25	252	27.1	0	277	19.4	2	233	24.1	0	268	18.2	3	204	33.4	0
2	203-218	15	562	15.6	1	500	18.3	1	490	18.7	1	520	14	2	522	15	1
3	218-224	6	18	20	0	27	17.3	1	9	22.7	0	25	17	0	22	17	1
4	224-238	14	64	29.4	0	62	22.9	2	69	30.3	0	50	19	2	60	18	0
5	238-276	38	556	21.1	2	588	23.5	1	554	24	1	587	24	2	557	22	2
6	276-321	45	681	22.1	2	664	29.5	0	647	28.8	0	703	25	1	659	20	1
7	321-325	4	35	19.8	0	38	16.2	0	40			48	14	1	29	14	1
8	325-334	9	88	22.8	0	111	18.3	1	112	17.2	1	86	22.5	1	109	18	1
9	337-350	13	135	30.4	0	143	31	0	125	30.7	0	124	30.5	0	135	30	0
10	350-356	6	142	21.4	0	95	34.3	0	135	16.2	1	102	32	0	115	18	1
11	356-379	23	237	34.1	0	253	27.9	1	223	23.3	0	237	33	0	276	24	1
12	379-421	42	547	24.6	2	548	25.2	2	576	24.4	1	511	25	1	514	22	3

Test Segments Determined to be Comparable Highlighted with Frame

Fuel Savings for Comparable Segments from Tests Conducted with Loaded Train

Run-Segment No.	Fuel Used (gal)	% Savings	Avg. % Savings for Segment
2-1	252	19.05	19.05
6-1	204		
4-2	500	2.00	4.56
3-2	490		
2-2	562	7.12	
6-2	522		
2-3	17	47.06	32.79
3-3	9		
4-3	27	18.52	
6-3	22		
2-4	64	-7.81	5.77
3-4	69		
4-4	62	19.35	
5-4	50		

Run-Segment No.	Fuel Used (gal)		% Savings	Avg. % Savings for Segment
4-5	588		5.78	2.80
3-5	554			
2-5	556		-0.18	
6-5	557			
4-8	111		1.80	1.80
6-8	109			
4-9	143	139	7.91	7.91
2-9	135			
3-9	125	128		
5-9	124			
6-9	135			
2-12	547	548	6.39	6.39
4-12	548			
5-12	511	513		
6-12	514			

Average For All Segments	*10.13*

Identification of Comparable Segments from Tests Conducted with Empty Train

			Run 2, Unlubricated			Run 4, Unlubricated			Run 3, Lubricated			Run 5, Lubricated			Run 6, Lubricated		
Segment	MP	Miles	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops	Fuel Used (gal)	Avg. Speed (mph)	No. of Stops
13	421-379	42	317	34.3	2	282	35	0	302	25.4	2	284	33	2	307	38	0
14	379-356	23	197	36.5	1	173	44.9	0	184	40.9	1	168	44	0	183	45.5	0
15	356-350	6	26	42	0		25.4	1	38	26.4	0	29	29	1	27	47	0
16	350-337	13	85	42	0		40.4	0	79	44.9	0	70	40	0	84	45	0
17	334-325	9	94	23.9	0	94	24.1	0	82	31.7	0	87	24	0			
18	325-321	4	50	20.5	0	53	16.4	0	51	19.1	0	38	14	1			
19	321-276	45	297	30.9	2	258	33.8	0	221	29.4	0	251	27	2	243	27	1
20	276-238	38	250	33.3	0	251	24.8	5	231	31.4	0	243	31	1	236	30	1
21	238-224	14	130	30.3	0	130	30.8	0	129	20.4	2	125	19	1	131	15	2
22	224-218	6	91	24.2	0	91	25.2	0	88	23	0	98	20	0	89	22	0
23	218-203	15	32	21.7	2	29	19.1	2	38	19.7	1	21	22	1	36	19	2
24	203-178	25	174	23.8	1	173	17.6	4	178	20.6	3	151	29	1	160	22	1

Test Segments Determined to be Comparable Highlighted with Frame

Fuel Savings for Comparable Segments from Tests Conducted with Empty Train

Run-Segment No.	Fuel Used (gal)	% Savings	Avg. % Savings for Segment
2-13	317	10.41	10.41
5-13	284		
4-14	173	2.89	2.89
5-14	168		
2-16	85	17.65	17.65
5-16	70		
4-17	94	7.45	7.45
5-17	87		
2-19	297	15.49	14.91
5-19	251		
4-19	258	14.34	
3-19	221		

Run-Segment No.	Fuel Used (gal)	% Savings	Avg. % Savings for Segment
2-20	250	7.60	7.60
3-20	231		
4-22	91	3.30	3.30
3-22	88		
4-23	29	-24.14	-24.14
6-23	36		
2-24	174	8.05	8.05
6-24	160		

Average For All Segments	*5.35*

APPENDIX E

TRIP MONITOR READINGS

Trip Monitor Readings Made on Locomotives 8709 and 8702

Test Run 2 Date: 2/19/98
Unlubricated Loaded Train
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.676	0.03	114.4	80.13
7	0.135	0.006	19.48	13.63
6	0.113	0.005	12.96	9.075
5	0.116	0.006	10.88	7.618
4	0.102	0.009	10.89	7.624
3	0.095	0.008	6.821	4.775
2	0.108	0.012	4.695	3.286
1	0.075	0.011	1.564	1.095
Idle	0.093	0.083	0	0
Dyn.Brake	0.871	0.042	0.401	0.28
Totals	2.384	0.212	182.091	127.513

Test Run 2 Date: 2/19/98
Unlubricated Loaded Train
Locomotive: 8702

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.676	0.03	101.6	71.17
7	0.135	0.006	17.56	12.29
6	0.113	0.005	12.23	8.564
5	0.116	0.006	10.5	7.35
4	0.102	0.009	10.68	7.477
3	0.095	0.008	6.368	4.457
2	0.108	0.011	4.255	2.978
1	0.075	0.01	1.441	1.009
Idle	0.093	0.082	0	0
Dyn.Brake	0.871	0.042	0.451	0.315
Totals	2.384	0.209	165.085	115.61

Test Run 2 2/20/98
Unlubricated Empty Train
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.659	0.019	74.39	52.07
7	0.178	0.005	16.81	11.76
6	0.14	0.004	10.65	7.455
5	0.174	0.005	10.01	7.01
4	0.198	0.007	9.32	6.523
3	0.153	0.007	6.384	4.472
2	0.129	0.01	4.046	2.832
1	0.085	0.005	0.923	0.646
Idle	0.111	0.066	0	0
Dyn.Brake	0.377	0.017	0.038	0.026
Totals	2.204	0.145	132.571	92.794

Test Run 3 Date: 2/22/98
Lubricated Loaded Train
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.763	0.033	124.7	87.32
7	0.106	0.004	13.57	9.503
6	0.099	0.004	9.938	6.956
5	0.076	0.004	6.764	4.738
4	0.074	0.003	4.704	3.293
3	0.072	0.004	3.691	2.584
2	0.054	0.005	1.89	1.322
1	0.073	0.007	1.104	0.772
Idle	0.082	0.047	0	0
Dyn.Brake	0.796	0.04	0.597	0.418
Totals	2.195	0.151	166.958	116.906

Test Run 3 Date: 2/22/98
Lubricated Loaded Train
Locomotive: 8702

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.763	0.033	107.1	74.98
7	0.106	0.004	13.05	9.14
6	0.099	0.004	9.527	6.669
5	0.076	0.004	6.605	4.623
4	0.074	0.003	4.572	3.2
3	0.072	0.004	3.74	2.617
2	0.054	0.005	1.843	1.29
1	0.073	0.007	1.1	0.77
Idle	0.082	0.046	0	0
Dyn.Brake	0.796	0.041	0.693	0.485
Totals	2.195	0.151	148.23	103.774

Test Run 3 Date: 2/23/98
Lubricated Empty Train*
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.587	0.017	66.03	46.22
7	0.145	0.004	14.56	10.19
6	0.125	0.004	9.769	6.8387
5	0.134	0.005	8.542	5.979
4	0.146	0.005	7.076	4.953
3	0.173	0.008	7.369	5.158
2	0.166	0.01	3.984	2.788
1	0.026	0.002	0.325	0.227
Idle	0.231	0.055	0	0
Dyn.Brake	0.433	0.018	0.047	0.032
Totals	2.166	0.128	117.702	82.3857

Trip Monitor Readings Made on Locomotives 8709 and 8702

Test Run 4 Date: 2/24/98
Unlubricated Loaded Train
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.86	0.037	141	98.75
7	0.076	0.003	10.03	7.025
6	0.083	0.003	8.063	5.644
5	0.054	0.002	4.406	3.084
4	0.078	0.004	4.968	3.478
3	0.082	0.005	4.448	3.114
2	0.085	0.006	2.445	1.711
1	0.054	0.006	0.897	0.628
Idle	0.085	0.041	0	0
Dyn.Brake	0.734	0.037	0.625	0.437
Totals	2.191	0.144	176.882	123.871

Test Run 4 Date: 2/24/98
Unlubricated Loaded Train
Locomotive: 8702

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.86	0.037	116.4	81.52
7	0.076	0.003	7.44	5.207
6	0.083	0.003	7.434	5.203
5	0.054	0.002	4.133	2.893
4	0.078	0.003	4.604	3.222
3	0.082	0.005	4.356	3.049
2	0.085	0.006	2.354	1.648
1	0.054	0.005	0.995	0.627
Idle	0.085	0.041	0	0
Dyn.Brake	0.734	0.037	0.704	0.493
Totals	2.191	0.142	148.42	103.862

Test Run 4 Date: 2/25/98
Unlubricated Empty Train*
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.58	0.017	64.96	45.47
7	0.126	0.004	11.94	8.358
6	0.17	0.005	13.33	9.333
5	0.172	0.007	11.45	8.021
4	0.199	0.008	9.887	6.92
3	0.185	0.012	10.02	7.014
2	0.231	0.021	7.692	5.384
1	0.118	0.009	1.439	1.007
Idle	0.131	0.068	0	0
Dyn.Brake	0.047	0.021	0.094	0.066
Totals	1.959	0.172	130.812	91.573

Test Run 5 Date: 2/27/98
Lubricated Loaded Train
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.755	0.034	126.9	88.86
7	0.103	0.004	13.78	9.652
6	0.094	0.004	10.58	7.41
5	0.085	0.004	7.261	5.083
4	0.082	0.004	5.946	4.162
3	0.079	0.004	4.188	2.932
2	0.063	0.006	2.239	1.569
1	0.069	0.009	1.207	0.845
Idle	0.07	0.09	0	0
Dyn.Brake	0.883	0.046	0.687	0.481
Totals	2.283	0.205	172.788	120.994

Test Run 5 Date: 2/27/98
Lubricated Loaded Train
Locomotive: 8702

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.755	0.034	106	74.24
7	0.103	0.004	12.3	8.611
6	0.094	0.004	9.666	6.765
5	0.085	0.004	6.908	4.835
4	0.082	0.004	5.687	3.981
3	0.079	0.005	3.968	2.778
2	0.063	0.006	2.219	1.553
1	0.069	0.009	1.189	0.832
Idle	0.07	0.09	0	0
Dyn.Brake	0.883	0.046	0.744	0.52
Totals	2.283	0.206	148.681	104.115

* Empty data for trip 5 was not taken

Trip Monitor Readings Made on Locomotives 8709 and 8702

Test Run 6 Date: 3/2/98
Lubricated Loaded Train
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.644	0.029	109.6	76.76
7	0.092	0.004	13.28	9.3
6	0.097	0.005	11.78	8.25
5	0.089	0.005	9.359	6.551
4	0.084	0.006	7.162	5.013
3	0.094	0.008	6.832	4.782
2	0.092	0.006	2.641	1.848
1	0.05	0.005	0.821	0.574
Idle	0.13	0.134	0	0
Dyn.Brake	0.812	0.044	0.732	0.512
Totals	2.184	0.246	162.207	113.59

Test Run 6 Date: 3/2/98
Lubricated Loaded Train
Locomotive: 8702

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.644	0.029	95.65	66.95
7	0.092	0.004	11.71	8.203
6	0.097	0.005	11.26	7.885
5	0.089	0.005	9.047	6.333
4	0.084	0.006	7.011	4.907
3	0.094	0.008	6.703	4.691
2	0.092	0.006	2.559	1.791
1	0.05	0.005	0.801	0.561
Idle	0.13	0.133	0	0
Dyn.Brake	0.812	0.046	0.793	0.555
Totals	2.184	0.247	145.534	101.876

Test Run 6 Date: 3/3/98
Lubricated Empty Train*
Locomotive: 8709

Throttle	Mileage (x100)hrs	Hours (x100)hrs	HP-hrs (x100)hrs	kW-hrs (x100)hrs
8	0.487	0.014	53.32	37.32
7	0.129	0.004	13.45	9.419
6	0.159	0.005	12.56	8.796
5	0.216	0.008	14.03	9.825
4	0.254	0.01	12.67	8.871
3	0.2	0.009	8.278	5.795
2	0.182	0.013	5.239	3.667
1	0.156	0.01	1.835	1.284
Idle	0.087	0.122	0	0
Dyn.Brake	0.358	0.021	0.075	0.052
Totals	2.228	0.216	121.457	85.029

*No readings available from CSXT 8702 on "empty Runs"; CSXT 8702 taken off-line during return trips

APPENDIX F

MECHANICAL ENERGY RESULTS

Calculated Mechanical Energy (kW-Hrs), Unlubricated Runs

Segment No.	Run 2	Run 4	Average Mechanical Energy
1	938.85	931.35	935.10
2	5520.78	4891.71	5206.25
3	-1343.64	-1638.51	-1491.07
4	-948.89	-1240.42	-1094.66
5	3368.55	2367.04	2867.80
6	4835.91	4480.30	4658.11
7	51.73	-179.30	-63.78
8	-189.40	-530.22	-359.81
9	969.26	1099.95	1034.60
10	1456.56	971.82	1214.19
11	866.03	1007.53	936.78
12	2619.92	2768.41	2694.17
Total, Loaded Train	18145.66	14929.68	16537.67

Segment No.	Run 2	Run 4	Average Mechanical Energy
13	2653.86	2232.86	2443.36
14	1760.15	1594.98	1677.56
15	141.37	114.11	127.74
16	714.03	653.84	683.94
17	804.54	797.70	801.12
18	440.90	455.54	448.22
19	2174.06	2032.91	2103.49
20	2006.03	1703.70	1854.87
21	1099.52	1135.14	1117.33
22	739.05	763.59	751.32
23	-208.62	-272.38	-240.50
24	1331.49	1137.76	1234.62
Total, Empty Train	13656.38	12349.75	13003.06
Total, Round Trip	31802.04	27279.43	29540.74

Calculated Mechanical Energy (kW-Hrs), Lubricated Runs

Segment No.	Run 3	Run 5	Run 6	Average Mechanical Energy
1	-393.95	439.09	978.25	341.13
2	4944.62	4939.62	5133.06	5005.77
3	-1250.55	-1552.60	-1442.33	-1415.16
4	-1027.11	-994.77	-1001.36	-1007.75
5	3089.02	2620.27	3060.13	2923.14
6	4376.83	4482.17	4349.13	4402.71
7	?	-6.99	-137.49	-72.24
8	-773.78	-179.49	-479.39	-477.55
9	857.17	837.36	1031.80	908.78
10	1266.74	1017.41	976.00	1086.72
11	207.14	643.33	1065.75	638.74
12	2904.61	1973.27	2907.52	2595.14
Total, Loaded Train	14200.74	14218.66	16441.07	14929.41

Segment No.	Run 3	Run 5	Run 6	Average Mechanical Energy
13	2665.33	2335.67	2741.18	2580.73
14	1610.93	1590.75	1863.52	1688.40
15	337.69	97.85	279.89	238.47
16	747.16	572.58	882.65	734.13
17	722.88	656.75	512.80	630.81
18	451.94	345.65	411.58	403.05
19	2026.30	1636.94	1160.18	1607.80
20	1674.02	1686.86	2612.89	1991.26
21	1084.68	986.76	987.65	1019.70
22	719.63	779.40	251.35	583.46
23	-237.00	-295.82	553.61	6.93
24	1331.57	1269.18	34.92	878.56
Total, Empty Train	13135.12	11662.57	12292.22	12363.30
Total, Round Trip	27335.85	25881.23	28733.29	27292.71

Mechanical Energy Savings, Individual Segments

Segment No.	Avg. Mechanical Energy (kW-Hrs), Unlubricated Runs	Avg. Mechanical Energy (kW-Hrs), Lubricated Runs	% Savings
1	935.10	341.13	63.52
2	5206.25	5005.77	3.85
3	-1491.07	-1415.16	5.09
4	-1094.66	-1007.75	7.94
5	2867.80	2923.14	-1.93
6	4658.11	4402.71	5.48
7	-63.78	-72.24	-13.26
8	-359.81	-477.55	-32.72
9	1034.60	908.78	12.16
10	1214.19	1086.72	10.50
11	936.78	638.74	31.82
12	2694.17	2595.14	3.68

Segment No.	Avg. Mechanical Energy (kW-Hrs), Unlubricated Runs	Avg. Mechanical Energy (kW-Hrs), Lubricated Runs	% Savings
13	2443.36	2580.73	-5.62
14	1677.56	1688.40	-0.65
15	127.74	238.47	-86.69
16	683.94	734.13	-7.34
17	801.12	630.81	21.26
18	448.22	403.05	10.08
19	2103.49	1607.80	23.56
20	1854.87	1991.26	-7.35
21	1117.33	1019.70	8.74
22	751.32	583.46	22.34
23	-240.50	6.93	102.88
24	1234.62	878.56	28.84
		Average Percentage of Savings Per Segment =	*8.59*

Mechanical Energy Calculations, Overall Results

	Run 2 Unlubricated (kW-Hrs)	Run 3 Lubricated (kW-Hrs)	Run 4 Unlubricated (kW-Hrs)	Run 5 Lubricated (kW-Hrs)	Run 6 Unlubricated (kW-Hrs)	Average Mechanical Energy Unlubricated Runs (kW-Hrs)	Average Mechanical Energy Lubricated Runs (kW-Hrs)	% Savings
Loaded Train	16586.53	12980.56	13646.87	12996.95	15028.40	15116.70	13668.64	9.58
Empty Train	12482.98	12006.51	11288.62	10660.48	11236.03	11885.80	11301.01	4.92
Round Trip	29069.51	24987.07	24935.49	23657.43	26264.43	27002.50	24969.64	7.53