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Administration**

Electronically Controlled Pneumatic Brake Revenue Service Tests

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Letter Report

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INTRODUCTION

This letter report, prepared by the Transportation Technology Center, Inc. (TTCI), Pueblo, Colorado, a subsidiary of the Association of American Railroads (AAR), summarizes the findings of the service testing of Electronically Controlled Pneumatic (ECP) Brakes, carried out between the spring of 1996 and the summer of 1997. This report focuses on the Conrail Revenue Service Test, which is one of the two tests specifically featured in Task Order No. 1 — Advanced Braking System Safety Evaluation. In addition, selected results from the other revenue service tests, conducted during the same time, are included for comparison purposes. Also, the actions taken by the AAR in the specification development process, as a result of the findings of the revenue service tests, are discussed.

BACKGROUND

An AAR Working Group was established in 1993 to evaluate the use of ECP brakes on heavy haul freight trains in North America. TTCI was tasked, under the AAR funded research program, to coordinate the Working Group activities and to develop a performance specification for ECP brake systems for eventual incorporation into the AAR *Manual of Standards and Recommended Practices*. The specification development process, which culminated in the acceptance of the new specification, S-4200, relied heavily on information gathered from engineering analysis performed on behalf of the AAR Working Group, on laboratory and full-scale testing performed by the ECP brake developers and TTCI, and on service testing by individual member railroads. Of all of these, it was the service testing experience that provided the most vital information on system safety and reliability.

During 1993-95, numerous successful revenue service tests of ECP brakes had been conducted on the former Burlington Northern (BN) and Southern Pacific (SP) railroads and the Union Pacific (UP), aimed at demonstrating the performance benefits of the ECP brakes and to provide preliminary data on system reliability. As a result of these tests, it was widely acknowledged that ECP brake systems had the potential to improve safety through shorter stopping distances, the use of the graduated release capability, continuous reservoir charging, and constant brake system health monitoring. However, it was also concluded that, if ECP-brake systems were ever to be implemented into widespread revenue service, they would have to be proven safe, reliable, and economically viable in the long term.

In the early spring of 1996 planning began for the test on Conrail (the main focus of this report) to address the safety, reliability, and economic issues. The major participants in the initial planning of this test, in addition to the host railroad, were: Technical Services Marketing (TSM) Inc. and TTCI. During the implementation phase of the test, the FRA later became a participant and the joint FRA/AAR and Volpe National Transportation Systems contract was enacted.

The methodology employed in this test, which is described in detail in the Conrail Test report and attached as Appendix A, consisted of directly comparing the service histories (mechanical repairs and energy consumption) of two nearly identical train sets in the same service. One of the train sets was equipped with the TSM overlay ECP brake system and the other train (referred to as the "placebo" train in the Conrail report) was equipped with conventional air brake equipment.

At approximately the same time as the Conrail Test was being planned, a separate revenue service test was initiated by Burlington Northern Santa Fe (BNSF) and TSM, to evaluate the potential issues related to a broader implementation of ECP brake technology. The methodology employed for the BNSF Test was slightly different from that used in the Conrail Test. In the BNSF Test the service history data were compared for multiple trains (both ECP brake equipped and conventional brake equipped) in three types of service (unit coal, intermodal, and taconite) over a much longer time frame. As in the Conrail Test, the TSM overlay ECP-brake system was used on the BNSF brake train sets. As this test progressed, TTCI was offered the opportunity by BNSF to participate in the review and analysis of the resultant data. This provided an independent set of data to cross check the conclusions of the Conrail Test and proved invaluable, since some of the results of the Conrail Test (discussed later) were unexpected and contrary to previous experience.

TEST OBJECTIVES

The primary objectives of each of the main participants in the Conrail Revenue Service Test were not necessarily the same, but were complimentary. The primary objective, as expressed by Conrail (see Appendix A), was to quantify the possible economic benefits of ECP brakes, meeting the AAR performance specification, to justify future investment in the technology. The primary objective of the TTCI/FRA partnership was to monitor the longer term operation of ECP brakes to ensure that all safety issues had been adequately addressed in the system design and that realistic system and component reliability targets could be established.

DESCRIPTION OF THE TECHNICAL SERVICES AND MARKETING INC. ECP BRAKE SYSTEM

All of the testing featured in this letter report were carried out using the TSM overlay ECP brake system. In order that the reader can more easily understand the issues discussed in this report, a short description of the main features of the TSM system follows.

The TSM brake system consists of a Car Control Device (CCD) and a manifold. The manifold contains the solenoid valves and pressure transducers which are used to fill and vent the brake cylinder and monitor brake pipe and reservoir pressure. The manifold is mounted between the pipe bracket and the service portion of the control valve. When the ECP system is energized, the manifold cuts off communication between the service portion and the brake cylinder, but the service portion continues its function of charging the reservoir. If the emergency portion is retained, then the car can operate in either an ECP train or in a conventionally braked train. This is known as an overlay ECP brake system. If the emergency portion is removed and replaced with a blanking plate, and the service portion is removed and replaced with a blanking plate equipped with charging chokes, then the car can only operate in ECP equipped trains and is known as a stand alone ECP system. All service train tests have been carried out using the overlay system. A stand-alone system has been tested by TTCI on the train at the Facility for Accelerated Service Testing.

The CCD is a separate box containing the computer, battery, battery charger, and other electrical components, which form the "brains" of the car brake system. The CCD can be mounted anywhere on the car, but is usually in close proximity to the manifold.

The system is controlled by the Head End Unit (HEU), which is mounted on the top of the engineer's control stand in the locomotive. The HEU consists of a control box, which has push buttons and soft keys. The service application and release button is mushroom shaped; pulling the button releases the brake, and pushing the button applies the brake. Brake applications are made as a percent of full service, with full service being a 100-percent application, a minimum service being a 15-percent application, and an emergency being a 120-percent application. The brake can be applied and released in 1 percent increments from 0 to 100 percent, or if the mushroom-shaped button is held, the application or release will continuously change up or down. The other push button is for emergency application, and it is caged to prevent accidental contact. The soft keys provide for an initial minimum service, full-service application, and direct release. The brake can be increased or decreased from minimum service with the button. They are also used when initializing the train-brake system. The HEU also has a flat screen which is used to inform the engineer of the status of the train-brake system. The readout includes the brake pipe pressure on the last car, the brake command in effect, and any error messages.

The car-brake systems are connected to each other by a shielded, two-conductor No. 8 gage cable. The cable carries both power and signal. Power at the locomotive is 230 Volts direct current, and it is provided by a power supply connected to the locomotive batteries. For the Conrail Test (and the BNSF tests), the cable between cars was connected using a Conomac connector, which is similar to a welding connector. This connector was considered to be a temporary connector until an AAR standard connector was developed. The drawbacks of the Conomac connectors are the exposed electrical contacts and the lack of a positive locking feature to keep the connectors together (the Conomac is held together by friction alone).

The communications protocol tested is LonWorks® by Echelon. This protocol was by AAR committees as the standard for cable-based ECP-brake system communication. LonWorks® is an off-the-shelf protocol widely used in applications such as in controlling building environment and in rail transit applications.

The system allows the engineer to directly control the brake cylinder pressure on every car in the train. The brake pipe is used only to charge the reservoirs, even during brake applications. This allows the system to maintain full-reservoir pressure at all times (except immediately after a brake application, when the reservoirs are drawing on the brake pipe to recharge), and it allows the CCDs to maintain brake-cylinder pressure even if moderate brake cylinder leakage is present. If a CCD cannot provide the brake-cylinder pressure commanded by the HEU, then that CCD will send an error message, which will be displayed on the HEU. If communications are disrupted, the system automatically goes into emergency, without venting the brake pipe. This allows for maintaining brake cylinder pressure even if some brake cylinder leakage is present. Automatic electric emergencies also result from loss of brake pipe pressure and reduction of operative brakes to less than 85 percent.

DISCUSSION OF THE RESULTS PRESENTED IN THE CONRAIL REPORT

The Conrail report covers five major topics:

1. Energy consumption and coupler force data
2. Car control device (CCD) reliability
3. Percentage of operability under ECP brake control
4. Stuck brakes in the overlay mode
5. Repair data

In this letter report, the test results from each of these topic areas is analyzed for validity and compared with the results of other tests, where appropriate. Where the findings have been used to modify the AAR specification S-4200, this will also be noted.

Energy Consumption and Coupler Force Data

It was concluded in the Conrail report that the energy consumption was higher with the ECP train than with the conventional train. This was an unexpected result, since earlier test results, supported by train performance modeling, had indicated that some energy savings could be expected from the use of ECP brakes. There were some operating differences between the two trainsets compared in the Conrail Test that could explain the energy data anomaly. First, the ECP train used three lead locomotive units while the conventional train used two. Second, the ECP train on average was loaded 1.6 percent heavier (the ECP train required more energy going up hill). It was also noted that helper locomotives sometimes stayed with the train while descending from Galitzen to

Altoona and the helpers were left in Run 1 while the lead units were in dynamic braking. All of these factors could account for the increased energy requirement of the ECP train.

The instrumented coupler on the test car at the head end of the train also indicated higher average coupler forces. The average draft forces were 204,000 pounds for the ECP train versus 149,000 pounds for the placebo train. The average buff forces were 41 pounds for the ECP train versus 25 pounds for the placebo train. The Conrail report urges caution in interpreting this data, and the report states that the ECP train regularly had more dynamic braking and tractive effort available than did the placebo train. In all the other ECP revenue service experience on other railroads, there has been a noticeable reduction in slack action as detected in the locomotive and observed along the train. The Conrail data supports this observation. The standard deviation of the coupler forces, which is a measure of the variability, was found to be 90 pounds for the placebo train and 38 pounds for the ECP train. However, caution in interpreting this data is also urged.

CCD Reliability

An unexpectedly high failure rate of CCDs was experienced during this test. Again, this is contrary to the experience gained on other railroads, where CCD reliability has been much higher than expected. Once the high failure rate was recognized, a complete investigation was carried out as a matter of urgency. First, the failed CCDs were examined by TSM. TSM found that the causes of the high-failure rate on Conrail were two related factors: (1) faulty manufacture and (2) a severe vibration environment. First of all it was found that the CCDs produced over a certain time period contained incorrectly assembled circuit boards. In the TSM design, the transceiver chip pins are bent prior to soldering the chips onto the circuit board. In order to provide added support against vibration, the chips are then glued solidly to the mother board with an epoxy glue. On the defective CCDs, some of the transceiver chips were not glued to the mother boards, and the errors were not caught by the TSM quality control process. These defects would not be revealed during any type of single car or train brake test. All of these faulty CCDs were among the batch of CCDs used on the Conrail test train.

Many of the faulty CCDs failed when they were subjected to high-coupling forces, when emptied cars rolled out of the car dumpers and impacted standing cuts of other empty cars. The unglued transceiver chips failed where the pins were previously bent, due to low-cycle fatigue. To compound the problem, the mounting location of these CCDs was on a shelf bracket welded to a vertical structural post between the center sill and the slope sheet (Figure 1). This subjected the already defective CCDs to considerable shock and vibration, resulting in early CCD failure.

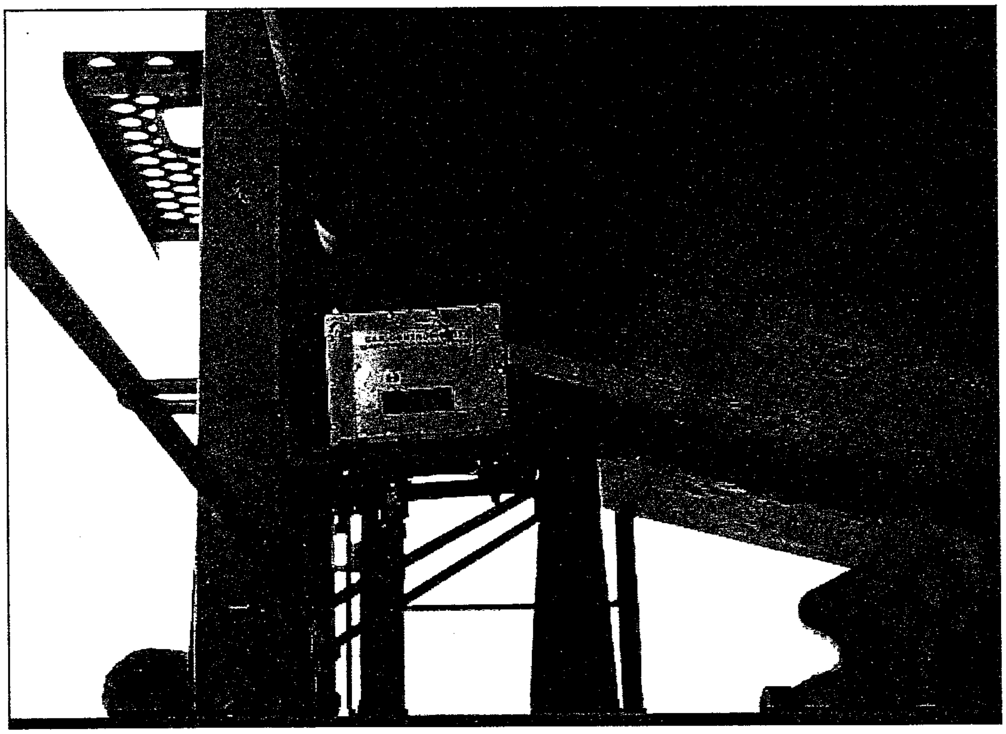

Figure 1. CCD Mounting on Conrail Coal Hopper

On a positive note, even though the CCD failure rate was high, the system always detected the CCD failures, warned the engineer, and adjusted the "percentage of operative brakes" readout accordingly. At no point did the percentage of operative brakes fall below 95 percent. The ECP-brake system worked as it was designed to work.

As a result of this experience, AAR, TSM, and Conrail personnel measured the shock and vibration environment due to the hard coupling on these cars and used the data to increase the shock and vibration requirement in the performance specification for ECP brakes, AAR Specification S-4200. A summary report (*Technology Digest* 97-022), which describes the test methodology and results, and containing the previous and current versions of the shock and vibration requirements, is attached as Appendix B.

Percentage of Operability Under ECP Brake Control

One of the primary problems, which affected the results of the Conrail Test, was the percentage of time that the ECP train was forced to operate as a conventionally braked train. It was planned at the start of the test that the ECP train could be directly compared with the conventional train, but the ECP train ran in ECP mode only 73 percent of the time. Thus the wheel savings shown in the maintenance data was only an indication of what might have been experienced if the ECP train had operated at 100 percent in the ECP mode. Some causes for conventional operation were lack of ECP equipped locomotives, lack of trained crews, and the abnormally high CCD failure rate, discussed above. Another problem was the reliability of the temporary train line connectors used in this test. These connectors had no positive latching mechanisms, and after numerous intentional uncouplings at the car dumper (on average about one uncoupling every five days), they began to cause problems on the road. Figure 2 shows one of these connectors after a road failure.

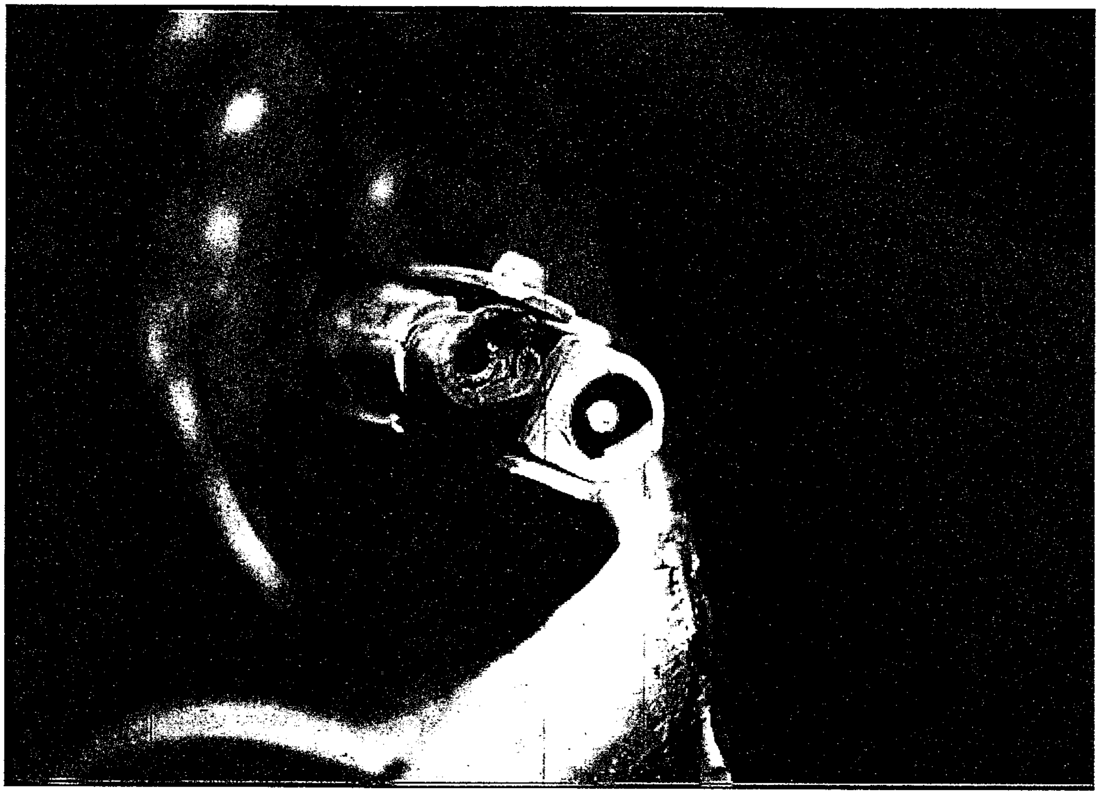

Figure 2. Failed Connector on Conrail

One of the actions undertaken by the AAR Working Group was the selection of a AAR standard connector design, for use in interchange service. The connector failure history experienced during the Conrail Test played an important part in setting the criteria for the selection of the new connector design. The new connector design (Figure 3), adopted by the AAR as part of the ECP-brake specification, is expected to solve the connector problems experienced on Conrail.

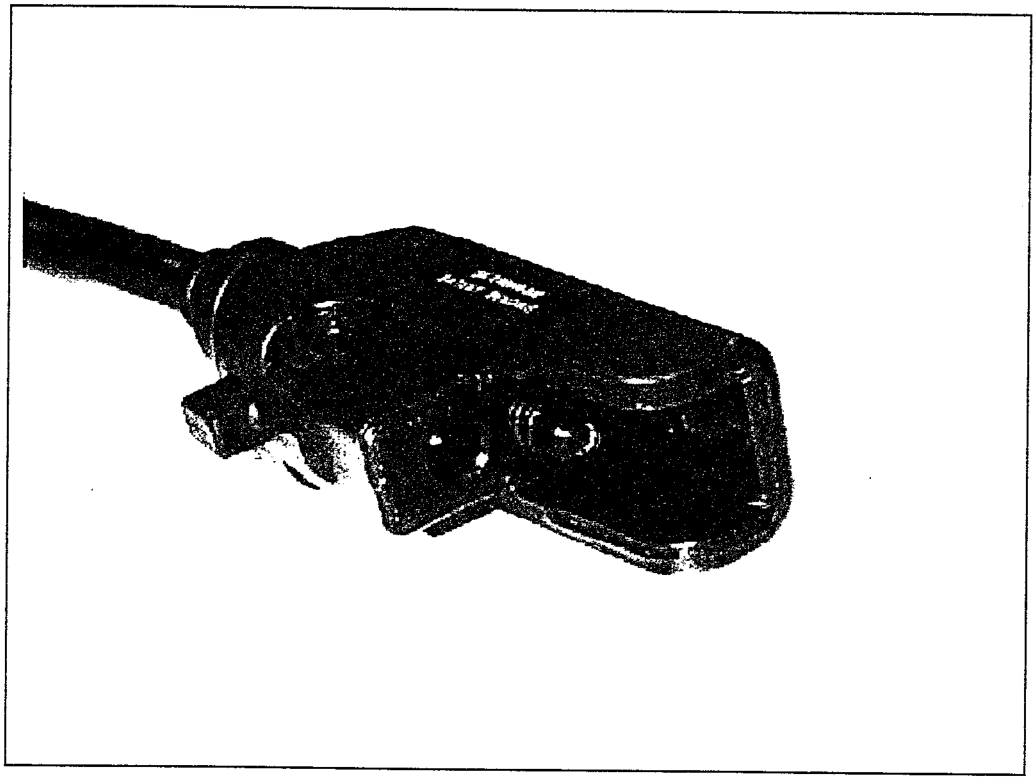

Figure 3. Connector Design adopted by the AAR

Sticking Brakes in the Overlay Mode

According to the Conrail maintenance records, two wheel sets were changed due to brake related causes on the ECP train versus eleven on the placebo train. The two wheel replacements on the ECP train could have been due to hand brakes left applied, they could have happened when the ECP train was operating in the conventional mode, or they could be due to sticking brakes when individual CCDs were cut out while in the ECP mode. During the Conrail Test, it was discovered that a sticking brake could occur on the version of the TSM system tested. This could result when the service portion of the conventional control valve is activated when the CCD is cut out. The service portion then reacts to small brake pipe pressure changes when the ECP brake is applied. If the car is in the rear portion of the train, the service portion could apply (due to the small transient brake pipe pressure changes caused by the operation of the ECP brakes on the adjacent cars), but not release. This is a problem with the current design of ECP overlay systems, but this does not occur in pure ECP systems. S-4200 has been changed to require that the brake valve must be cut out whenever an overlay CCD is cut out, unless the overlay CCD is designed so that it will not react to brake pipe pressure when cut out while the rest of the train is operating as an ECP train. At present, there appears to be no way to assure that a conventional service portion con be designed to stay isolated when its CCD is cut out in ECP mode.

Repair Data

The repair data shows some promising trends in wheel set change-outs due to brake related damage, such as shelling and built up tread. However, the brake shoe usage with the Conrail ECP is much higher than with the conventional train. This may be due to the increased use of ECP brakes over the flat to undulating territory east of Altoona, where the crews found the ECP brakes very useful as a speed-control tool. Some of these brake shoe change-outs in both trains were for missing shoes due to the keys falling out of the brake heads when the cars were emptied in a rotary dumper. The high brake shoe usage is contrary to experience with the BNSF ECP equipped unit coal and ore operations, which will be discussed later in this report, although a similar experience was recorded on double stack trains operating on undulating territory.

The "Other ECP Components" defect referred to the failed connectors, some of which were damaged when they were caught between couplers or snagged when the cars were emptied. This problem should be cured with connector support straps which are now a requirement in S-4200. In the long term, the reliability of CCDs is expected to exceed the reliability of current pneumatic control valve portions, and it may well have done so in this test were it not for the manufacturing problems and the mounting arrangement used on these cars. The repair data, as recorded by Conrail mechanical personnel, is summarized in Table 1.

Table 1 - Conrail Test Repair Data Summary

	Conventional	ECP
CCDs	n.a.	9
Other ECP components	n.a.	7
Control valve portions	4	n.a.
Wheel set change-outs	11	2
Brake shoes renewed	19	57
Other brake components	33	29

BNSF Test Results

It is of value here to relate experiences with ECP equipped trains on BNSF. Some of the results from intermodal and unit-coal revenue service testing on the BNSF are also distorted by the high percentage of time that the ECP trains have had to operate in conventional mode. The most successful test train to date, and the one that has produced the most reliable data, is the BNSF taconite train operating between Superior, Wisconsin, and Hibbing, Minnesota. This train has operated under ECP mode about 90 percent of the time and has shown significant reductions in wheel replacements, brake shoe usage, and replacement of coupler and draft gear components. Even with this train, it is impossible to determine whether or not some of the wheel damage listed below occurred while the train was operating in conventional mode. The percentage of time that the remaining BNSF ECP trains operate in ECP mode ranges from about 30 percent (intermodal) to 80 percent (unit coal). The results from the taconite train are summarized in Table 2 and are current up to June, 1997. *Technology Digest* 97-008 is attached as Appendix C.

Table 2. BNSF Taconite Train Maintenance Data
90 Retrofitted ECP Cars vs. 90 Conventional Cars
Data from Oct. 1996 through June 1997

	Conventional	ECP
Wheels (due to brake related defects)	15	7
Coupler and draft gear components	32	3
Brake shoes	764	206

CONCLUSIONS

- The Conrail Test, although not as effective as initially envisioned in producing high-confidence economic and maintenance data, was instrumental in providing substantial assistance to the AAR in developing S-4200, as follows:
  - — The shock and vibration requirements in AAR Specification S-4200 were improved.
  - — This test reinforced the need to select, as an AAR standard, a train line connector with a positive latching mechanism and a quick and reliable means of making field replacements of damaged connectors.
  - — The possibility of a sticking brake when an overlay CCD is cut out was identified, and this problem was addressed in S-4200.
- Due to the high percentage of time that the ECP train operated in the conventional mode, and due to the unexpected manufacturing problems which contributed to a high CCD failure rate, some of the maintenance data is not necessarily representative of the long-term

expectations for this technology.

- From the overall system safety perspective, it should be noted that while the CCD failure rate was high, the system never failed to respond correctly to these CCD failures. The engineer always received an error message informing of the CCD failure, and the percentage of operative brakes was always adjusted downward and displayed to the engineer.

FUTURE PLANS

The primary focus of the AAR's ongoing work is to establish a non-overlay ECP test train, assure that the system is safe for revenue service, and then compare its operation to an identical standard train. Once a pure ECP test train is established, it will not be capable of operating in a conventional mode, and the data from such a test will be a true indication of the economic benefits possible through the use of ECP brake systems.

Additional plans are to complete the development of the draft AAR ECP Performance Specifications and submit them to AAR Safety and Operation's technical committees.

Appendix A

Conrail Test Report

ECONOMIC CONSIDERATIONS OF OPERATING A TRAIN WITH ELECTRONICALLY CONTROLLED PNUEMATIC (ECP) BRAKES

By E. D. Chen, L. F. Myers, PE, and Y. H. Tse

ABSTRACT

This study attempts to quantify the economic benefits that the electronically controlled pneumatic brake (ECP) technology can provide the operator of a unit coal train and the owner of the associated fleet. A controlled study over a fixed northeastern U. S. rail route was performed with two equivalent unit coal trains. The cars of the first train set were equipped with the latest generation of an Electronic Air Brake System (EABS), while the cars of the later train remained unmodified, and acted as the control. These two trains made round trips between the southwestern Pennsylvania coal fields and two electric utility plants in eastern Pennsylvania. Incorporated in the data collection process was the compilation of dynamic train energy measurements from a sample of round trips for each of the two trains, and the collection of repair and service data associated with the cars of each train.

BACKGROUND

The braking system utilized in the rail industry has changed little over the last few decades. While the pneumatic system originally developed by George Westinghouse in 1869 has served the industry well, it no longer can efficiently provide the type of service that is desired of today's heavier and faster freight trains. A natural transition is to incorporate electronic controls to provide the integrity and quick response that the current pneumatic system lacks. Technical Service and Marketing, Inc. (TSM), Kansas City, began work on the concept of an electronically controlled air brake system in 1991. They have determined that Echelon's LonWorks® control network provides an efficient means of providing communications to individual rail vehicles and have developed the first generation of electronic overlay systems. TSM provided a prototype of this overlay system in revenue service in the Fall of 1993.[1] Since then, a number of railroads have studied this technology and today more than 70 million car miles of ECP operation have been logged.[2] Previous studies have shown that the basic hardware and software issues of the technology have been successfully addressed. Today, TSM and other suppliers are continuing to investigate improvements and new uses for the LonWorks® communications link that has become the standardized network for this application. The AAR anticipates that nearly 70% of the communication's capacity will be available for other applications, including a broad array of sensors; however, quantifying the benefits of ECP braking systems is the next big step.[2]

The ECP Brake Economic Working Group, spearheaded by the AAR, has developed a workbook for evaluating the economic value to railroads and car owners of implementing ECP brake systems on freight cars. The workbook includes as much data and information as possible to provide a sound basis for this economic evaluation. However, the workbook is to be considered a work-in-progress.[3] Future economic studies of the ECP brake technology need to provide realistic data that can be used to support this workbook.

JOINT STUDY

The Association of American Railroads (AAR), Technical Service and Marketing, Inc. (TSM), and the Consolidated Rail Corporation (Conrail) jointly participated in a study of the economic benefits of the electronically controlled pneumatic brake (ECP) technology. A controlled study over a fixed Conrail route incorporated two equivalent unit coal trains. The cars of the first were equipped with the latest generation of TSM's Electronic Air Brake System (EABS), while the cars of the later train remained unmodified, and acted as the control or "placebo" train. Each train consisted of a pool of 120 Coalporter (bathtub) gondolas with a capacity of 286,000 lbs. These two trains made round trips between the southwestern Pennsylvania coal fields and two power generation plants located in Cromby and Eddystone in eastern Pennsylvania. The study was conducted between June 18, 1996 and April 2, 1997.

Test Route

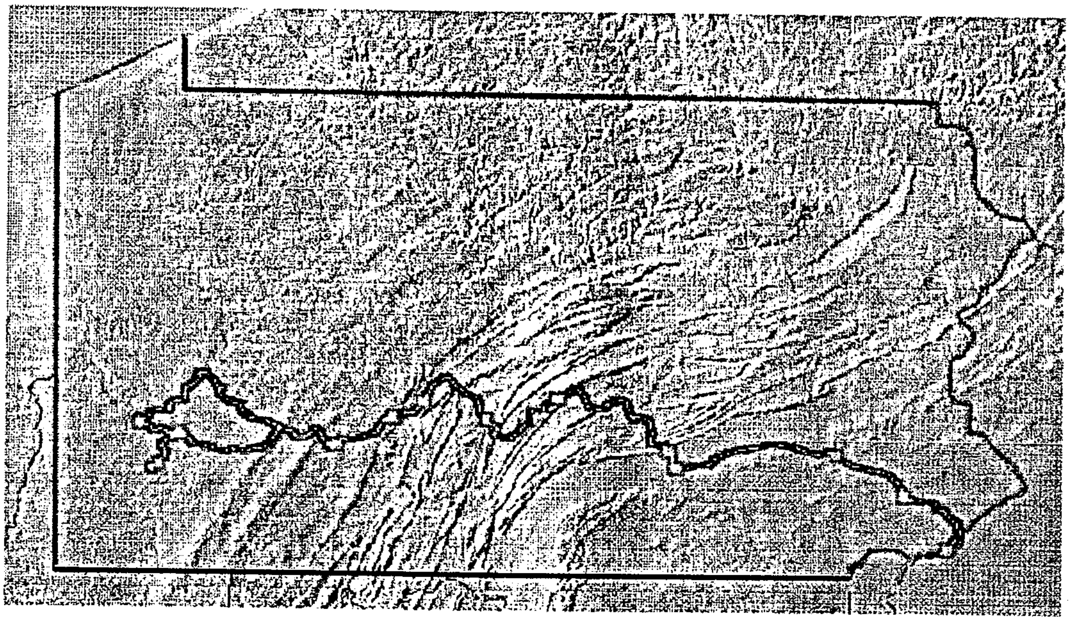

Figure 1 Relief map of test route.

The heavy line in the relief map representation of Figure 1 illustrates the test route utilized. Conrail's Shire Oaks Yard is in the southwest corner of Pennsylvania. The coal mines serviced by the test trains are below the Shire Oaks Yard in the extreme southwest corner of the state, and are located on the former Monongahela Railroad. The Cromby power plant is forty route-miles northeast of the Eddystone plant which is in the southeastern corner of the state. Furthermore, the test section through central Pennsylvania is mountainous reaching an apex of roughly 2200 feet in Gallitzin, PA. The track utilized east of Gallitzin continues to descend towards the Eddystone plant, which is basically at sea level. This eastern section of the test route requires braking of eastbound trains and was expected to provide a good comparison between the EABS and placebo trains.

Section	Miles	Lowest Elevation	Highest Elevation
Shire Oaks to Penn	25.7	640	776
Penn to C-Tower	101.0	714	1211
Shire Oaks to Wing	17.7	623	799
Wing to C-Tower	64.2	757	1222
to Gallitzin	23.9	1168	2168
Gallitzin to Rose	13.7	1109	2180
Rose to Hunt	31.1	575	1229
Hunt to Lewis	36.1	465	792
Lewis to Banks	57.6	296	564
Banks to Harris	8.7	272	461
Harris to Reading	54.6	248	548
Reading to Cromby	27.5	87	249
Cromby to Eddystone	39.5	7	256

Table 1 Segment characteristics.

To provide a more specific comparison between the operating dynamics of the EABS trains and the placebo trains during over the road testing, the test route was subdivided into segments with varying terrain and expected operating conditions. Table 1 is a summary of these segments, and Figures 2 and 3 display the position and elevation data that were recorded through these segments. Note in Figure 2 that the eastbound, loaded trains utilized two routes between Shire Oaks Yard on the Mon Line and C-Tower, Johnstown, PA. Initially, the trains were operated from Shire Oaks directly to the Pittsburgh Line at Wilmerding, PA, Control Point (CP)-Wing. These trains continued on the Pittsburgh Line to Johnstown typically receiving additional locomotives, helper-units, on the rear of the train at Pitcairn, PA. Pitcairn is several miles east of CP-Wing. Eventually, the more common routing for the eastbound, loaded move of these trains was to operate northwest to Pittsburgh, PA, CP-

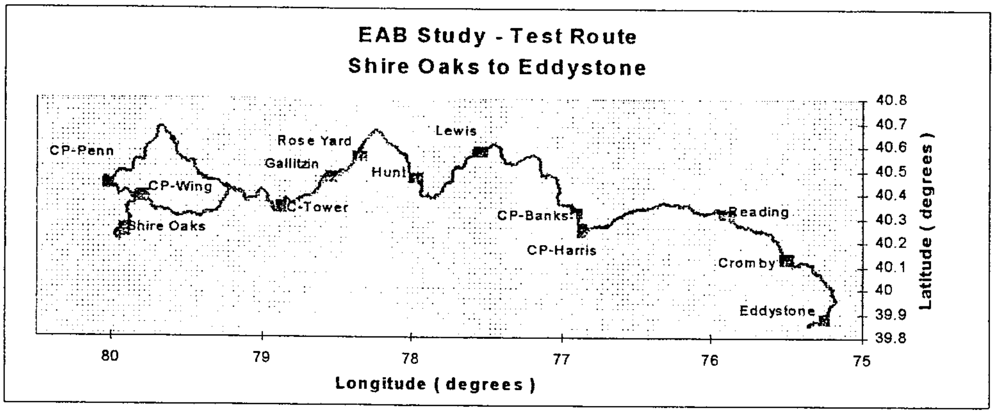

Figure 2 Test route and segment locations.

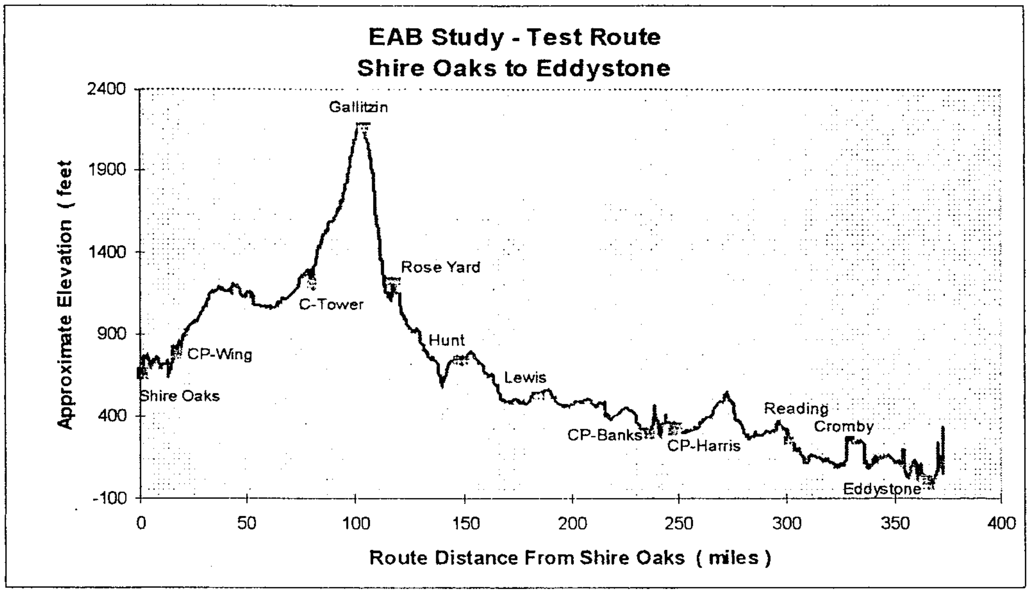

Figure 3 Approximate elevation of test route.

Penn, and then proceed towards Johnstown via the Conemaugh Line. This later route is longer, but has a milder grade such that the helper-units were not required.

Test Car and Locomotive Preparation

Conrail's Enola Car and Locomotive Shops, near Harrisburg, PA, provided the preparation work for the 240 railcars and six locomotives utilized in this study. Each of these cars received a single car air brake test, new brake shoes, every wheel was inspected and measured, wheel sets that would not last the length of the study were replaced, and all known defects were corrected. Paint was applied to the corner posts of all the cars to aid identification. The corner posts of the EABS cars were painted yellow, and the placebo cars received orange paint on their corner posts. The electronic modules, Car Control Units (CCUs), of the EABS equipment were mounted on the vertical end posts of the B end of the cars, $26^1/_4$" above the draft sills.

Head end equipment of the TSM system was installed in four SD-60M locomotives. Two SD-40-2 locomotives were equipped with hardware to monitor the electric trainline. Of the four SD-60M locomotives, only three were utilized for train operation at any one time. The SD-40-2 engines did not require the head end equipment since they were utilized as rear end, helper units for eastbound moves of the EABS trains. An 'electric' emergency application does not significantly alter the pneumatic trainline pressure; therefore, the hardware installed on these locomotives provided for power knock out in this situation.

Test Train Operation

The two trains sourced coal from two mines for the generating plants at Cromby, PA and Eddystone, PA. The typical consumption rate of coal at the Cromby plant required that thirty cars of roughly every other train would be setoff at Cromby. The remaining cars would then continue on to the Eddystone plant. The cars were rotary dumped one at a time at each of the terminating locations. After the cars were unloaded, the train moved westbound from Eddystone. If cars were previously setoff at Cromby, they were picked up, and the consist returned to the mine to load. The distances between the Eddystone plant and the loading facility was approximately 390 miles from Mine 84 and 425 miles from Emerald Mine. During the study, the EABS train logged 42,420 miles over fifty-two round trips while the placebo train made forty-five round trips to log 36,250 miles. The EABS equipment averaged an operational rate of 73% after providing repairs to the Car Control Units (CCU) which proved to be susceptible to the localized vibrations of the chosen mounting area.

The two trains were intended to be operated with 115 cars per train; therefore, each train had five spare cars kept at the Eddystone plant. These cars were inserted into the appropriate train when any of the active 115 needed repair. Field repairs were commonly performed at Shire Oaks Yard, the Enola Car Shop, or at the Eddystone plant.

Eight to ten train crews were utilized to operate each train over a round trip. Additionally, helper engines were added at the rear of the test trains on the eastbound moves. They provided assistance in climbing the mountain to Gallitzin, PA and descending the east slope into Altoona. The helpers operated between either Pitcairn, PA if the Pittsburgh Line was utilized, or C-Tower if the Conemaugh Line was used, and Rose Yard in Altoona, PA.

IN TRAIN DATA

Instrumentation

Conrail's Technical Services Laboratory inserted their Instrumentation Car, CR-19, directly behind the locomotives of several round trips of both trains. The equipment on board the Instrumentation Car allowed test personnel to monitor and record the operating dynamics of the two trains. Of specific interest was the correlation between the location of the train and its speed, coupler (drawbar) force, and the Engineer's braking requirements. The Instrumentation Car made nine trips in the ECP train and five trips in the placebo train. Although nine ECP trips were monitored with the test car, the data collection method and the operation of the EABS braking system was not consistent early in the study; therefore, data collected from three trains were not utilized in the comparison study.

The in-train data were recorded on a SoMat 2100 Field Computer. This system is designed to allow multiple channels of analog, digital, and frequency signals to be filtered, mathematically adjusted, and recorded in a wide variety of manners. For this study, much of the data were recorded in a histogram format, while a computed channel of the drawbar energy was continually summed throughout each test segment. Figure 4 illustrates the

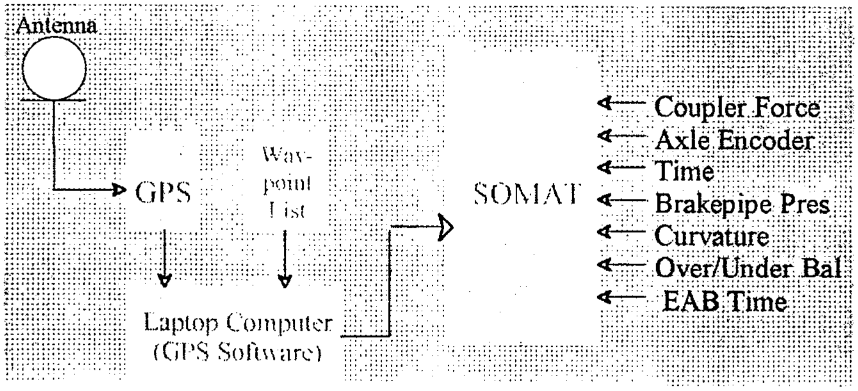

Figure 4 In-train instrumentation.

hardware involved and the parameters monitored during the in-train evaluation. The GPS system was continuously polled by a laptop computer to provide instantaneous location readings. These readings were compared to a listing of desired waypoints, which included the thirteen locations illustrated in Figure 2. As each of these waypoints were passed, the laptop computer signaled the SoMat device. This process allowed the data of the previous sub-segment to be stored in SoMat local memory, and new data to begin compiling for the next sub-segment just entered.

Train Energy

The effect that operating an ECP train has on fuel economy is one of the most anticipated results of this study. An AAR simulation of a loaded ECP coal train descending Tennessee Pass illustrated significant fuel savings when compared to the same train operated with conventional air brakes.[1] The operation of the unit coal trains in this study made measuring direct fuel consumption quite difficult. Rather than quantifying fuel consumption, an alternate method of determining train energy requirements was devised. The Instrument Car is equipped with a calibrated, strain gaged coupler; therefore, the energy required by the locomotives to pull and brake the train can be computed by sampling the draft and buff forces of the drawbar and the train speed. The following relationship is true:

$$DrawbarEnergy_{HP-Hrs} = F_{coupler} \times v_{train} \times t_{sample} \times 5.051 \times 10^{-7}$$

where,

$F_{coupler}$ is the measured coupler force in pounds (*lbs*),

v_{train} is the speed of the train in feet-per-second (*fps*),

t_{sample} is the computer's data acquisition rate in seconds (*sec*), and

5.051×10^{-7} is the units conversion factor ($^{HP\text{-}Hrs}/_{ft\text{-}lb}$).

This calculation was continuously performed at one-second intervals by the SoMat computer. The energy required to traverse each sub-segment was thereby provided for each of the test runs and can be seen in Table 2. The energy requirements of the EABS train were statistically compared to those quantified for the placebo train. Figure 5 illustrates the comparison of the energy data for eastbound, loaded trips. Of the thirteen sub-segments analyzed, it is interesting to note that the energy requirements are statistically separable at a 95% confidence interval in eight of the segments. Furthermore, the EABS train required more energy to pull a like train through these segments; even in segments that required little braking. Figure 6 displays the comparison of the energy requirements measured for the westbound, empty moves. While the average energy requirements of the EABS train was consistently higher than that of the placebo train, the measures were statistically separable in only four of these moves. These findings did not agree with the AAR simulation of Tennessee Pass, and it was necessary to find the reason for this outcome.

	Eastbound, Loaded				Westbound, Empty			
	EABS Train		Placebo Train		EABS Train		Placebo Train	
Segment	Avg Energy HP-hr/Car-mi	95% CI HP-hr/Car-mi	Avg Energy HP-hr/Car-mi	95% CI HP-hr/Car-mi	Avg Energy HP-hr/Car-mi	95% CI HP-hr/Car-mi	Avg Energy HP-hr/Car-mi	95% CI HP-hr/Car-mi
Shire Oaks to Penn	1.35	0.30	1.10	0.12				
Penn to C-Tower	1.96	0.34	1.53	0.08				
Shire Oaks to Wing	1.60	0.62	1.17	0.23	0.64	0.13	0.47	0.05
Wing to C-Tower	2.03	0.30	1.26	0.49	0.57	0.14	0.37	0.06
C-Tower to Gallitzin	4.18	0.31	3.77	0.73	-0.37	0.38	-0.54	0.07
Gallitzin to Rose	-1.42	0.32	-1.26	0.35	2.83	0.10	2.68	0.21
Rose to Hunt	-0.26	0.25	-0.61	0.14	1.17	0.22	1.06	0.08
Hunt to Lewis	0.85	0.12	0.54	0.06	0.96	0.12	0.87	0.04
Lewis to Banks	0.98	0.18	0.58	0.06	0.84	0.11	0.81	0.08
Banks to Harris	0.99	0.04	0.57	0.21	0.57	0.14	0.49	0.07
Harris to Reading	1.28	0.20	0.83	0.06	0.99	0.25	0.59	0.05
Reading to Cromby	0.63	0.18	0.33	0.07	0.85	0.11	0.69	0.04
Cromby to Eddystone	1.31	0.39	0.74	0.14	0.66	0.22	0.62	0.11

Table 2 Required drawbar energy.

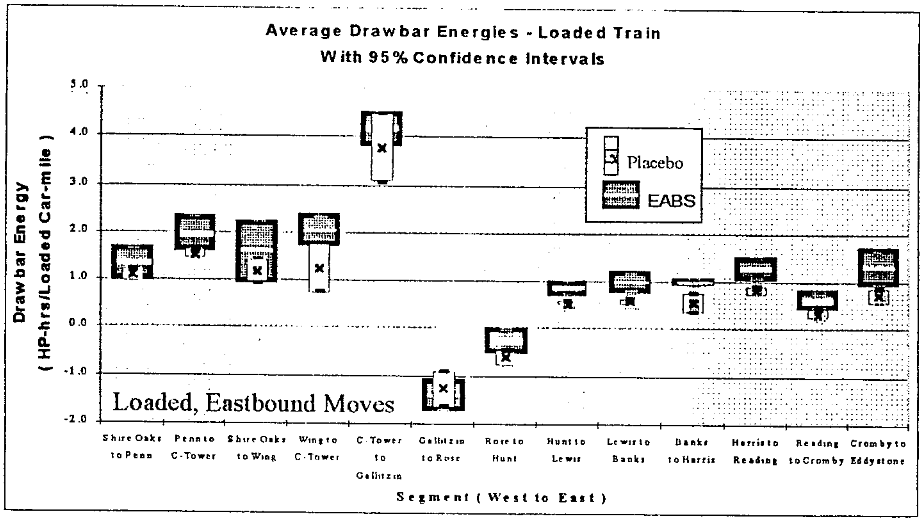

Figure 5 Energy requirements of eastbound shipments.

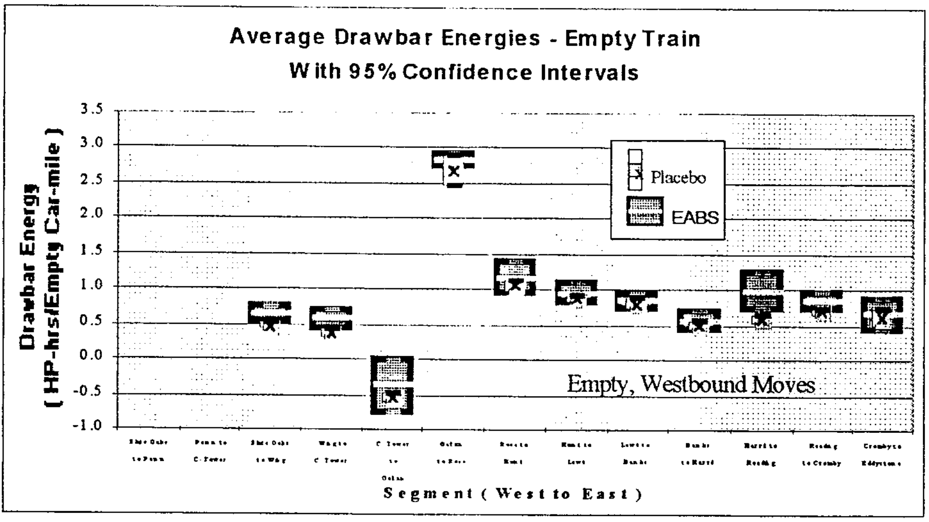

Figure 6 Energy required of westbound shipments.

Coupler force and train speeds are the two variables that affect the energy calculation. During this study, the locomotive crews made comments of improved stopping distance; therefore, it was presumed that the crews might have operated the EABS train more aggressively than their counterparts operating the placebo train. The speed of each train was recorded as a histogram; therefore, a time dependent history of train speed could not be developed, and train acceleration or deceleration could not be determined. Hence, to verify the accuracy of the hypothesis, the average in-motion train speed within each segment was compared. This corrected for abnormally long idle periods from segment-to-segment and train-to-train. Figure 7 indicates the segmented range and average operating speeds of the two trains operating in an eastbound, loaded condition. Figure 8 indicates the segmented range and average operating speeds of the two trains operating in a westbound, empty condition. Unlike the significant differences in their energy requirements, there seems to be little difference in their average operating speeds, which discounts the former presumption.

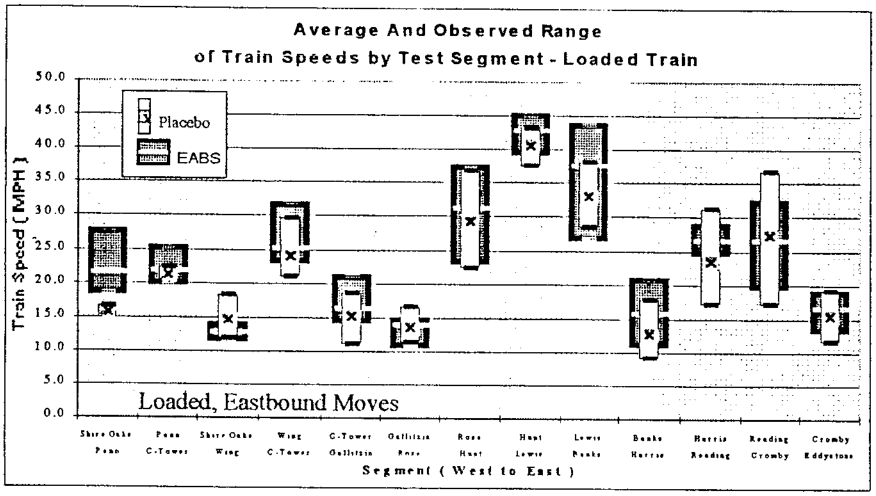

Figure 7 Range of speeds of eastbound shipments.

Further reasoning for the energy differences observed centered around coupler forces. Each train was comprised of similar cars; therefore, the typical pulling forces should be equivalent unless they were loaded unequally. These trains operated over Conrail's Wheel Impact Load Detector near Huntingdon, PA. Data obtained from this detector indicated that the average weight of the sampled EABS trains were 1.6% heavier than the monitored placebo trains. Additionally, these data show that the placebo trains were operated with two head end locomotives while the EABS trains were consistently operated with three head end units. The additional tractive effort offered by the additional locomotive in the EABS trains was able to provide higher coupler forces during

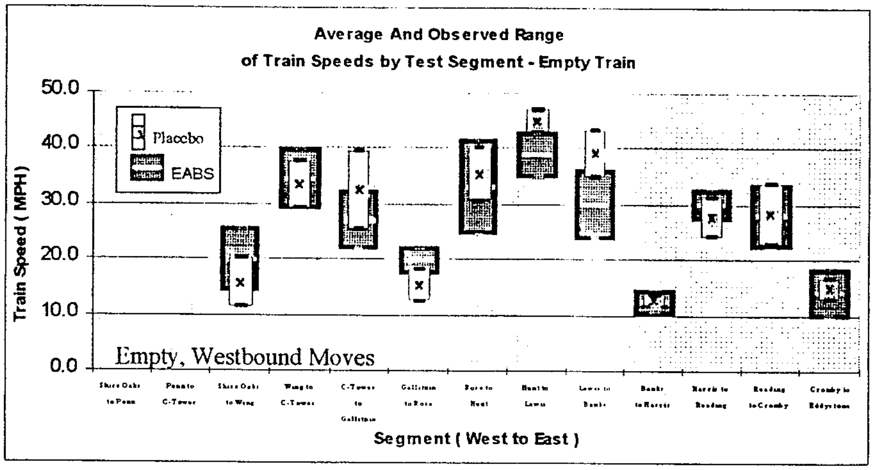

Figure 8 Range of speeds of westbound shipments.

acceleration and deceleration of the trains. This supports the aggressive train handling postulation, but the segmented average speeds of the EABS trains were not significantly higher than the placebo's speeds.

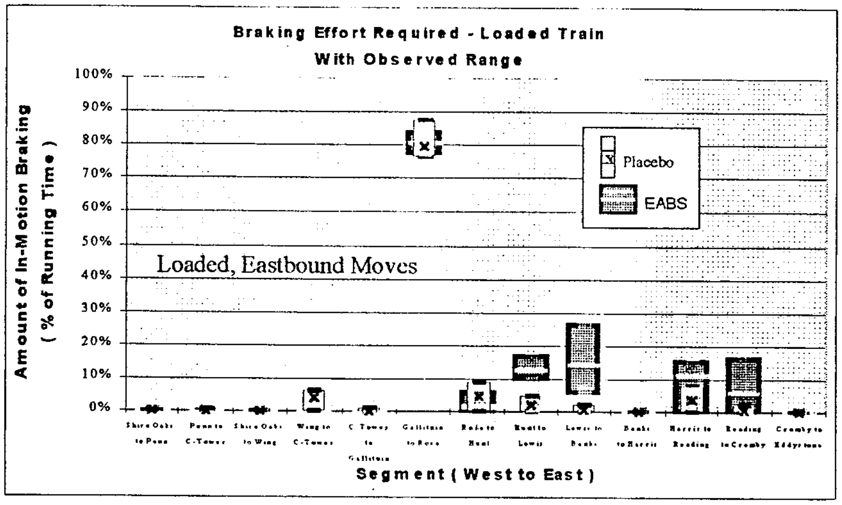

Figure 9 Range of braking effort of eastbound shipments.

The braking methods utilized by the Engineers of the test trains did vary. The Engineers of the EABS train utilized the train braking, while their counterparts operating the placebo train did not. This is illustrated in the later, downhill segments of the test route as shown in Figure 9. The crews operating the EABS trains enjoyed utilizing the new braking technology. When braking of the train was required, their response was to apply the ECP brakes rather than the head-end dynamic brakes. The crews of the placebo train would be more likely to use locomotive dynamic braking, as in normal train operation. These alternate methods of train braking affect the resultant coupler forces differently.

Potential energy is stored within a train by raising it to a higher elevation. As the train is lowered, the potential energy is converted to kinetic energy (speed). The speed of the train can be controlled by dissipating heat energy through two primary locations. The kinetic energy of each car can be dissipated through its own brake equipment. This form of energy dissipation does not react through the coupler, and is not accounted for by analyzing coupler forces. This was the case in EABS braking. The second method of train energy dissipation is by locomotive dynamic braking. This method does react through the coupler, and is accounted for by analyzing coupler forces. Dynamic braking was utilized to slow the placebo train runs.

It appears logical to speculate that the difference in coupler energies observed in this testing is due entirely to the braking difference. However, the EABS train required more energy even in the uphill segments. A portion of the higher energy requirements must be due to the additional train weight, dragging brakes, and/or power braking (throttling the locomotive with the train brakes applied).

Head End Coupler Forces

Ride quality of coal shipments has rarely been a concern for the rail industry other than for equipment wear and tear issues. However, the services offered by railroads have become quite diverse and ride quality of other traffic sectors is of major concern. To determine what affect the use of ECP brakes may have on ride quality, the coupler forces of heavy

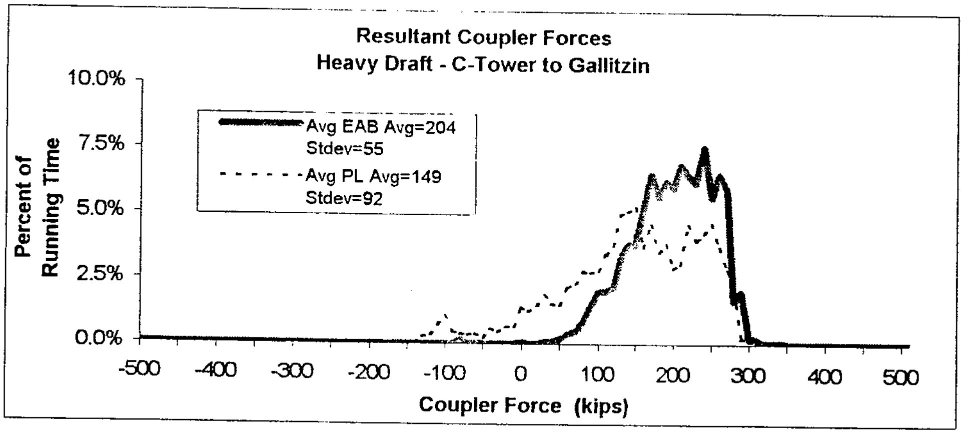

Figure 10 Head-end forces, heavy draft.

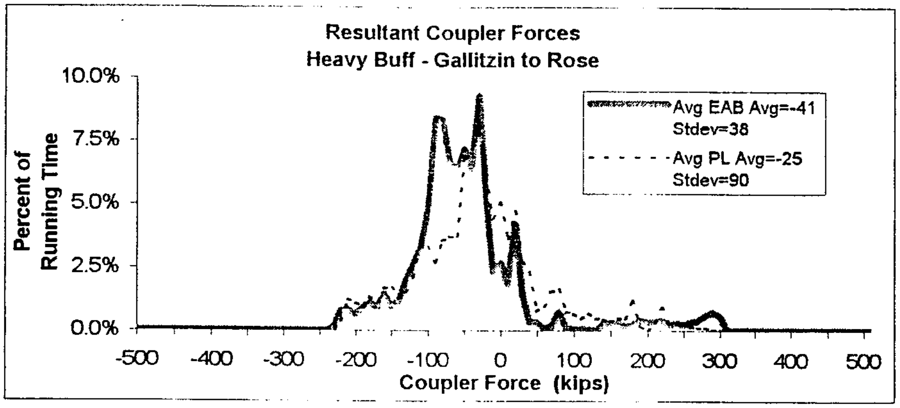

Figure 11 Head-end forces, heavy buff.

buff and draft operations were analyzed. Referring to the elevation information of Figure 3, two segments of the eastbound trips were used to provide this comparison, the uphill run from C-Tower to Gallitzin, and the downhill segment from Gallitzin to Rose. Coupler force data were compiled in a histogram format whenever the train speed was greater than two miles per hour. The coupler force data in the histogram could range from -500 kips (compressive, buff forces) to +500 kips (tensile, draft forces) in 10 kip increments. Used for the comparative analysis were six EABS test runs averaged to represent a typical ECP train, and five placebo test runs averaged with one EABS test run that operated in conventional braking mode to represent the typical placebo (PL) train. Each of these trains were aided up and over these segments by a pair of helper locomotives on the rear of the train. Additionally, the collected histogram data were converted from counts per cell, to a percentage of total counts recorded. This normalization process provided a direct comparison between the trains and illustrates the distribution of the head-end coupler forces while the train is in motion. The resultant, normalized histograms are illustrated in Figures 10 and 11 for the draft and buff operations, respectively.

Among the anticipated benefits of the ECP brake system is improved train handling resulting in reduced costs of equipment, track, roadbed, lading, and collateral damage.[4] The resultant coupler forces illustrated in Figures 10 and 11 indicate that the EABS trains did have less variation in dynamic coupler action than did the placebo trains. However, one must be cautious in the interpretation of these data. The data collected cannot be used to describe the influence that the helper locomotives had on the train dynamics, and the EABS trains regularly had more braking and tractive effort available to control the train. Three SD-60M locomotives always powered the EABS trains while two locomotives powered the placebo trains. The effect of the additional tractive and braking effort can be seen in these figures by the higher average draft and buff forces, respectively.

OBSERVED MAINTENANCE DATA

Conrail's Mechanical Engineering personnel monitored the location and mechanical maintenance of the EABS and placebo cars on a daily basis. A history of the maintenance data were compiled through the following sources:

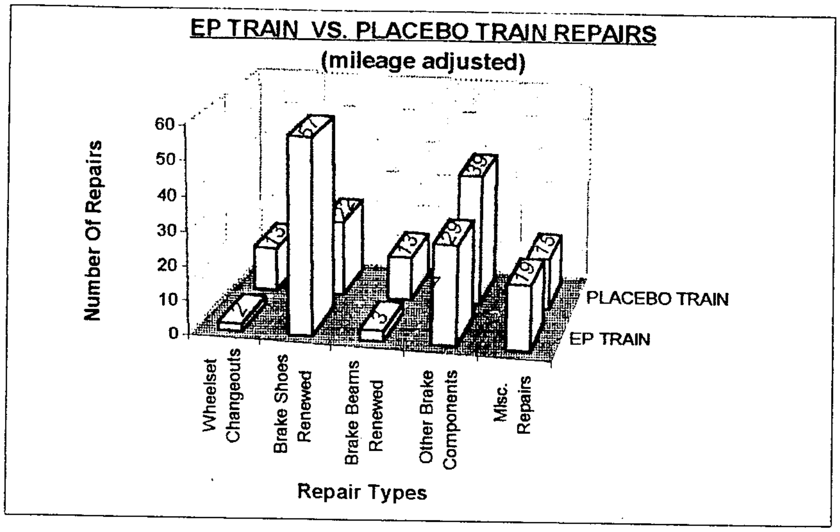

Figure 12 Mileage adjusted repair requirements.

- routine communications with repair shops at Stony Creek, Reading, Enola, and Shire Oaks,
- repair reports from Conrail field personnel,
- the Car Repair Billing computer data, and
- TSM field technicians travelling with the EABS consist.

Detailed records of the repairs recorded during the study are in Appendix A. Although differences between the two test trains on most mechanical repairs are negligible, four specific components stand out when comparing the two trains over the test period. Figure 12 illustrates significant differences in wheel change out rates, brake beam change out rates, and brake shoe replacements between the two trains. These data for the placebo cars have been linearly adjusted upwards to reflect the equivalent mileage of the EABS cars. The fourth component to stand out were the Car Control Units (CCU) mounted on the EABS train. These had high failure rates, especially early in the test program.

As seen in Figure 12, the wheel change out rate on the EABS equipped cars was much lower than the cars of the placebo train. When adjusted for mileage, the EABS equipped train had two sets of wheels replaced versus thirteen wheel sets for cars of the placebo train. It is worth noting that the two wheel sets changed on the EABS train were from a single car reported to have slid flats caused by a dragging hand brake. Regardless of the braking technology, human error is still present.

The placebo train required four times as many brake beam replacements than did the EABS train during the test period. Most of the brake beams were replaced due to a burnt brake head. However, it is not clear why the conventional brake system would result in more burnt brake heads. This finding appears to be inconsistent with observations made during tests on other railroads.

The repair data suggest that brake shoes wear out much faster on cars in an ECP train than those in a train with conventional air brakes. Nearly a threefold number of brake shoes required replacement on the EABS cars when compared to the cars of the placebo train. It may be attributed to the fact that the train crews had a tendency to use the EABS brake more frequently as it provided better train control than a conventional brake system. This statement is supported by the additional braking witnessed during the in-train evaluation among the eastern segments of the route.

During the test period, two problems developed on the EABS train involving the brake system's CCUs. Some units would unexpectedly lose power and terminate their communications with the Head End Control Unit located inside the cab of the lead engine. This first problem started from the beginning of the test, and in association with failing CCUs, brake lock-up problems were reported on three cars with faulty CCUs.

Individual CCUs were mounted on a bracket that was welded onto the inboard flange of a vertical pillar (end post) which extended upward from the car's center sill to the top of the end slope sheet. Twenty-three CCUs had failed within the first two months of the test. This alarming failure rate was thought to be caused by improper potting of particular circuit components. The retrofitting of the existing CCUs with improved units for the test train was started on August 28. By September 19, all EABS test cars were retrofitted with the new units. Most of the fifty-two round trips were operated in full EP mode; however, the EABS equipment averaged an utilization rate of 73% after providing repairs to the CCUs. The graph of Figure 13 illustrates why the EABS train did not operate completely in electro-pneumatic mode. CCU failure continued to be a major reason for non-EP operation. Consequently, the AAR and TSM personnel conducted a series of

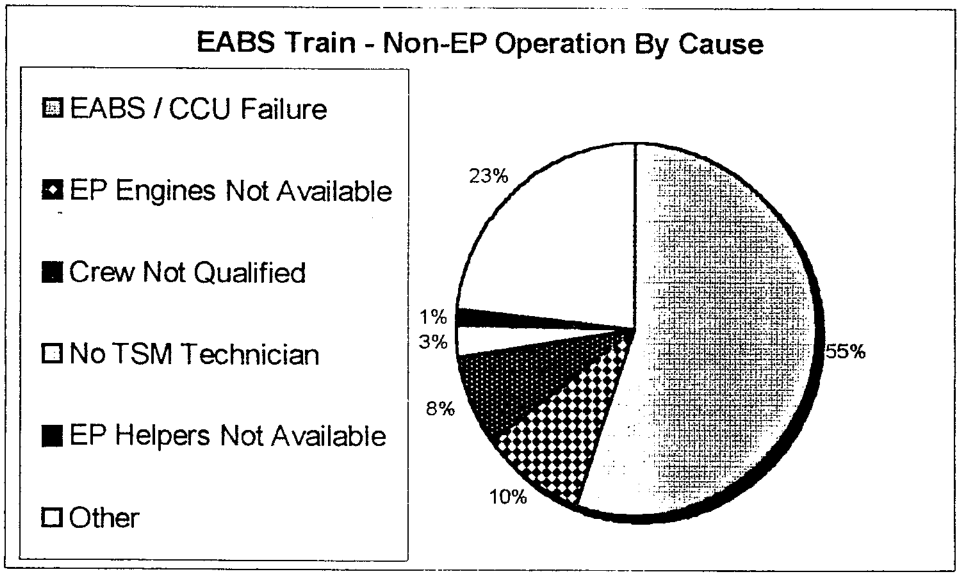

Figure 13 Reason for non-EP operation.

vibration tests at both ends of the terminals to determine the proper design criterion for the EAB system. This investigation determined that the localized vibrations witnessed by the CCUs during unloading operation were too severe for reliable performance.[5]

To investigate the problem of a locking brake when the CCU fails, CR 505171 (one of the cars with the sticking brake problem) and CR 504511 were coupled and tested at the Eddystone shop on December 18, 1996. The CCU on CR 505171 was disabled to simulate a failed CCU. A series of EP applications and releases on car CR 504511 would cause the brake cylinder pressure on CR 505171 to build up and set its brake unintentionally. The investigation revealed that the stuck brake situation could occur on a car with a power failure to its CCU. The reason for this occurring can be explained.

When a CCU of the current EABS design fails, the car automatically reverts to pneumatic brake mode. Furthermore, electric brake applications in an EABS train are commanded by computer message through the electric trainline, instead of a pressure reduction of the pneumatic trainline. Normal applications of the EP system will disturb the pneumatic trainline that acts as an air supply to the braking system. The pressure in the supply line will drop slightly as the air is exhausted from the reservoir to the cylinder in each car. This slight drop in the trainline pressure is enough to activate the default pneumatic service portion of a car with a failed CCU. Hence, the brake becomes set-up on that car. Unfortunately, when the brake pipe pressure stabilizes, the rise in the pressure is so slight that it does not trigger a release on the car, resulting in a stuck brake situation. Normal Conrail operating rules for conventionally braked trains require Engineers to apply a minimum of 10 psi brake reduction before attempting to release a brake application to avoid the stuck brake situation.

ECONOMIC ANALYSIS

Locomotive Energy Requirements

The train energy data accumulated with CR-19's instrumentation showed that the EABS train required more drawbar energy to complete a round trip of the test route. A significant difference in drawbar energy requirements for the eastbound test trains is found in the gradual, downhill segments east of Altoona, PA. These energy differences were the result of three probable causes. First, the method of braking utilized (train brakes versus locomotive dynamic brakes), affected the resultant coupler forces. Secondly, individual cars with dragging brakes within the EABS train resulted in higher energy requirements. Finally, the Engineers operating the EABS train could very easily perform power braking. The first cause occurs from the inability of the data acquisition method to account for train energy that is dissipated within the cars themselves. It is likely that a significant amount of the energy difference between the two trains is due to this cause. However, the later two causes, dragging brakes and power braking, will result in an increase in fuel consumption.

An effort was made to quantify the additive cost associated with the operation of an EABS train based on the in-train energy data compiled and some simple assumptions. Table 3 provides the amount of locomotive energy that is expected to be required to operate both an EABS train and a conventional train through the test route of this study.

ACKNOWLEDGMENTS

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Appendix A

Car Repair Records

Placebo Train
EABS Train

4/7/97

Placebo Train Repair Records

PLACEBO TRAIN REPAIR DATA

CAR #	DATE	SITE	REPORT_BY	DEFECTS	CAUSE	LOCATION	PART_RENEW
505132	17-Jun-96	Waynesburg	Roger Bennett	H.B.rivet broke inside housing	U/K	B-end	H.B. Univsl. 9300
507027	25-Jun-96		CRB DATA	renew cplr knuckle pin	U/K		cplr knuckle pin
504715	28-Jun-96	EDDYSTONE	C.DGANTONIO	FIX BENT HANDHOLD	N/A		
504715	28-Jun-96		CRB DATA	renew air hose support & coupl	U/K	A-end	hose support &coup
504715	28-Jun-96		CRB DATA	renew air hose support & coupl	U/K	B-end	hose support &coup
504715	28-Jun-96		CRB DATA	RENEW WHEELSET	U/K	#1	WHEELSET
504715	28-Jun-96		CRB DATA	RENEW WHEELSET	Tread Shelled	#2	WHEELSET
506042	17-Jul-96		CRB DATA	renew brk shoe & key	U/K		brake shoe & key
504682	26-Jul-96	Eddystone	David Campbell	renew wheels	slid flat	#3	36" wheel set
504682	26-Jul-96	Eddystone	David Campbell	renew wheels	slid flat	#4	36" wheel set
505632	1-Aug-96		CRB DATA	brk beam hanger	U/K		brk beam hanger
505186	8-Aug-96	EDDYSTONE	BOB MUNDELL	valve gasket blown	U/K		pipe bracket gasket
507372	12-Aug-96	ENOLA	DON PAUL	BURNED IN BRK BEAM HEAD	LOST SHOE	U/K	brake beam
507372	12-Aug-96	ENOLA	DON PAUL	MISSING BRK SHOE	LOST SHOE	U/K	brake shoe
505186	15-Aug-96		CRB DATA	EMERGENCY PORTION REP/CLN			EMERGENCY PORTIO
504062	19-Aug-96	Eddystone	John Warren	Side Wiped	U/K	AL	
507068	19-Aug-96	Eddystone	John Warren	Side wiped	U/K	BL	
507168	19-Aug-96	Eddystone	Bob Mundell	Brake beam head burnt in	U/K	L1	brake beam
507168	19-Aug-96		CRB DATA	brk shoe & key	U/K		brake shoe & key
507168	19-Aug-96		CRB DATA	brk shoe & key	U/K		brake shoe & key
507168	19-Aug-96	Eddystone	Bob Mundell	MISSING BRK SHOE	U/K	L1	brake shoe
507168	19-Aug-96	Eddystone	Bob Mundell	MISSING BRK SHOE	U/K	R1	brake shoe & key
505814	28-Aug-96		CRB DATA	brk hanger/conn pin	U/K		brk hanger/conn pin
503507	30-Aug-96	EDDYSTONE	DAVID CAMPBELL	brk pipe fitting gasket leaking	U/K		brk pipe fitting gaske
506640	30-Aug-96	EDDYSTONE	DAVID CAMPBELL	RENEW WHEELSET	Tread Shelled	#1	WHEELSET
506640	30-Aug-96	Eddystone	David Campbell	RENEW WHEELSET	Tread Shelled	#4	wheel set
506821	30-Aug-96	EDDYSTONE	DAVID CAMPBELL	BURNT BRAKE BEAM HEAD	MISSING BRK SHOE		BRAKE BEAM
506821	30-Aug-96	EDDYSTONE	DAVID CAMPBELL	MISSING BRK SHOE	MISSING BRK SHOE		brake shoe
505912	20-Sep-96		CRB DATA	brk hanger/conn pin	U/K		brk hanger/conn pin
505912	20-Sep-96		CRB DATA	top rod	U/K		top rod
503507	30-Sep-96	Eddystone	David Campbell	hi impact wheel	U/K	#3	wheelsets
504333	30-Sep-96	ENOLA	STEVEN OWENS	BAD SLACK ADJUSTER	U/K		SLACK ADJUSTER
505610	30-Sep-96	ENOLA	STEVEN OWENS	BRK CYL. HOUSING CRACK	U/K		BRAKE CYL
506895	30-Sep-96	ENOLA	STEVEN OWENS	BRAKE BEAM BURNT IN	U/k	#4	BRAKE BEAM

PLACEBO TRAIN REPAIR DATA

CAR #	DATE	SITE	REPORT_BY	DEFECTS	CAUSE	LOCATION	PART_RENEW
506895	30-Sep-96	ENOLA	STEVEN OWENS	MISSING BRK SHOE	U/k	#4	brake shoe & key
503507	7-Oct-96		CRB DATA	pipe fitting	U/K		pipe fitting
507168	14-Oct-96	Eddystone	Bob Mundell	brk beam head burnt in	U/K	R2	brake beam
507168	14-Oct-96	Eddystone	Bob Mundell	MISSING BRK SHOE	U/K	R2	brake shoe & key
506992	25-Oct-96	Eddystone	Bill	Burnt Brk Head	U/K	L3	Brake Beam
506992	25-Oct-96	Eddystone	Bill	missing brk shoe	U/K	L3	brake shoe & key
505275	26-Oct-96	Eddystone	CRB DATA	air hose support	U/K	A-end	air hose support
505275	26-Oct-96	Eddystone	CRB DATA	air hose support	U/K	B-end	air hose support
505275	26-Oct-96	Eddystone	Bill	Burnt Brk Head	U/K	#3	Brake Beam
505275	26-Oct-96	Eddystone	Bill	missing brk shoe	U/K	R2	brake shoe & key
505275	26-Oct-96	Eddystone	CRB DATA	wheel set changeout	U/K	#4	wheelsets
503327	13-Nov-96	West Brownsville	Chip Durant	Comb.cutout cock/dirt collector	U/K		Comb.cutout cock/dir
503834	21-Nov-96		CRB DATA	brake shoe	U/K		brake shoe
507146	2-Dec-96	Eddystone	Bob Mundell	Brake beam head burnt in	U/K	L1	brake beam
507146	2-Dec-96	Eddystone	Bob Mundell	worn brake shoe	U/K	L1	brake shoe
507068	5-Dec-96		CRB DATA	brake hanger	U/K		brake hanger
504665	9-Dec-96		CRB DATA	air hose support	U/K	A-end	air hose support
504665	9-Dec-96		CRB DATA	air hose support	U/K	B-end	air hose support
507224	9-Dec-96	Eddystone	Bob Mundell	Brake beam head burnt in	U/K	#3	brake beam
507224	9-Dec-96		CRB DATA	Brake beam head burnt in	U/K	#2	brake beam
507224	9-Dec-96		CRB DATA	slack adjuster	U/K		slack adjuster
507224	9-Dec-96		CRB DATA	WHEEL SET	U/K	#1	WHEEL SET
507224	9-Dec-96		CRB DATA	WHEEL SET	U/K	#4	WHEEL SET
507224	9-Dec-96	Eddystone	Bob Mundell	worn brake shoe	U/K	R2	brake shoe
507224	9-Dec-96		CRB DATA	worn brake shoe	U/K	L3	brake shoe
503535	11-Dec-96	Eddystone	Bob Mundell	carrier iron broken	U/K	B-end	carrier iron & 12" we
504842	11-Dec-96	Eddystone	CRB DATA	brake hanger	U/K		brake hanger
504842	11-Dec-96	Eddystone	Bob Mundell	worn brake shoe	U/K	L3	brake shoe
503367	18-Dec-96		CRB DATA	KNUCKLE PIN	U/K	A-end	KNUCKLE PIN
504695	19-Dec-96	Eddystone	Bob Mundell	broken air reservoir pipe	U/K		air reservoir pipe
504695	19-Dec-96	Eddystone	Bob Mundell	shelled wheel	U/K	R1	wheelsets
506759	19-Dec-96	Eddystone	Bob Mundell	defective air brake	U/K		
506820	7-Jan-97		CRB DATA	emergency valve gasket leak	U/K		emergency valve gas
506820	7-Jan-97		CRB DATA	service portion valve gasket leak	U/K		service portion valve

4/7/97

Placebo Train Repair Records

PLACEBO TRAIN REPAIR DATA

CAR #	DATE	SITE	REPORT BY	DEFECTS	CAUSE	LOCATION	PART RENEW
505182	8-Jan-97	Eddystone	Bob Mundell	worn brake shoe	U/K	R3	brake shoe
504333	15-Jan-97	Eddystone	Bob Mundell	burnt brk head	U/K	L1	brk beam
506523	15-Jan-97	Eddystone	Bob Mundell	broken cutting lever	U/K	B-end	cutting lever
506523	15-Jan-97	Eddystone	Bob Mundell	broken lock lift	U/K	B-end	cplr lock lift
507372	15-Jan-97	Eddystone	Bob Mundell	burnt brake shoe	U/K	R1	brake shoe
507372	15-Jan-97	Eddystone	Bob Mundell	burnt brake shoe	U/K	L1	brake shoe
504794	20-Jan-97	Eddystone	Bob Mundell	service valve leaking	U/K		tightened bolts&teste
503367	24-Jan-97	Shire Oaks	Chip Durant	defective slack adjuster	U/K		slack adjuster
505204	24-Jan-97		CRB DATA	Coupler knuckle pin	U/K		Coupler knuckle pin
505486	24-Jan-97		CRB DATA	Misc repair Welding	U/K	B-end	tack or fillet welds
507275	24-Jan-97		CRB DATA	bottom rod safety support	U/K		bottom rod safety su
507275	24-Jan-97	Shire Oaks	Chip Durant	defective slack adjuster	U/K		slack adjuster
503318	27-Jan-97		CRB DATA	knuckle pin	U/K		knuckle pin
505418	11-Feb-97	Eddystone	Bob Mundell	defective service valve	U/K		service valve
505204	15-Feb-97	Eddystone	Bob Mundell	defective slack adjuster	U/K		slack adjuster
505861	21-Feb-97	Eddystone	Bob Mundell	air resvoir flange broken	U/K		air resvoir flange
506895	21-Feb-97	Eddystone	Bob Mundell	body S.B. broken	U/K	AL	body side brg
504751	25-Feb-97	Eddystone	Bob Mundell	Side Bearing bolts & roller missing	U/K	BR	side brg bolts & roller
505181	25-Feb-97	Eddystone	Bob Mundell	defective emergency valve	U/K		emergency valve
506515	7-Mar-97	Eddystone	Bob Mundell	bad slack adjuster	U/K		slack adjuster

NOTE: Data include reported repairs as of 3/15/97 and CRB data as of 1/31/97.

Repaired Items	*No. Incidents*	*Percentage*
Wheelset Changeouts	11	12.64%
Brake Shoes Renewed	19	21.84%
Brake Beams Renewed	11	12.64%
Other Brake Components	33	37.93%
Misc. Repairs	13	14.94%
Total	87	100.00%

EP TRAIN REPAIR DATA

EAB_CAR	DATE	SITE	REPORT_BY	DEFECTS	CAUSE	LOC	PART_RENEW
503549	01-Jul-96	CROMBY	E.WILLIAMS	REPLACE BRK.SHOE & KEY	SHOE AND KEY MISSING	R4	SHOE AND KEY
503628	01-Jul-96	CROMBY	E.WILLIAMS	RENEW BRAKE SHOE	BOTTOM PART SHOE	L1	BRAKE SHOE
504160	01-Jul-96	CROMBY	E.WILLIAMS	RESEAT BODY CENTEPLATE	POOR LOADING		
506012	01-Jul-96	CROMBY	E.WILLIAMS	RESEAT BODY CTR.PL. TO	POOR LOADING		
507354	01-Jul-96	EDDYSTONE	D.CAMPBELL	FIX BENT LADDER TREAD	SIDE WIPED AT EMERALD		
507354	01-Jul-96	EDDYSTONE	D.CAMPBELL	FIX BENT LADDER TREAD	SIDE WIPED AT EMERALD		
506914	10-Jul-96	SHIREOAKS	S.JENSHENKO	REPLACE END CONNECTOR	UNKNOWN	B-END	END CONNECTOR
506914	10-Jul-96	SHIREOAKS	S.JENSHEKO	REPLACE JUNCTION BOX	UNKNOWN	B-END	JUNCTION BOX
504463	16-Jul-96	EDDYSTONE	D.CAMPBELL	RENEW BRAKE SHOES	WORN OUT	#2	BRAKE SHOE
506836	16-Jul-96	EDDYSTONE	D.CAMPBELL	RENEW BRAKE BEAM	HEAD WORN OFF	#2	BRAKE BEAM
507141	16-Jul-96	B'VILE/EMER		TRIGGERED HOT BOX	DEFECTIVE CCU	U/K	CCU
507141	16-Jul-96	EDDYSTONE	D.CAMPBELL	RENEW CENTERPLATE	C.P. BOLTS SHEARED	U/K	CENTER PLATE BOLTS
503587	26-Jul-96	SHIRE OAKS		RENEW BRAKE SHOES	WORN OUT	R3	BRAKE SHOE
503587	26-Jul-96	SHIRE OAKS		RENEW BRAKE SHOES	WORN OUT	L3	BRAKE SHOE
503587	26-Jul-96	SHIRE OAKS		RENEW BRAKE SHOES	WORN OUT	L2	BRAKE SHOE
505251	[illegible]-Jul-96	SHIRE OAKS	GCF - UNK	REATTACH SLACK	LOST COTTER KEY	U/K	COTTER KEY
504823	06-Aug-96	Enola	Don Paul	RENEW BRAKE SHOES	lost shoe	L2	BRAKE SHOE
504963	06-Aug-96	Enola	Don Paul	burned in brake beam head	lost shoe	L2	brake beam
507186	06-Aug-96	Harrisburg	Robert Sanders	Brake lever pin broke	U/K		Brake lever pin broke
507186	06-Aug-96	Stony Cr	David Campbell	end connector plug broken	U/K		end connector plug
503587	07-Aug-96	Eddystone	Robert Sanders	brake piston stuck	U/K		
503867	07-Aug-96	Eddystone	Robert Sanders	CCU not responding to HEU	U/K		CCU
506191	07-Aug-96	Eddystone	Robert Sanders	abnormal CCU readings	U/K		CCU
506374	07-Aug-96	Eddystone	Robert Sanders	CCU not responding to HEU	U/K		CCU
506421	07-Aug-96	Eddystone	Robert Sanders	CCU not responding to HEU	U/K		CCU
507034	07-Aug-96	Eddystone	Robert Sanders	CCU not responding to HEU	U/K		CCU
506269	14-Aug-96	Eddystone	David Campbell	End connector broken	U/K		end connector
504996	15-Aug-96		CRB DATA	RENEW BRK SHOE	U/K		BRAKE SHOE
504996	15-Aug-96		CRB DATA	RENEW BRK SHOE	U/K		BRAKE SHOE
507034	15-Aug-96	Eddystone	David Campbell	AB valve service portion leak	loose fasteners		gasket
507197	19-Aug-96	Eddystone	Bob Mundell	pin missing from H.B.	U/K		pin
504920	28-Aug-96	Waynesburg	car inspector	renew pin on brake lever	U/K	U/K	brake pin
503723	06-Sep-96		CRB DATA	BRK BEAM HANGER	U/K		brk beam hanger
505239	06-Sep-96		CRB DATA	BRK BEAM HANGER	U/K		brk beam hanger
507279	06-Sep-96		CRB DATA	RENEW CPLR KNUCKLE PIN	U/K		coupler
503549	17-Sep-96	W.Brownsville	Chip Durant	leaking service portion gasket	U/K		gasket

EP TRAIN REPAIR DATA

EAB CAR	DATE	SITE	REPORT BY	DEFECTS	CAUSE	LOC	PART RENEW
504823	01-Oct-96	EDDYSTONE	John Rus	Dead CCU-stuck brake(new	U/K		CCU
505373	05-Oct-96	West Falls	John Rus	Replace damaged End	broken hanger		end connector
506481	10-Oct-96		CRB DATA	brk. shoe changeout	U/K		brake shoe
507031	10-Oct-96		CRB DATA	brk. shoe changeout	U/K		brake shoe
507141	10-Oct-96		CRB DATA	brk shoe changeout	U/K		brk shoe
507257	14-Oct-96		CRB DATA	brk. shoe changeout	U/K		brake shoe
507257	14-Oct-96		CRB DATA	brk. shoe changeout	U/K		brake shoe
504397	16-Oct-96	Eddystone	John Rus	Cutting lever &bracket	bypass coupler	B-end	cutting lever &bkt
505424	19-Oct-96	Shire Oaks	Chip Durant	Dead CCU-stuck brake(new	loose screw -circuit board		CCU
503363	21-Oct-96		CRB DATA	coupler lock lifter	U/K	B	lock lifter
507141	21-Oct-96		CRB DATA	coupler lock lifter	U/K	B-end	coupler lock lifter
507141	21-Oct-96		CRB DATA	cutting lever & bracket	U/K	B-end	cutting lever & bracket
504823	22-Oct-96		CRB DATA	brk shoe changeout	U/K	L4	brk shoe
506352	22-Oct-96		CRB DATA	brk shoe changeout	U/K	R4	brk shoe
506634	22-Oct-96		CRB DATA	brk shoe changeout	U/K	L4	brk shoe
506634	22-Oct-96		CRB DATA	brk shoe changeout	U/K	R4	brk shoe
503565	31-Oct-96	Eddystone	Bob Mundell	BENT CUTTING LEVER	U/K		UNCPL. LEVER
505171	31-Oct-96	Eddystone	Bob Mundell	BROKEN SIDE BRG	U/K		SIDE BRG
506967	31-Oct-96	Eddystone	Bob Mundell	defective slack adjuster	U/K		Slack Adjuster
503363	01-Nov-96		CRB DATA	brk. shoe changeout	U/K		brake shoe
504920	01-Nov-96		CRB DATA	brk shoe changeout	U/K		brk shoe
506967	04-Nov-96		CRB DATA	replace bolts	U/K	A-end & B-end	bolts
504823	05-Nov-96		CRB DATA	brk shoe changeout	U/K	L2	brk shoe
504881	05-Nov-96		CRB DATA	brk shoe changeout	U/K	L2	brk shoe
503565	14-Nov-96		CRB DATA	service valve gasket	U/K		service valve gasket
504881	14-Nov-96	W.Brownsville	Chip Durant	Serv.port.gasket blown	U/K		valve gasket
504785	17-Nov-96		CRB DATA	brk shoe changeout	U/K		brk shoe
504881	21-Nov-96	Harrisburg	John Rus	Dead CCU-stk brk-hot box	U/K		CCU
504881	25-Nov-96	Eddystone	John Rus	Bad Slack Adjuster	U/K		Slack Adjuster
504881	26-Nov-96		CRB DATA	brk shoe changeout	U/K		brk shoe
504881	26-Nov-96		CRB DATA	brk shoe changeout	U/K		brk shoe
504881	26-Nov-96		CRB DATA	brk shoe changeout	U/K		brk shoe
504996	26-Nov-96		CRB DATA	RENEW BRK SHOE	U/K		BRAKE SHOE
504996	26-Nov-96		CRB DATA	RENEW BRK SHOE	U/K		BRAKE SHOE
503999	02-Dec-96		CRB DATA	brk shoe and key	U/K		brk shoe
506352	02-Dec-96		CRB DATA	brk shoe & key	U/K		brk shoe & key

EP TRAIN REPAIR DATA

EAB_CAR	DATE	SITE	REPORT_BY	DEFECTS	CAUSE	LOC	PART_RENEW
506352	02-Dec-96		CRB DATA	brk shoe & key	U/K		brk shoe & key
504920	03-Dec-96		CRB DATA	slack adjuster changeout	U/K		slack adjuster
504920	03-Dec-96		CRB DATA	brk shoe changeout	U/K	L1	brk shoe
504920	03-Dec-96		CRB DATA	brk shoe changeout	U/K	R1	brk shoe
504920	03-Dec-96		CRB DATA	brk shoe changeout	U/K	L2	brk shoe
504920	03-Dec-96		CRB DATA	brk shoe changeout	U/K	R2	brk shoe
504920	03-Dec-96		CRB DATA	brk shoe changeout	U/K	L3	brk shoe
504920	03-Dec-96		CRB DATA	brk shoe changeout	U/K	R3	brk shoe
504920	03-Dec-96		CRB DATA	brk shoe changeout	U/K	L4	brk shoe
504920	03-Dec-96		CRB DATA	brk shoe changeout	U/K	R4	brk shoe
504920	03-Dec-96		CRB DATA	Cutter Key/Split Key	U/K	A-end	Cutter Key/Split Key
504390	09-Dec-96	Shire Oaks	John Rus	burnt brk shoe	H.B. was set	U/K	brake shoe
506232	09-Dec-96	Shire Oaks	Chip Durant	built up tread	H.B. was set	#1	Wheel set
506481	09-Dec-96	Shire Oaks	John Rus	burnt brk shoe	H.B. was set	U/K	brake shoe
506711	09-Dec-96	Shire Oaks	Chip Durant	built up tread	H.B. was set	#2	Wheel set
506352	16-Dec-96		CRB DATA	Angle Cock Changeout	U/K	A-end	angle cock
504511	19-Dec-96		CRB DATA	brake beam changeout	U/K	#2	brake beam
504511	19-Dec-96		CRB DATA	brk shoe & key	U/K	L2	brk shoe & key
504511	19-Dec-96		CRB DATA	brk shoe & key	U/K	R2	brk shoe & key
503999	19-Jan-97	Eddystone	Bob Mundell	Broken cutting lever	U/K	A-end	cutting lever
507031	19-Jan-97	Eddystone	Bob Mundell	H.B. pin missing	U/K		pin
507141	19-Jan-97	Eddystone	Bob Mundell	broken cutting lever	U/K	A-end	cutting lever
507257	19-Jan-97	Eddystone	Bob Mundell	H.B. pin missing	U/K		pin
506634	23-Jan-97	Eddystone	John Rus	brake inoperative	U/K		
504390	30-Jan-97	Eddystone	Bob Mundell	bad emergency valve	U/K		emergency valve
504927	06-Feb-97	?????		brake inoperative	U/K		
506836	06-Feb-97	Eddystone	Bob Mundell	burnt brk shoe	U/K	L1	brake shoe
503678	07-Feb-97	Shire Oaks	R.W.Benette	vent valve gasket leak	U/K		gaskets
506994	07-Feb-97	Shire Oaks	R.W.Benette	missing brk pin	U/K		brk pin
507101	07-Feb-97	Shire Oaks	R.W.Benette	service portion valve gasket	U/K		gaskets
504339	11-Feb-97	Eddystone	Bob Mundell	bad emergency valve	U/K		emergency valve
505059	11-Feb-97	Eddystone	Bob Mundell	slack adj disconnected	U/K		
503678	19-Feb-97	Shire Oaks	Chip Durant	serv. valve gasket	U/K		serv. valve gasket
504160	19-Feb-97	Cromby	John Teel	damaged end connector	U/K		end connector
506285	19-Feb-97	Cromby	John Teel	damaged end conn. & J.box	U/K		end connector & box
507363	19-Feb-97	Shire Oaks	Chip Durant	serv. valve gasket	U/K		

EP TRAIN REPAIR DATA

EAB_CAR	DATE	SITE	REPORT_BY	DEFECTS	CAUSE	LOC	PART_RENEW
504511	22-Feb-97	Shire Oaks	John Teel	retainer valve blowing	U/K		
503427	24-Feb-97	Eddystone	Bob Mundell	Burn in brk shoe	U/K		brake shoe
507257	24-Feb-97	Eddystone	Bob Mundell	burnt brake shoes	U/K	L2	brake shoe
507257	24-Feb-97	Eddystone	Bob Mundell	burnt brake shoes	U/K	L4	brake shoe
507257	24-Feb-97	Eddystone	Bob Mundell	burnt brake shoes	U/K	R3	brake shoe
507257	24-Feb-97	Eddystone	Bob Mundell	burnt brake shoes	U/K	R4	brake shoe
503427	28-Feb-97	Eddystone	Bob Mundell	brake shoe	U/K	L1	brake shoe
503427	28-Feb-97	Eddystone	Bob Mundell	brake shoe	U/K	R1	brake shoe
503427	28-Feb-97	Eddystone	Bob Mundell	brake shoe	U/K	L2	brake shoe
503427	28-Feb-97	Eddystone	Bob Mundell	brake shoe	U/K	R2	brake shoe
503427	28-Feb-97	Eddystone	Bob Mundell	brake shoe	U/K	L3	brake shoe
503427	28-Feb-97	Eddystone	Bob Mundell	brake shoe	U/K	R3	brake shoe
503427	28-Feb-97	Eddystone	Bob Mundell	brake shoe	U/K	L4	brake shoe
503427	28-Feb-97	Eddystone	Bob Mundell	brake shoe	U/K	R4	brake shoe
504385	1-Mar-97	Eddystone	Bob Mundell	servicec valve leaking	U/K		tightening valve
505456	7-Mar-97	Eddystone	Bob Mundell	air reservoir pipe crack	U/K		
506467	7-Mar-97	Eddystone	Bob Mundell	broken lock lift	U/K		cplr lock lift
504059	13-Mar-97	Eddystone	John Teel	bad EP brake manifold	U/K		EP brake manifold
503913	13-Mar-97	Eddystone	Bob Mundell	severe damage	derailed at PECO		
507279	13-Mar-97	Eddystone	Bob Mundell	severe damage	derailed at PECO		
507034	13-Mar-97	Eddystone	Bob Mundell	severe damage	derailed at PECO		
503745	13-Mar-97	Eddystone	Bob Mundell	severe damage	derailed at PECO		

EP TRAIN REPAIR DATA

EAB_CAR	DATE	SITE	REPORT_BY	DEFECTS	CAUSE	LOC	PART_RENEW
NOTE:	1. Data include reported repairs as of 3/15/97 and CRB data as of 1/31/97. Data include only faulty CCUs that had resulted cars to be set off from the train. The total number of failed CCUs is 37 during the period including 14 retrofitted new CCUs.						
	2. Completed CCU retrofitting - 9/10/96.						
Bad CCUs	*ate Failed*	*Count*		*Repaired Items*	*No. Incidents*	*Percentage*	
504823	1-Oct-96	1		EP Brake CCUs	9	7.14%	
506634	19-Oct-96	2		Other EP Brake Compo	7	5.56%	
505171	21-Nov-96	3		Wheelset Changeouts	2	1.59%	
504717	12-Dec-96	4		Brake Shoes Renewed	57	45.24%	
506066	12-Dec-96	5		Brake Beams Renewed	3	2.38%	
506012	25-Dec-96	6		Other Brake Componen	29	23.02%	
506897	25-Dec-96	7		Misc. Repairs	19	15.08%	
504339	12-Jan-97	8		Total	126	100.00%	
506408	13-Jan-97	9					
506352	19-Jan-97	10					
506094	19-Jan-97	11					
507315	1-Feb-97	12					
504997	7-Mar-97	13					
506408	7-Mar-97	14					

Appendix B
Technology Digest 97-022

TECHNOLOGY DIGEST
Timely Technology Transfer

SHOCK AND VIBRATION REQUIREMENTS FOR ELECTRONIC EQUIPMENT MOUNTED ON FREIGHT CARS

by A.J. Peters and H.G. Woy

TD 97-022

Summary

An investigation of failed control modules for electronically controlled pneumatic (ECP) brake systems in a unit coal train operated by Conrail has yielded new recommendations to protect electronic equipment. The electronic modules were mounted on one of the car structural strength members which resonated during longitudinal impacts, amplifying the base-structure vibration levels. As a result of these studies it is now recommended that the module be mounted directly to the car base structure, or that vibration isolation be provided. For added protection, the shock requirements in the ECP brake performance specification were increased.

These tests were conducted in light of a small number of circuit-board mounting failures experienced on the electronic control modules for the ECP brakes which had been installed on this train as part of an ongoing industry evaluation of these systems. Since these were the first significant number of component failures reported in any service, attention was immediately focused on the mounting arrangement of the electronic module on these cars, and the resultant shock and vibration environment to which the electronic module is subjected.

The basic rotary dump service train moves coal from mines located near Pittsburgh to two power plants in the Philadelphia area. In early January 1997, a test was carried out in which accelerometers were applied to several of the cars to measure the shock and vibration response to impacts resulting from the coal-dumping operation at the power plant. In addition, acceleration measurements were made during the over-the-road moves.

Suggested Distribution:

- ☐ Equipment/Rolling Stock
- ☐ Train Handling
- ☐ Intermodal/Safety
- ☐ Car Department

Association of American Railroads
Railway Technology Department

July 1997

TECHNOLOGY DIGEST
July 1997

INTRODUCTION

A series of tests in 1997 evaluated the shock and vibration environment of unit coal-train equipment in a rotary dump service operated by Conrail. These tests were arranged as a result of a small number of circuit-board mounting failures experienced on the electronic control modules for Electronically Controlled Pneumatic (ECP) brakes, which had been installed on this train as part of an ongoing industry evaluation of this technology. Since these were the first component service failures that had been reported, attention was immediately focused on the mounting arrangement of the electronic modules and the shock and vibration environment to which they were being subjected. The subsequent tests, together with recommendations for changes in the environmental specifications, are the subject of this paper.

BACKGROUND

Since 1994, the Railway Technology (formerly R&T) Department of the Association of American Railroads (AAR) has been working closely with the member railroads and the supply industry to develop performance specifications for the application of ECP brakes to heavy-haul freight trains. The installation of electronic equipment on freight cars, other than for temporary testing purposes, is a new and radical step and the survival of this equipment in such a harsh service environment is a relatively unknown quantity.

The draft performance specification contains shock and vibration provisions, based mainly on measurements and experience derived from impact and over-the-road testing of coal cars for fatigue analysis, and of box cars for lading damage prevention. Furthermore, these data were based on measurements made on the base structure of the car and do not take into account any vibration amplification on individual structural strength members and side- or end-sheet panels due to local resonances.

CONCLUSIONS

The following conclusions were reached as a result of the test data analysis:

- The most significant vibrations, defined in terms of peak acceleration levels, occurred during the dumping operations at the power plant.
- The acceleration levels measured on the base structure of the car were consistent with previous data.
- Resonances of local structural members could significantly amplify the levels experienced by equipment directly mounted on these members.
- The test findings will be used for the establishment of recommended practices for the sensors and equipment being designed to monitor in-train health and safety monitoring.

RECOMMENDATION

It is recommended that the environmental requirements in the ECP brake performance specification be modified to read as follows:

Vibration and Shock Environment

The Car Control Device (CCD) shall be designed and mounted on the base structure of the car to withstand continuous vibrations, in the three major axes, of 0.4 g rms with a frequency content from 1 Hz to 150 Hz, containing peak values of ± 3 g in the 1 Hz to 100 Hz bandwidth. The CCD and its mounting shall also be designed to withstand a longitudinally oriented shock impulse (half sine wave) of 10 g peak with a ramp time of 20 msec to 50 msec. If the CCD is mounted on the car strength members (ribs, slope-sheet support columns, etc), then the bracket and mounting arrangements, together with the electronics packaging, shall be designed to provide protection from the amplification effects of any local vibration resonances. It should be noted that peak resonant acceleration levels in excess of 15 g in the 100-150 Hz range and values in excess of 50 g in the 200-500 Hz range have been measured on car strength members as a result of shock impulses sustained during yard impacts.

OPERATION OVERVIEW

The operation moves coal from mines located near Pittsburgh to two power plants in the greater Philadelphia area. Three train sets, each consisting of 115 cars, are used to service this operation. The three train sets are made up from a pool of cars dedicated to this particular service. It was for this reason that, during the spring of 1996, one of these train sets was equipped with ECP brakes, the main objective being to quantify the economic benefits of this technology compared with conventional braking equipment in identical service.

The trains are loaded at one of the two mines in the Pittsburgh area. The loaded trains are then routed over Conrail mainline trackage to Philadelphia, where they are delivered to the two power plants (Crombie and Eddystone) owned by the Pennsylvania Electric Company (PECO). After being unloaded, the empty trains are returned to Pittsburgh for loading. The round-trip sequence is accomplished in approximately five days.

ECP BRAKE INSTALLATION

In the Conrail conversion, the ECP brake equipment is mounted on the car, adjacent to the conventional air brake equipment. The ECP brake control manifold is mounted between the air brake pipe bracket and the service portion. The associated electronic control module, generally referred to as the Car Control Device (CCD), is mounted on a bracket welded onto the inboard side of a vertical pillar (strength member) which extends vertically upward from the car center sill to the top of the end slope sheet, see Exhibit 1. This location was chosen for convenience and to provide added protection from flying debris and the elements.

TEST PROCEDURES

The test plan was developed by the Technical Services Marketing (TSM) Division of Rockwell International (the company which supplied the ECP brake equipment), endorsed by the AAR and approved by Conrail. The subsequent testing was carried out by personnel from TSM, Rockwell International Engineering and the AAR, with logistics support provided by the Operations and Mechanical Departments of Conrail and full cooperation from PECO.

The test plan was developed with two objectives in mind. The first objective (addressed by TSM) was to determine the cause of these particular electronic circuit board failures. The second objective (addressed by the AAR) was to ensure that the environmental requirements in the ECP brake performance specification were adequate.

The main focus of the testing was targeted at the coal-dumping operation at the power plant because this was where the highest acceleration levels were expected, due to the nature of the operation. However, test data was also collected for one round trip of the over-the-road operation and during the coal loading operation, to ensure that all possible options were covered.

The test data were collected using battery-operated, portable data-collection systems. The sensor package consisted of a triaxial (vertical, lateral, longitudinal) cluster of accelerometers, mounted on a rigid base plate. Both the data-collection system and the accelerometer package were rigidly clamped to the car structure, using heavy-duty C-clamps.

The AAR data was acquired using a Somat Series 2100 programmable digital collection system. The data collected by TSM/Rockwell, which will be the subject of a separate report, was acquired using EDR-3 and EDR-4 programmable ride-quality packages.

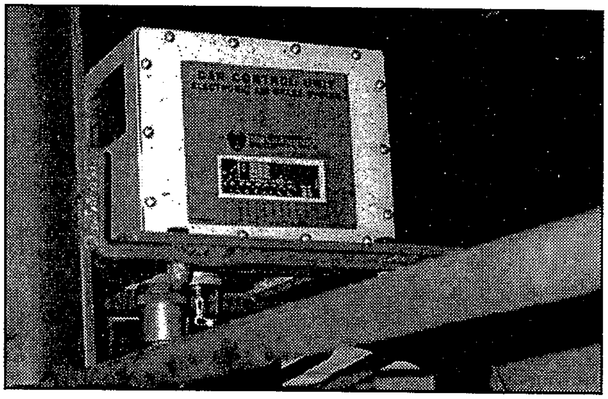

Exhibit 1. CCD Mounting Arrangement

COAL-DUMPING OPERATION

The rotary coal dumpers at both of the power plants are designed to handle a single car. This requires that the loaded cars be separated and the empty cars reassembled into a train during the dumping operation. The testing described in this paper was performed at the Eddystone plant, near the Philadelphia International Airport, so the following description pertains to that operation.

Upon arrival at the power plant, the loaded train is separated into four cuts of cars for ease of handling. The unloading operation is performed using a "hump yard" approach. The cut of cars is pushed to the top of the "hump" using a switching locomotive. A single loaded car is released and rolls under gravity down to the dumper where it impacts into the empty car that has just been dumped, propelling it out of the dumper. The loaded car is captured by the dumper and rotated through approximately 150 degrees about its longitudinal axis, emptying the coal into an "underfloor" collection bin. In cold weather, a vibrator, placed against the side of the car during the clamping process, is used to provide a 15-second burst of energy to break the coal away from the car structure. Meanwhile, the previously ejected empty car rolls under gravity into a holding track, where it impacts into the string of empty cars. The maximum impact speeds, observed during the testing period, were estimated to be 6 mph.

TEST DATA

The test data collected during the dumping operation consisted of two-second bursts of acceleration, triggered by an exceedance of ± 0.5 g in any of the three axes, with a full-scale value of ± 20 G. A sample rate of 1,000 samples/second and a filter setting of 200 Hz was used. For the over-the-road testing, a trigger level of ± 0.4 g was

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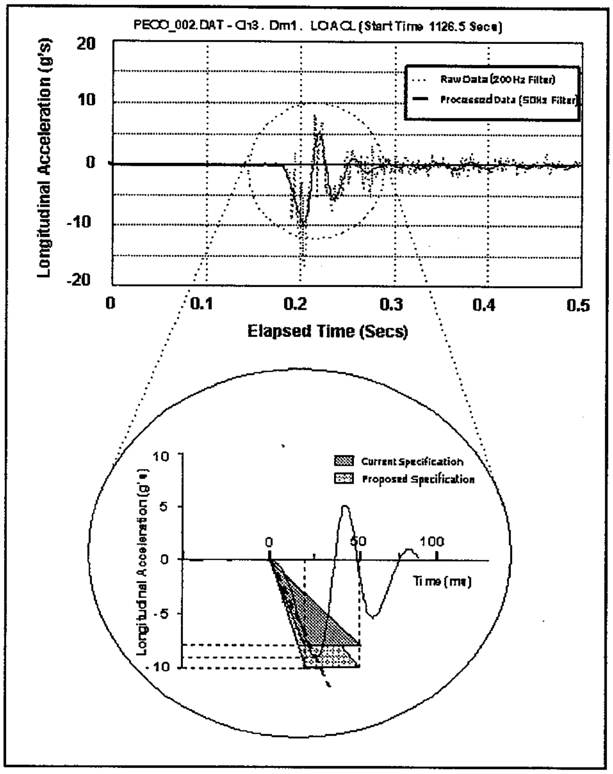

Exhibit 2. Longitudinal Impact Data

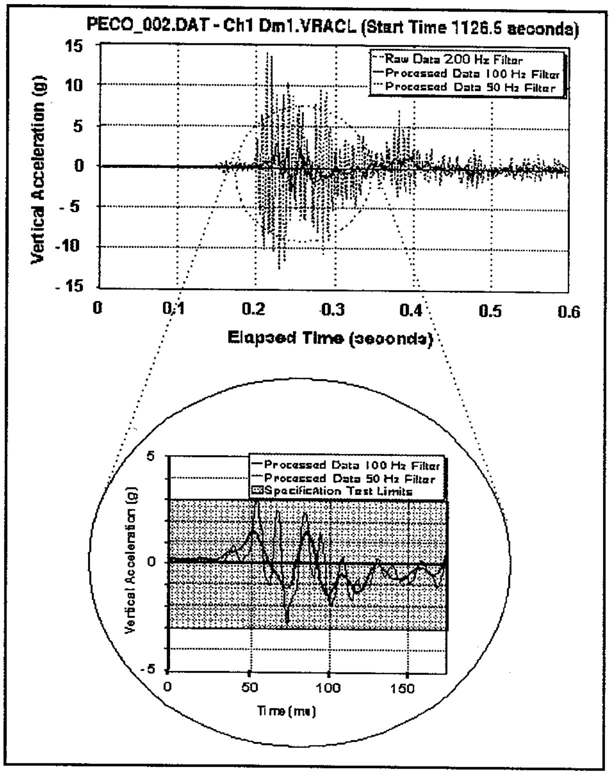

Exhibit 3. Vertical Acceleration Data

employed, with full-scale values of ± 10 G, a sample rate of 300 samples/sec and a filter setting of 100 Hz. The data-collection system was programmed to capture the 40 highest events between downloads and to perform a time-at-level analysis on all the data.

The data used to support the performance specification modification resulted from impacts sustained during the coal-dumping operation. The two limiting examples are presented in Exhibits 2 and 3.

In each case, the data has been processed by post-test filtering the "raw" data to extract the relevant details. Exhibit 2 illustrates this process for the longitudinal data. The "worst-case" impact data has been filtered at 50 Hz to remove the local structural resonant effects. The resultant "clean" waveform is deemed to represent the impact impulse function. The resultant peak value exceeds the existing 8 g limiting case and, on that basis, a recommended peak-value limit of 10 g has been proposed, with the same ramp time tolerance.

The "worst-case" vertical acceleration has been processed in a similar manner (Exhibit 3) to extract the rigid car body and fundamental bending frequency components. The effect of local structural resonances, which tend to occur above 60 Hz, are minimized and then eliminated by the filtering operations at 100 Hz and 50 Hz respectively. On the basis of these data, the general vibration level requirement of ± 0.4 g rms in the performance specification has remained unchanged, although a peak value limit of ± 3 g within the rms level has been recommended.

The data collected during the over-the-road operation fell well within the limits established by the impact data and did not warrant further modifications to the specification.

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Appendix C
Technology Digest 97-008

TECHNOLOGY DIGEST
Timely Technology Transfer

"ECP BRAKE REVENUE SERVICE TESTING UPDATE"

by Fred G. Carlson

TD 97-008

Summary
The Association of American Railroads (AAR) has been conducting revenue service tests of electronically controlled pneumatic (ECP) brake systems since summer 1995. Preliminary results of the ongoing tests show that the cable-powered ECP system continues to operate reliably and the benefits of extended wheel life are becoming evident. Although over-the-road performance and stopping ability continue to be impressive, brake shoe usage has increased with the ECP brake system.

Draft specifications covering the performance of the brake system, connectors, cable, power supply, and brake communications will be delivered to working committees as ECP testing continues in 1997. In addition, the selection process of a standard AAR ECP connector will begin. In the coming year, AAR's research and testing efforts will focus on establishing implementation guidelines for the railroad industry and testing the interoperability of different manufacturers' ECP systems.

Currently, Burlington Northern Santa Fe operates three double stack trains, two unit coal trains, one taconite train, and one unit grain train equipped with the ECP brake system. In addition, Conrail is operating one ECP-equipped unit coal train and CP Rail has begun using ECP brakes on an intermodal train operating between Toronto and Montreal. There are already indications that the number of ECP trains in service will increase in 1997.

Suggested Distribution:
- ☐ Equipment/Rolling Stock
- ☐ Train Handling
- ☐ Intermodal Safety
- ☐ Car Department

Association of American Railroads
Railway Technology Department
March 1997

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March 1997

INTRODUCTION AND CONCLUSION

Preliminary tests of electronically controlled pneumatic (ECP) brakes show that the cable-powered system continues to operate reliably and the benefits of extended wheel life are beginning to become evident. Revenue service testing conducted by the Association of American Railroads (AAR) has been under way since summer 1995. The over-the-road performance and stopping ability of the ECP systems remain impressive; however, brake shoe usage has increased.

Draft specifications covering the performance of the brake system, connectors, cable, power supply, and brake communications will be delivered to AAR working committees as revenue service testing continues. In addition, the selection process will begin for a standard AAR ECP connector. AAR's research and testing efforts this year will focus on establishing implementation guidelines for the railroad industry and testing the interoperability of different manufacturers' ECP systems.

Currently, Burlington Northern Santa Fe (BNSF) operates three double stack trains, two unit coal trains, one taconite train, and one unit grain train equipped with the ECP brake system. Conrail operates one ECP unit coal train while CP Rail has begun using ECP brakes with an intermodal train operating between Toronto and Montreal. The following is a full list of trains using ECP and where they operate:

Train	Route	Specific Items Under Test
2 BNSF Double Stacks	Chicago - Los Angeles	Wheels, Brake Shoes
BNSF Double Stack	Chicago - Seattle	
2 BNSF Unit Coal Trains	Powder River-Becker, MN	ECP Connectors
BNSF Taconite Train	Superior, WI-E. St. Louis	ECP Connectors
BNSF Unit Grain Train	Kansas City-Galveston	
Conrail Unit Coal Train (and conventional train)	Pittsburgh-Philadelphia	Wheels, fuel consumption, brake shoes, train delays
CP Rail Intermodal	Toronto-Montreal	

STOPPING DISTANCES

Additional stop distance tests have been made on some of the BNSF trains. Exhibit 1 summarizes the tests.

Exhibit 1. BNSF Stop Distance Tests

	Conventional	ECP
Loaded taconite train: 20,000 tons, 6,000 feet, 165 cars, 38 mph	~4,500 ft.	1,830 ft.
Empty taconite train: 5,000 tons, 6,000 feet, 165 cars, 40 mph	~1,459 ft.	800 ft.
Unit coal: 15,428 tons, 6,181 feet, 113 cars, 50 mph	5,429 ft.	3,524 ft.

The stop distance numbers for the conventional taconite train are estimates by a BNSF road foreman. The empty taconite train was not stopped with a full-service application in conventional mode because the road foreman was reluctant to risk a derailment due to brake induced slack action. There were no concerns about slack action with the empty ECP train.

As dramatic as the stop distance improvements are, the most valuable train handling feature has proven to be graduated release. This allows for a control of train speed superior to that of the dynamic brake. Crews using the ECP brake instead of the dynamic as the variable speed-controlling brake were able to control train speed on difficult grades within 1 mph of track speed.

REDUCTION IN BRAKE-RELATED WHEEL DEFECTS

Wheel replacement savings have improved on BNSF and they have become noticeable on Conrail. Two of the BNSF double stack trains have been operating between Chicago and Los Angeles since December 1995. These trains are made up of 70 three-unit, drawbar-connected Gunderson cars constructed in late 1995. Data given in Exhibit 2 was taken after approximately 150,000 miles of service. The ECP cars have been compared with a like number of conventionally braked cars from the same production run.

Exhibit 2. Wheel Replacement Comparison–BNSF

	Conventional	ECP
Wheels replaced for slid flats—hand braked axles	7	0
Wheels replaced for slid flats—non-hand braked axles	1	0
Wheels replaced for shells or spalls	7	0

Admittedly, some flat spots on the conventional cars could have been caused by misapplied hand brakes, but the ECP cars also equipped with hand brakes. Even if some of the slid flats are attributed to hand brakes, the trend is positive and encouraging.

Initial performance of the Conrail ECP train is being compared with an identical conventionally braked unit coal train in the same service. Items such as wheel replacement due to brake-related defects, fuel consumption, brake shoe consumption, and brake-related train delays are being compared. With about 15,000 miles of service on each train, the wheel change due to brake-related defects are given in Exhibit 3.

Exhibit 3. Wheel Replacement Comparison–Conrail

	Conventional	ECP
Wheels replaced for slid flats	2	0
Wheels replaced for high impact (out of round)	1	0
Wheels replaced for shells or spalls	3	0

Wheel replacement rates for brake-related defects on the conventional BNSF double stacks and the Conrail unit coal trains were 1.43 and 3.86 wheels per million car miles, respectively. Actual mileage on the Conrail conventional train used in calculation was 13,500 miles. The ECP train had run 16,500 miles during the same period.

The higher wheel replacement rate on the Conrail conventional train is most likely a result of the ECP train having a much lower empty brake ratio. The better brake cylinder pressure control of ECP brakes may also be a factor. Note that the cars in the double stack trains are almost never operated empty or lightly loaded, while the unit coal train is empty 50 percent of the time. None of the unit coal cars are equipped with empty/load. The conventional coal train has a full-service brake cylinder pressure of 64 psi and a resulting empty brake ratio of 35 percent. However, the empty ECP-equipped coal train is limited to 35 psi full-service brake cylinder pressure, which results in an empty brake ratio of 20 percent. This limitation is made when the ECP brake system is set up at the initial terminal.

Note that the lower empty brake ratio of the ECP train is achieved entirely with software control and without troublesome car-mounted load sensing equipment. The lower brake ratio sharply reduces the likelihood of wheel slide on the empty ECP train. The stopping ability of the empty ECP train is still shorter than the conventional empty train due to the much faster response of the ECP brake.

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REDUCED SLACK ACTION

A test car was used in both the Conrail ECP and conventional trains to measure the drawbar energy during a number of trips. The preliminary results show a marked reduction in buff and draft forces, but the data cannot be adequately quantified at this time. More runs are needed with the test car in the ECP train before statistically significant numbers can be published. Certainly the feature most noticed by first time ECP train riders is the lack of slack action. The improvement in longitudinal ride quality could have a significant benefit; especially for autorack service

BRAKE SHOE USAGE

Brake shoe wear, to date, on the Conrail test and on the BNSF double stacks is shown in Exhibit 4.

The Conrail test started with new brake shoes on both the ECP and the conventional trains, but has not accumulated enough mileage to wear out the brake shoes. Those that have been replaced fell off in the rotary dumper.

Exhibit 4. Brake Shoe Usage - Conrail, BNSF

After 150,000 miles of service	Brake Shoes Replaced	
	ECP	Conventional
BNSF	585	84
Conrail	8	7

Brake shoe wear has been surprisingly high on the ECP-equipped BNSF double stacks. This may be attributed to the crews taking the opportunity to use the new system whenever possible. The high brake shoe wear could also indicate the ECP brake system is a superior train handling tool; thus, is used by engineers more frequently.

STATUS OF AAR SPECIFICATIONS

As stated earlier, draft specifications covering the performance of the brake system, connectors, cable, power supply, and brake communications will be delivered to the AAR Mechanical Division working committees in January 1997. The selection process of a standard AAR ECP connector will also begin at that time.

Work remains on the communications requirements for distributed power, sensor interface, and locomotive interface as part of the Locomotive Systems Integration project. Two manufacturers are developing radio as an alternative to cabled ECP systems; these will be evaluated as developed. The radio alternative would do away with cable connections but requires an on board power source for every car. The radio systems must demonstrate superior reliability and economics before the radio option can be implemented. The proposed wireless systems essentially follow the AAR draft specifications. However, if they are adopted as an industry standard, a new communications specification must be written. Finally, establishing implementation guidelines for the railroad industry will be the a major focal point of AAR research and testing efforts in 1997.

Note: Contact Fred Carlson at (719) 584-0718 with questions or comments about this document. E-mail: fred_carlson@aar.com.

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