Track Lubrication: Its Application and Potential for Reducing Fuel Consumption

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ABSTRACT

Most railroads in North America control excessive wear of wheels and rails by lubricating the gauge face of the outside (high) rail of curves. In 1983 an experiment at the Transportation Test Center (TTC) indicated that effective lubrication also has an additional benefit of reducing train energy and fuel consumption. This resulted in considerable research activity with tests being conducted on railroad properties to quantify these savings. These earlier tests were all carried out on highly curved territory and have demonstrated that significant fuel savings are possible on curved routes. There are also definite indications that train resistance can be reduced by lubrication on tangent track. Two recent experiments, one on a long section of tangent track and one in the laboratory, have provided evidence to support this possibility. It is unlikely that trackside lubricators alone can realize the maximum potential energy savings, and a number of alternative vehicle-mounted lubrication systems have been tested at TTC. These tests have demonstrated the potential benefits and limitations of operating these systems in revenue service. Different methods of monitoring the effectiveness of lubrication have also been developed. All of the foregoing research is summarized.

Wayside lubricators are used quite extensively on curved track in North America to control excessive wear of wheels and rails. Lubrication is typically applied to the gauge face of the outside (high) rail of curves and in addition to reducing wheel and rail wear, it has been shown to reduce rail end batter and the rate of corrugation growth (1). Recent research, however, has demonstrated that effective lubrication has the added benefit of reducing energy and fuel consumption, which is causing many railroads to pay increased attention to their lubricating practices.

Research on the effects of wheel and rail lubrication has been carried out under the auspices of two research programs: the Association of American Railroads (AAR) Energy Research Program and the Facility for Accelerated Service Testing (FAST) Program. The AAR's involvement in energy consumption was expanded in 1983 to include studies aimed at identifying and quantifying the discrete elements associated with train resistance. Train resistance has previously been estimated by using empirically derived equations such as the familiar Davis equation, for which there is only a limited theoretical justification and limited knowledge of the detailed contributions of individual parameters to the overall train resistance. Thus, although improvements might be made in individual car components, for example, through the use of improved car or truck designs or both, it is difficult to evaluate the overall effect of these improvements on energy or fuel consumption.

Hence, efforts were made to develop an improved understanding of the individual parameters that collectively determine total train resistance. The projects are part of a multiyear program and include analyses of aerodynamics, vehicle-track interaction, and roadbed resistances. Data generated in this program are to be used to develop more accurate economic and train energy models for use by the industry in evaluating fuel conservation alternatives. A train energy model was made operational and will be improved as test data are generated in the program. A Rail Energy Cost Analysis Program (RECAP) is also operational and is designed to use data from the train energy model to evaluate the economic potential of various fuel conservation strategies.

Coincident with the initiation of the train resistance studies in 1983, experimentation in the FAST Program at the Transportation Test Center (TTC) in Pueblo, Colorado, indicated the potential for energy savings due to lubrication and resulted in increased activity in this area.

EARLY EXPERIMENTATION AT FAST

Wayside lubrication has been used at FAST in order to obtain wear information for different rail metallurgies under both lubricated and unlubricated conditions. Experience from revenue service has shown increases in rail life due to lubrication; rail life is typically 50 to 100 percent greater with lubrication than without. However, at FAST, where a high level of control is much easier to achieve than in revenue service, large increases in rail life with lubrication have been obtained.

The effect of various levels of lubrication on the gauge face wear rate of standard carbon rail is as follows (MGT = million gross tons):

Level of Enforcement	Wear Rate (in./MGT)	Avg Relative Improvement (%)
Dry rail (no lubrication)	0.005-0.007	1
Low	0.001	5
Medium	0.00029	17
High	0.000064	80

It can be seen that with high levels of enforcement, large improvements can be obtained, which almost eliminate gauge face wear as a problem. Under these conditions, fatigue of the rail gauge corner becomes the limiting factor (1), and this will be the subject of a future FAST experiment.

During the course of the lubricated-wear experiments at FAST, it had been noticed that train handling and throttle position were quite different between lubricated and unlubricated periods. As a result, locomotive fuel consumption was monitored quite closely by measuring the fuel that was required to top off the tank. From these measurements, it was determined that an average savings in fuel consumption of 32 percent was being obtained because of lubrication.

Subsequently, AAR personnel at TTC developed a system (2) designed to measure train resistance by characterization of locomotive tractive effort versus input power to each traction motor. The Roll Dynamics Unit (RDU) was utilized as a dynamometer to calibrate the measuring system. The locomotive, which was kindly loaned to the AAR by the Burlington Northern, is shown mounted on the RDU in Figure 1. The product of input voltage and current to each traction motor was compared with power at the dynamometer to determine the traction motor efficiency. This effort was accomplished for all throttle positions and speeds up to 60 mph. The RDU was utilized to power the locomotive to characterize the dynamic brake tractive effort relationship.

This instrumentation scheme was then used for an experiment (3,4) utilizing a six-car test train on a 4.8-mi FAST loop. This loop consists of 45 percent tangent track and 55 percent curved track ranging from 3 to 5 degrees. Grades of up to 2 percent are encountered.

For the six-car train operating on the FAST loop, an average of 414 kW of power was required at the wheel-rail interface to maintain a constant speed of 40 mph on unlubricated rail. The Davis equation approximation for the FAST loop is 442 kW.

These on-track tests were repeated for track generously lubricated by trackside lubricators, simulating a territory with a lubricator located every 2.5 mi. The average power consumed was measured at 270 kW. This represents a saving of 34 percent in energy required to move the identical train over the identical territory, which, of course, correlates well with the fuel saving mentioned previously. Breaking the FAST loop into individual sections yields the following relationships (energy consumed because of train acceleration and track gradient over each section has been removed):

FAST Section	Energy Savings due to Lubrication (%)
Tangent	30
Curved	
Three degrees	36
Four degrees	39
Five degrees	51

The large savings on tangent track were surprising, and this phenomenon will be discussed later.

REVENUE SERVICE TESTS

As a result of the FAST test, the decision was made to conduct a number of tests on railroad properties to determine the magnitude of energy savings due to wheel-rail lubrication for different operating conditions in actual train service. The first of these tests was conducted jointly by the AAR and the Seaboard System Railroad in cooperation with the Norfolk Southern Corporation in October 1983 (5,6).

A loaded unit coal train consisting of four 3,000-hp six-axle locomotives, the Norfolk Southern Corporation rail lubrication car, the Seaboard System test car, 72 loaded coal cars, and a regular crew caboose was assembled at Corbin, Kentucky. The gross trailing weight of this train was 9,091 tons.

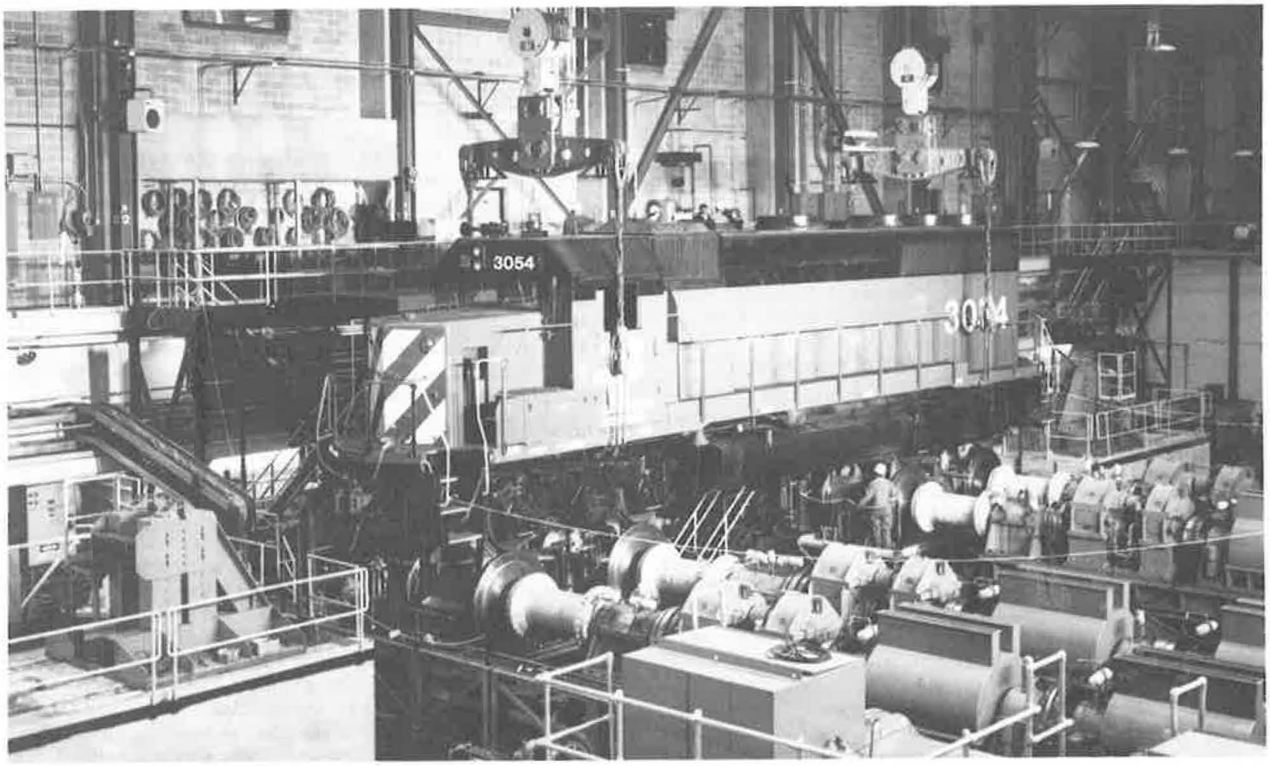

FIGURE 1 Locomotive mounted on RDU.

The locomotive units were instrumented to record train speed and main generator output voltage and amperage (power). The data were collected by a desktop computer mounted in the cab of one of the locomotives. Coupler force and locomotive throttle position were also measured.

The test was conducted on the Seaboard System main line south of Corbin on a 14-mi segment that had an average grade of 0.568 percent. For the last 5 mi of the test route, the average grade was 0.9 percent and contained reverse curves of up to 10 degrees. Approximately 70 percent of this 14-mi segment was curved track.

Three days before the start of the test, all wayside lubrication devices in the area of the test were made inoperative in order to allow time for lubrication from these sources to be dissipated by passing trains. These devices were not operative during any part of the test.

The first three runs were made without lubrication from any source in order to establish base-line data for comparison with data from lubricated track. On the second day, three further runs were made on lubricated rail with the lubricant being applied from the Norfolk Southern lubrication car. During all test runs, the same speed profile as established during the first run was maintained as closely as possible by increasing or decreasing the locomotive throttle as necessary.

The energy savings on the lubricated runs as compared with the dry runs were immediately noticeable during the test by examination of the throttle notch position data as seen on the strip chart recorder. On dry rail, throttle position 8 was used 68 percent of the time but only 26 percent of the time on lubricated rail, and the average speed varied only 0.1 mph between the two runs.

The force data obtained by the computerized data acquisition system from the coupler were converted to horsepower-hours and are therefore expressed as energy consumed rather than pounds force. The locomotive alternator power measurements were similarly converted to energy consumed and both sets of data are as follows:

Track Condition	Energy Consumption (hp-hr) Drawbar	Energy Consumption (hp-hr) Locomotive Alternator
Dry	5,143	6,756
Lubricated	4,370	5,744

Train acceleration effects have been removed from these calculations of energy consumption in order to minimize the difference between runs due to train handling. In these particular tests, however, the removal of acceleration energy is not a major factor, because train accelerations during the test were small and do not significantly affect the results.

The energy consumption as measured at the locomotive alternator is higher than the drawbar measurement because, of course, the latter is measuring only the energy required to pull the trailing consist whereas the locomotive data include the energy for the complete consist. However, both measurements indicate a 15 percent energy saving due to lubrication.

Subsequent to this test, Consolidated Rail Corporation (Conrail) ran tests (7) to measure the energy required to pull unit coal trains over a 200-mi section of railroad. Repeated tests were conducted with no lubrication at all, trackside lubricators, on-board lubricators, and combined trackside and on-board lubricators. Lubrication clearly reduced train resistance, and trackside lubricators produced better results than did on-board lubricators. Combining both types of lubrication reduced train resistance more than either type alone as follows (GTM = gross ton miles):

Lubrication Method	GTM Per Kilowatt-Hour	GTM Per Gallon of Fuel
None	156	1,999
On board only	183	2,294
Trackside only	194	2,498
On board and trackside	223	2,590

Conrail ran this test on a generally level but mostly curved route in central Pennsylvania. Sixty percent of the route is highly curved (up to 12 degrees) secondary track, and the other 40 percent is moderately curved main line. The train consisted of one SD40-2 and one SD50 locomotive, the Conrail instrument car, 125 to 130 loaded 100-ton hoppers, and a caboose. The train speed was less than 45 mph throughout the test. The 200-mi route has 44 well-maintained trackside lubricators.

A similar test run over curved territory by Norfolk Southern has indicated energy and fuel savings due to lubrication of the same order as those measured by Conrail.

TANGENT TRACK INVESTIGATIONS

Thus, there is ample evidence that effective lubrication has a dramatic effect on fuel and energy savings on curves. There is also some evidence that lubrication may reduce train resistance on tangent or straight track. The original FAST test with the six-car consist was conducted so that energy savings on individual sections of track could be identified, and 30 percent savings on tangent track were clearly measured. Although not measured directly, similar tangent track savings were noted from the Seaboard test data.

Both tests were conducted on track containing numerous curves with only small sections of tangent track in between. One hypothesis is that, in such a situation, the three-piece trucks, with all their inherent friction characteristics, do not have sufficient time to straighten out of the attitude assumed in the curves and consequently continue to run with misaligned axles, which results in flange contact on straight track.

It is also feasible that lubrication will have a beneficial effect on energy consumption even on long tangent track sections. It has been shown analytically (5) that relatively small misalignments of the axles on a three-piece truck can result in flange contact on tangent track and that reduction in the flange-rail contact patch through lubrication will decrease train resistance. The required misalignments are achievable in practice because of the longitudinal clearances that exist between the bearing adapters and the side frame pedestals.

To investigate tangent track resistance, two tests were carried out in 1984. In the first, the AAR participated in a joint test with the Atchison, Topeka and Santa Fe Railroad on a 5-mi-long section of tangent track in Kansas. The train consisted of eight open-tip gondolas pulled by one locomotive (Figure 2), which, as for the previous tests, was instrumented to measure alternator and traction motor power. The power required to pull this consist over the tangent track at constant speed was measured for speeds between 20 and 70 mph in nominal 10-mph increments. Lubrication was applied by means of a system mounted on the locomotive. The results are shown in Figure 3, where the average resistance of the whole train in pounds force is plotted as a function of the train speed for four test cases. It

FIGURE 2 Santa Fe consist used for the long tangent test in Kansas.

will be noted that for the cars loaded to their 100-ton capacity, the reduction in resistance due to lubrication is considerable, particularly at speeds below 60 mph. It will also be noted that the empty cars had more resistance above 50 mph than the loaded cars, indicating the crucial importance of aerodynamic drag at higher speeds.

A second experiment to investigate tangent track resistance was also carried out in 1984 on the RDU at TTC. A conventional three-piece truck was placed on a pair of rollers (Figure 4) and the measurement of torque in the rollers allowed calculation of the rolling resistance. The effect of different axle misalignments on tangent track operation was assessed. Tests were carried out with and without lubrication. At the time of this writing, the results had not been fully analyzed. However, for the misalignments tested, which were equivalent to yawing the axles to take up (a) half the clearance and (b) all the clearance between the bearing adapters and side frames, initial indications are that the resistance measured on dry rollers was significantly higher than that measured when the rollers were lubricated.

FAST LUBRICATION STUDY

Thus, the research into energy consumption aspects has produced exciting results, and the potential economic benefits (8) are considerable. However, overlubrication, especially when lubricant finds its way to the top of the rail, has a detrimental effect on rail life as well as train handling and rail forces. However, the railroad industry is inexperienced in measuring and quantifying lubrication effectiveness. In addition, a wide variety of methods are available to apply the lubricant, and these factors led the FAST program at the TTC to undertake a 10-month lubrication study. The major objectives of this study include

- Development of methods for measurement of lubrication effectiveness;
- Development of performance criteria for types of greases, location and methods of application, and alternative application systems;
- Development of reliability and maintenance history records of various trackside systems;
- Determination of energy savings potential of various lubrication systems; and
- Development of ideas for better lubricators for FAST.

The first objective was to develop a method of assessing the effectiveness of lubrication. Methods such as monitoring overall fuel consumption, train handling, or rail-wheel wear are accurate but do not provide an easy-to-use instant reading of lubrication effectiveness. Grease output meters, installed in the trackside lubricator hoses, have been used previously at FAST but with mixed results. Frequent clogging, cold weather freezing, and erratic readings led to abandonment of this system. The "goop gauge" (Figure 5) was used for several years to monitor and control the level of visible grease on the rail. When FAST rail wear data were collected during recent periods of lubrication, it was attempted to maintain the lubricant at least at a +0 level and no higher than a +10 level based on gauge values.

A trackman would periodically inspect curves and

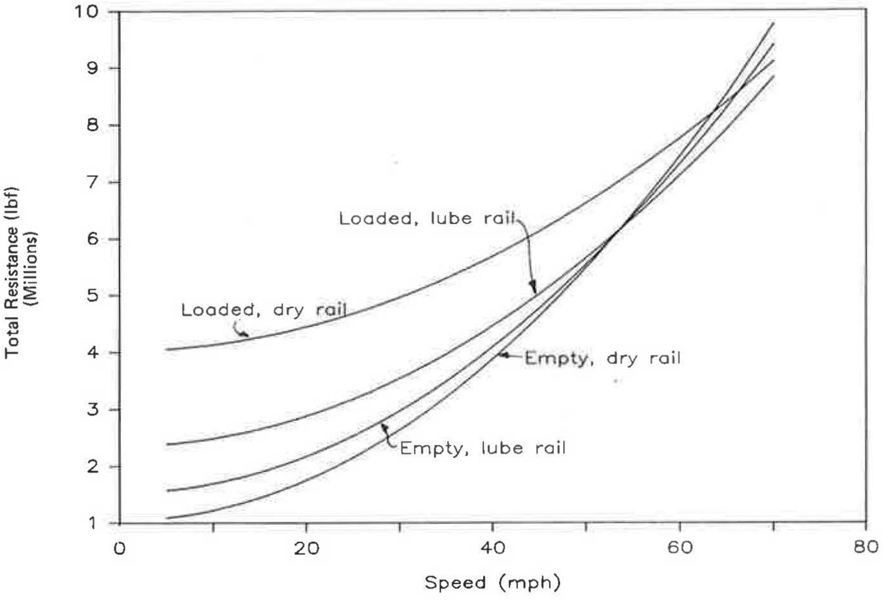

FIGURE 3 Resistance test results: low side mill gondolas.

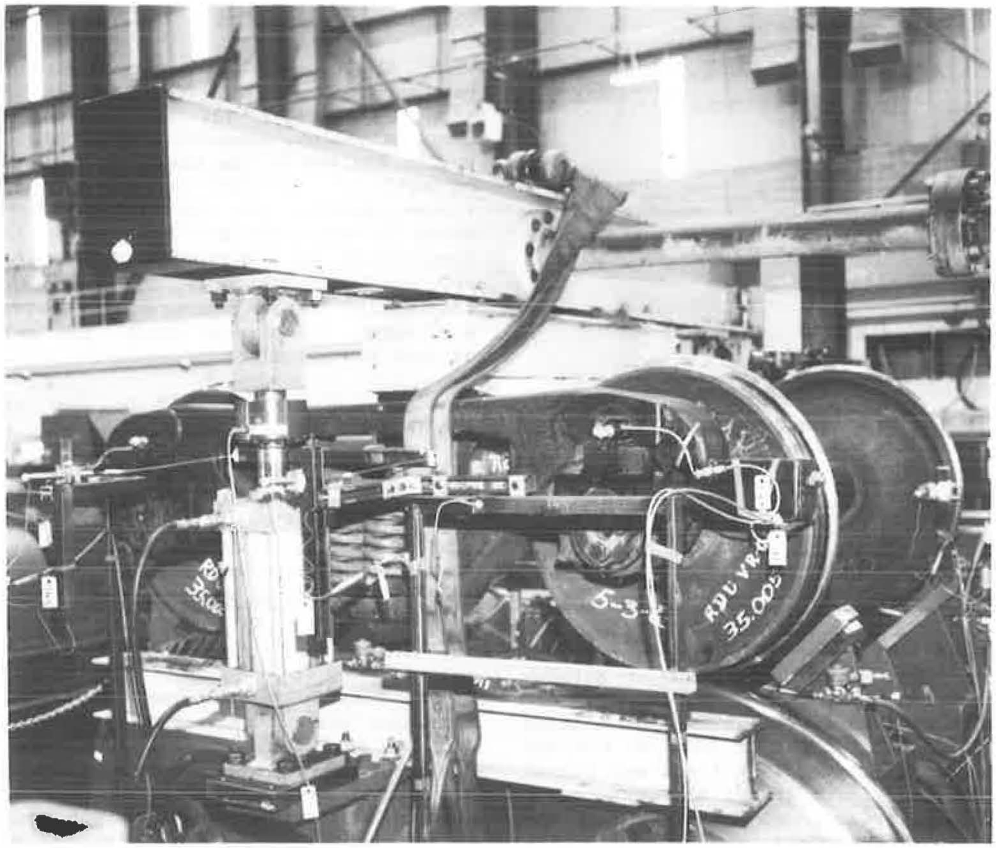

FIGURE 4 Three-piece-truck rolling resistance tests on RDU.

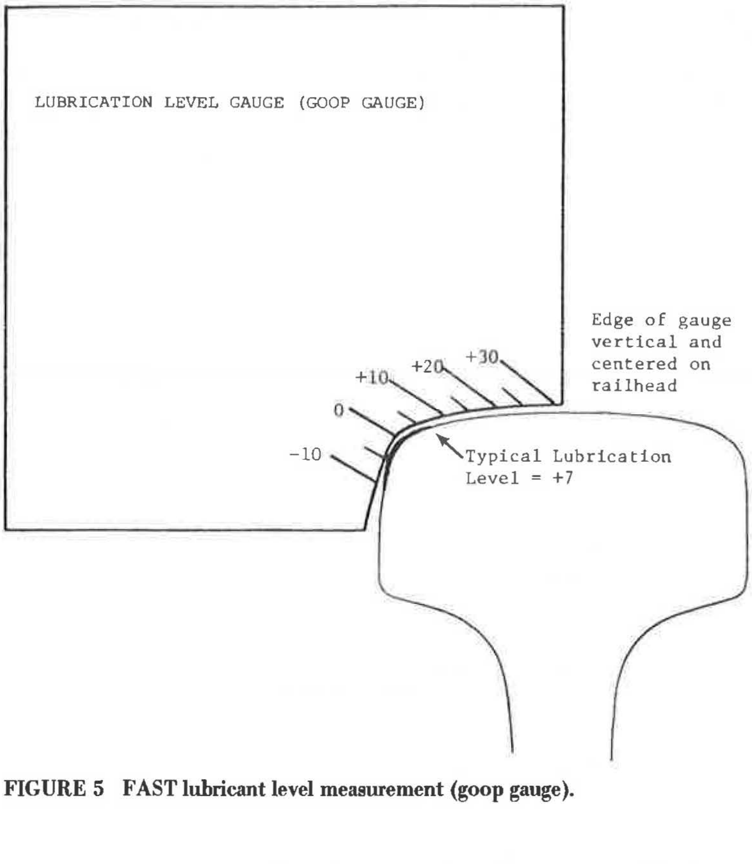

FIGURE 5 FAST lubricant level measurement (goop gauge).

adjust the lubricators to maintain grease at the desired level. The goop gauge is a useful tool for maintaining a constant level of lubricant, but it does not indicate effectiveness of the visible lubrication. The goop gauge is also useless when non-graphite-based greases are tested because the grease film is usually invisible.

Alternative methods of measuring lubrication effectiveness (9) were examined, and two were ultimately adopted for FAST tests. These are wheel-rail longitudinal force of a loaded hopper car (leading axle) and rise in rail-head temperature due to the passing of a train. The rail-head temperature rise measurement is being examined for potential everyday use by railroad field personnel.

Both techniques stem from the fact that during negotiation of sharp curves, flange contact occurs and substantial creep forces are generated in both the lateral and longitudinal directions. These forces and creepages cause considerable energy dissipation in the wheel-rail interface and result in a need for an increased drawbar force to pull the vehicle through the curve. Part of this energy is dissipated in the form of wheel and rail wear and part in the form of heat causing a rise in temperature of the rail, particularly of the high rail in a curve. When lubrication is applied to the contact area between the flange and the gauge face, the coefficient of friction is lowered and the magnitude of the longitudinal forces decreases dramatically. This reduces the energy dissipated in the wheel flange contact patch and hence reduces wheel and rail wear, drawbar force, and the temperature rise in the rail.

Longitudinal force is monitored by a specially instrumented wheelset, mounted in a conventional truck (leading axle) under a 100-ton loaded car and recorded by a data collection vehicle. (The axle is strain-gauged to measure torsion of the axle, which is a measure of wheel-rail longitudinal force.)

On Section 3 at FAST (Figure 6), which is a 5-degree curve with 4 in. of elevation, at a train speed of 45 mph longitudinal force provides a very uniform means of comparing dry and lubricated rail. A dry rail will result in longitudinal force values of 5,500 to 8,500 lb. On the same curve in a fully lubricated state, these forces decrease to 1,500 to 2,000 lb. Predictable values of force are observed between these two extremes at intermediate lubrication levels.

Longitudinal force measurements, although accurate and apparently very indicative of lubrication, would be costly to obtain and would not be practical for most railroads. An additional verification method was elected, that of rail-head temperature rise.

Creep forces, present during the flanging action as a train negotiates a curve, result in heat at the rail-flange interface. The amount of heat produced by a passing train is a function of many complicated actions, including curvature, speed, superelevation, truck characteristics, train weight, and lubrication. At FAST it is possible to control these variables, and during the lubrication experiment, all of these items (with the exception of lubrication) were kept constant; thus, the resulting temperature rises were an excellent indication of lubrication effectiveness. The field side of the high rail is used for temperature measurements because results obtained there would translate easily into applications by the railroad industry for portable systems.

Figure 7 shows the comparison of goop gauge, longitudinal force, and temperature rise under lubricated and dry rail conditions. The lower line on the graph indicates ambient rail temperature in FAST Section 3 monitored on a 4-ft segment of no. 136 rail adjacent to the track. The data for an 8,500-ton train on a 5-degree curve with 4-in. elevation at 45 mph are as follows:

	Dry	Lubricated
Longitudinal force (ft·kips)	15.0	2.0
Goop gauge level	-10	+10
Temperature rise at rail head (°F)	18	3

By monitoring both longitudinal force and rail-head temperatures as the FAST train negotiates a curve, the lubrication effectiveness of the system or product being tested can be assessed.

SELECTED LUBRICATION TEST DATA

Individual reports (10-13) on the alternative lubrication systems tested have been prepared and the following data have been selected from those reports.

The first alternative for applying lubrication at FAST was the lubricator car (Figure 8). This car is operated behind the last locomotive and applies lubrication to the rails from nozzles that spray conventional track grease onto one of the wheels of the car. The lubricator car was supplied courtesy of the Norfolk Southern.

Table 1 shows the lubrication effectiveness of the initial and the 1st, 5th, 10th, and 20th trains after a lubricator-car-equipped train. On the basis of these results, it was recommended that such a car, using conventional track grease, be operated in at least one train of every four in order to maintain an effective level of lubrication.

The Hyrailer lubricator vehicle test followed the lubricator car test. The Hyrailer vehicle was supplied by the Burlington Northern Railroad. This system utilized a conventional Hyrailer pickup truck to transport grease application equipment. Conventional track grease was sprayed directly onto the rail (Figure 9).

Trains operated after the passage of the Hyrailer vehicle spread grease along the rail surface. Figure 10 shows temperature and wheel force data for a simulation where the Hyrailer was operated every 10 trains, and Figure 11 represents a Hyrailer pass after almost 40 trains. In order to obtain significant lubricant on the rail, a large amount of track grease was applied, often resulting in wheel slip because the conventional grease migrated to the top of rail. An important observation during the Hyrailer test was made after a special drydown run. Under dry FAST loop conditions, approximately half the length of all tangents only was lubricated, and no grease was applied on curves. After the pass of one train, all curves were fully lubricated and remained effectively lubricated for at least 10 laps, gradually losing effectiveness in a fashion similar to those runs where only curves were lubricated. A subsequent series of test runs using an open-gear lubricant provided significantly better results. The lubricant was suspended in a carrier that evaporated within 10-15 min after application. The remaining lubricant film was very sticky and did not flow over the rail head as conventional track grease does.

The ability of grease to move from curves to tangent supported the conclusions made during the lubricator car test. Effective lubrication must be present on both tangents and curves to obtain the greatest fuel savings. If only curves are lubricated, the flanging effect of trucks will rapidly dry off wheels on long tangents and it will be impossible to

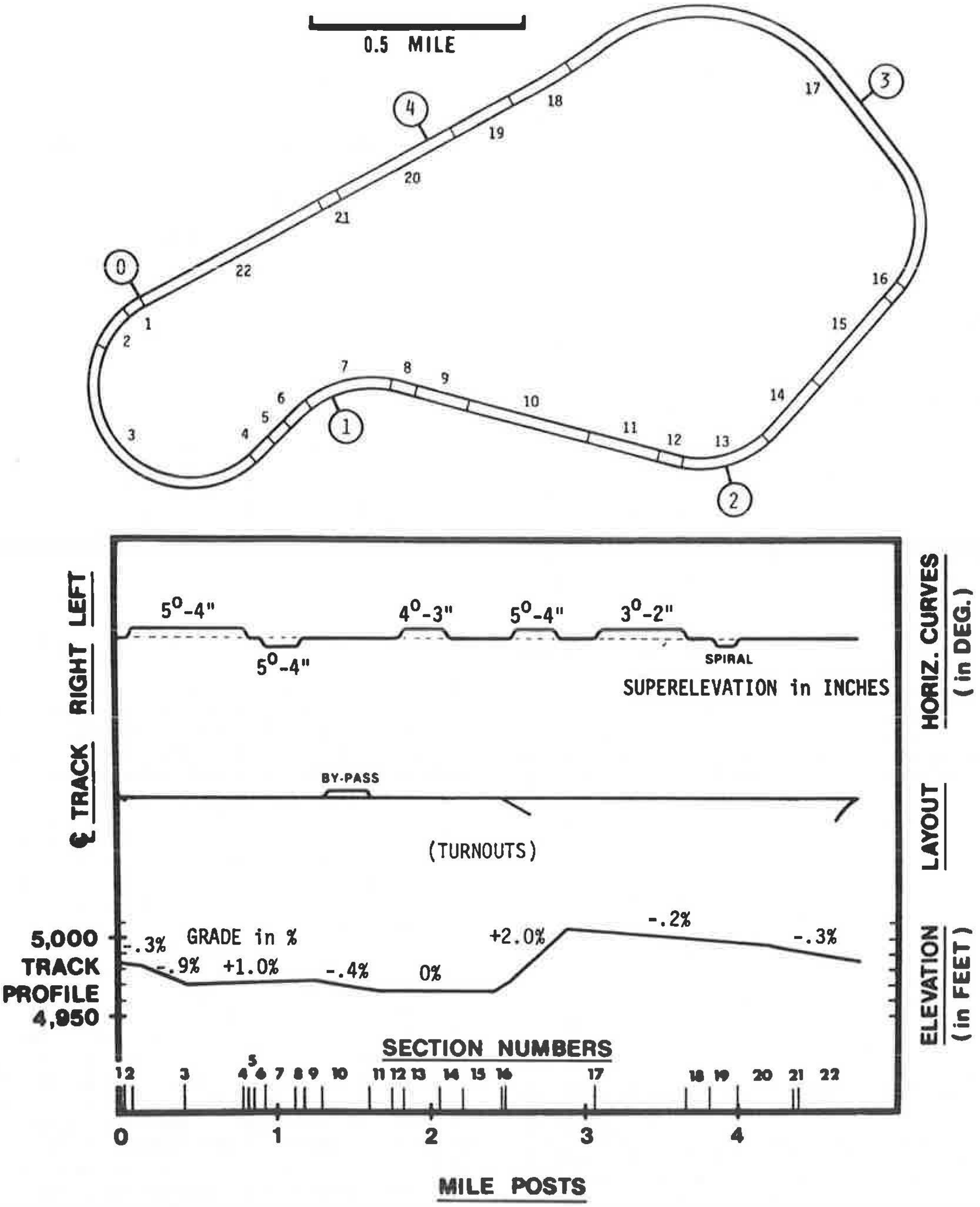

FIGURE 6 FAST track layout.

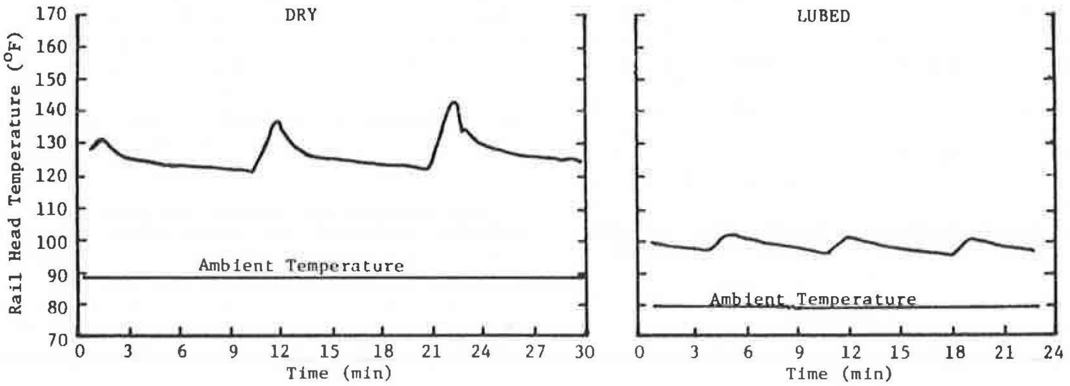

FIGURE 7 Lubrication effectiveness measurements.

TABLE 1 Rail Temperature and Wheel Force for Successive Laps After Grease Application (Lubricator-Car Test)

Lubrication Condition	Longitudinal Wheel Force (kips)	Rail-Head Temperature Rise[a] (°F)	Lubrication Adequate?
Bone dry (metal flakes); no lubrication	6.6	10-18	No
Fully lubricated during pass of lubricator car	1.0	2	Yes, too much
First train after lubricator car	1.1	2-3	Yes
Fifth train after lubricator car	1.7	6-8	Low
Tenth train after lubricator car	3.2	8-10	Marginal
Twentieth train after lubricator car	3.8	10-12	No

Note: Wheel force measured midtrain, rail-head temperature on high rail of 5-degree curve.

[a] Train with 80 cars.

FIGURE 8 Lubricator car in FAST consist.

FIGURE 9 Lubricator system mounted in Hyrailer truckbed.

maintain adequate lubrication between widely separated curves.

The on-board locomotive lubricator system followed the Hyrailer test. This system was supplied by the Bijur Lubricating Company and consists of a lubricant reservoir and spray system mounted in the locomotives (Figure 12). Oil (nongraphite lubricant) is periodically sprayed onto both wheels of the lead locomotive axle. The system operates whenever the locomotive is moving, applying a small amount of lubricant every 200 to 300 ft regardless of curve or tangent. The FAST train was tested by simulating two and three locomotives equipped with this system.

After the system output was adjusted to increase the level above that set at its European origin, sufficient lubrication was obtained to adequately lubricate all trains. It is important to note that the FAST simulation represented a railroad operation where each train was equipped with at least two locomotives (on a 75-car train) carrying such a system. Figure 13 represents typical wheel-force and rail-temperature measurements during the Bijur test. The on-board system differs from the other systems used at FAST in that no instant effectiveness was observed. Between 10 and 15 train passes with operating lubricators were required before system efficiency was obtained. Each train supplies a small amount of fresh lubricant to the rail, building on the layer already in place. The lubricant layer, once applied, lasts for quite some time, requiring at least 10 to 15 train passes to lose its effectiveness with the system turned off. Over 100 train passes were required after completion of this phase of the lubrication study to obtain a dry track free of all traces of this grease for the next series of tests.

Table 2 indicates the relative fuel efficiency of the systems tested to date. It is important to be aware of test conditions for the systems. For example, the Hyrailer system fuel efficiency was based on one pass of the vehicle every 30 to 35 trains and conventional track grease was used. Alternative operational modes, such as applying lubricant every 20 trains or using a different lubricant, could significantly improve fuel efficiency results.

A word of caution must be interjected when the wayside lubricator fuel efficiency figures are used. The lubrication under this operation was based on the use of backup lubricators located at each of the two sites. After every 10 laps of train operation, all curves were inspected with goop gauges and each lubricator was adjusted as required. The rail was in a highly lubricated condition almost all the time. It is not expected that railroads could economically maintain this level of lubrication at all locations by using trackside lubricators.

Other series of tests for the lubrication study assessed how rapidly different track greases spread around a curve and how they stand up to hot wheels from braking and are affected by locomotive sanding. Subsequent test series also investigated the effects of trackside lubricator location (tangent, point of spiral curve, etc.) and blade configuration (small individual blades, two moderate-length blades, and one long blade).

An additional test involved five different, conventional trackside lubricators in constant operation at FAST. These lubricators are installed in a normal manner, with the exception that lubricant is not applied to the track but is pumped into barrels. The amount of grease pumped from each lubricator is monitored daily, as are lubricator repair and adjustment activities.

An important note in all of the tests at FAST is that they were designed to simulate an entire territory equipped with the system being examined. Because the FAST track has but one train making multiple passes, each train is then subjected to the same conditions. Results of FAST testing, most notably those of fuel consumption, may not be directly

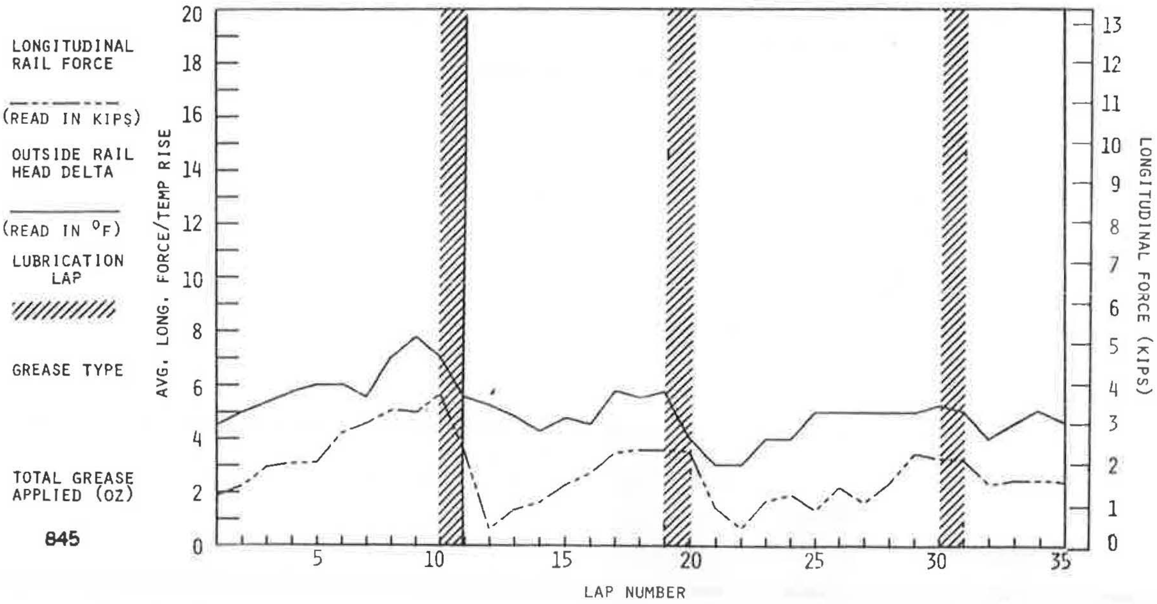

FIGURE 10 Wheel force and temperature rise with lubrication every 10 trains (Run 1216).

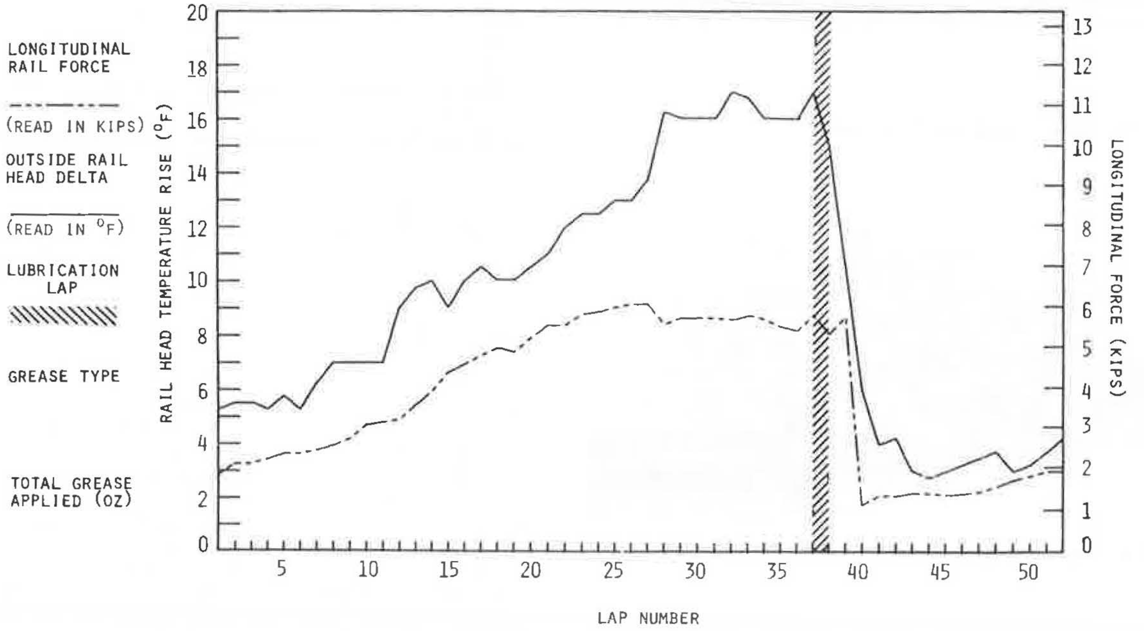

FIGURE 11 Wheel force and temperature rise: lubrication condition after 40 trains (Run 1220).

translatable to the field unless an entire territory is uniformly lubricated. In most revenue service environments, this is difficult to obtain, because long tangents may be interrupted by a series of curves to be followed by long tangents. Because of the variety of conditions seen in the field, no one lubrication application system tested to date has indicated that it can provide a uniform level of lubricant at all locations.

A combination of a mobile system suited to an operating property's environment with trackside lubricators at selected locations may provide the most appropriate means of applying a proper amount of lubrication yet controlling the tendency to over-lubricate.

CONCLUSIONS

It is quite apparent that effective wheel-rail lubrication has considerable potential for fuel savings in North America. This is particularly true in curved territory, and although more testing is required, indications are that operations on tangent track will also benefit. Proper lubrication will also provide noticeable increases in wheel and rail wear life as well as improved resistance of rail degradation to welded joint batter and corrugation.

Work has also begun to ascertain an optimum lubrication level to obtain the best combination of a number of factors. Nearly infinite rail wear life is not feasible because of rail fatigue along with the possible safety problems in train handling should too much lubrication be applied. A lubrication policy that allows moderate rail wear may provide the best compromise of wear and fatigue life and still permit significant energy savings. FAST experiments have indicated a large variation in resultant lubrication effectiveness by using different lubricants in a given application system.

FUTURE RESEARCH

There are still a number of potentially detrimental aspects of lubrication that remain to be investigated, including locomotive adhesion and train braking problems as well as rail fatigue failures. The AAR will conduct adhesion and braking tests with member railroads in 1986 and a FAST experiment on defect occurrence and growth will investigate the rail fatigue problem.

FIGURE 12 Spray nozzle, bracket, and grease spray pattern.

In addition, the AAR is investigating lubricants and application systems to determine desirable levels of lubrication. Results of these studies will be made available to the industry in order to aid in determining a given operating railroad's optimum lubrication policy.

ACKNOWLEDGMENTS

Most of the research described in this paper has been carried out under the auspices of two research programs, the AAR Energy Research Program and the FAST Program. The majority of the funding for the latter is supplied by the Federal Railroad Administration. In addition, a number of railroads have made significant contributions to the research findings through donations of materials and manpower, through participating in joint tests with the AAR, or through carrying out their own testing. The authors are most appreciative of the efforts, guidance, and assistance of all those who have contributed to the research described in this paper.

TABLE 2 Relative Fuel Efficiency of Lubrication Systems Tested at FAST to Date

System	Fuel Efficiency (gal/MGT[a])	Savings over Dry (%)
Dry track	6,000	–
Lubricated by wayside lubricator	4,100	32
Lubricator car (simulated for one train in four equipped); graphite grease	4,800	20
Hyrailer System (operated once every 30 to 35 trains)	5,500	8
On-board locomotive system (two locomotives equipped, modified for American use)	5,140	14

Note: Data for 80-car train, 45 mph, four locomotives on 4.8-mi loop, 56 percent curved track of 5, 4, and 3-degree curves. Baseline data: overlubricated by wayside systems; one trackside lubricator every 2.5 mi.

[a] Million gross tons.

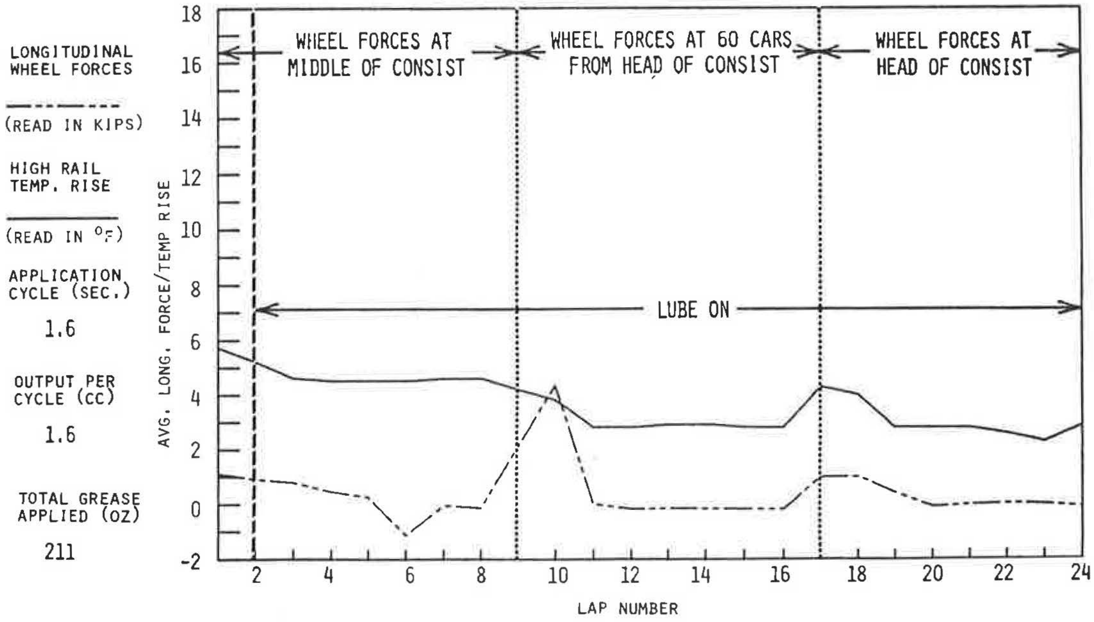

FIGURE 13 Example of wheel force and rail temperature data for Bijur Lubrication system test (Run 1253).

REFERENCES

1. R.K. Steele. The Consequences of Truly Effective Lubrication Upon Rail Performance. Presented at the Winter Annual Meeting of the American Society of Mechanical Engineers (ASME), New Orleans, La., Dec. 1984.
2. N.G. Wilson. Calibration of a GP40-2 Locomotive to Measure Its Tractive Effort. Presented at Joint Railroad Conference, American Society of Mechanical Engineers-Institute of Electrical and Electronics Engineers (IEEE), Chicago, Ill., April 1984.
3. K.C. Rownd and M. Dembowksy. Train Resistance Testing at the Transportation Test Center. Presented at Joint Railroad Conference, American Society of Mechanical Engineers-Institute of Electrical and Electronics Engineers, Chicago, Ill., April 1984.
4. S.P. Singh, R.A. Allen, A.V. Arslan, and K.C. Rownd. The Influence of Vehicle/Track Interaction on Train Energy Requirements--A Preliminary Evaluation. Presented at Conference on the Economics and Performance of Freight Car Trucks, Montreal, Canada, Oct. 1983.
5. R.A. Allen, W.E. Mims, K.C. Rownd, and S.P. Singh. Energy Savings Due to Wheel/Rail Lubrication. Winter Annual Meeting of the American Society of Mechanical Engineers, New Orleans, La., Dec. 1984.
6. R.A. Allen, J.D. Dincher, W.E. Mims, and K.C. Rownd. Wheel/Rail Lubrication Research--Energy Savings Test on the Seaboard System Railroad. AAR Report R-580. Association of American Railroads, Washington, D.C., Dec. 1984.
7. Conrail Rail/Wheel Lubrication Study Savings. Energy News, No. 6, July 1984, p. 2.
8. M.B. Hargrove. The Economics of Lubricating Rail. Winter Annual Meeting of the American Society of Mechanical Engineers, New Orleans, La., Dec. 1984.
9. J.A. Elkins, R.P. Reiff, and P.E. Rhine. Monitoring of Lubrication Effectiveness. Winter Annual Meeting of the American Society of Mechanical Engineers, New Orleans, La., Dec. 1984.
10. R.P. Reiff. Lubrication Application Methods at FAST. Winter Annual Meeting of the American Society of Mechanical Engineers, New Orleans, La., Dec. 1984.
11. R.P. Reiff. Southern Railway Lubricator Car Operation on FAST. TTC Technical Note TTC-006 (FAST-TN84). Transportation Test Center, Pueblo, Colo., Feb. 17, 1984.
12. R.P. Reiff. Hy-Rail Lubrication System on FAST. TTC Technical Note TTC-007 (FAST-TN84). Transportation Test Center, Pueblo, Colo., March 1, 1984.
13. R.P. Reiff. Preliminary Test Report for the Locomotive-Mounted Lubrication System. TTC Technical Note TTC-008 (FAST-TN84). Transportation Test Center, Pueblo, Colo., June 12, 1984.

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Research and Development and Productivity: High-Productivity Integral Trains

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ABSTRACT

Some preliminary conclusions concerning the rate of technological change and railroad productivity are drawn based on the railroad industry's High Productivity Integral Train project. First, the economic targets established for integral trains appear to be reasonable in light of already available alternatives to conventional technology and opportunities for further improvement resulting from the design of noninterchange equipment and the exploration of possible improvements in truck and brake systems. If the targets are realized, integral-train technology should affect at a minimum 20 percent of railroad business and enable the industry to meet competitive challenges in the foreseeable future. Second, integral trains are not new conceptually or radically different in engineering. What is new is the economic and institutional environment. Mergers, deregulation, changing transportation markets, and truck competition have all improved the potential for integral-train technology and for other innovations that promise productivity improvement. Third, innovation in railroad equipment must overcome the adverse impacts of slow output growth, current excess capacity, long asset life, and the financial condition of the railroad supply industry. Therefore, the railroad industry may well need to explore new approaches to R&D and equipment purchasing policies if the rate of innovation is to be increased.