INTRODUCTION
Pneumatic brake systems have been a part of railroad equipment since the late 1800’s, replacing human actuation of brake levers. This change was a revolutionary step in the operation of rail equipment. Since that time, incremental improvements in components resulting in increased reliability of brake equipment, reductions in false stops, more rapid signal propagation have been introduced. However, the performance-limiting factor of the pneumatic system remained: a communication media with a limited transmission rate (maximum transmission rate being the speed of sound). A single-air line, like that used in North America, provides both control signal and braking energy, yet is not optimal.

North America’s railroads recognize that other technologies might enhance the performance and capability of train brake systems if they can be proven to be robust and economically feasible. As a result of the increasing need to improve rail system efficiency, the Association of American Railroads (AAR) initiated a Strategic Research Initiative (SRI) program to investigate alternatives that may enhance brake system performance in North America.

This paper discusses the current developmental status of Electronically Controlled Pneumatic (ECP) brake systems and provides some early economic numbers for one stand-alone system in revenue service in North America. It is also intended to provide a background of the capabilities and benefits of ECP systems and to describe the development of interchange standards for ECP systems in North America by the AAR, its subsidiary Transportation Technology Center, Inc. (TTCI), member railroads, freight wagon owners, and the railroad supply industry.

Within the AAR, the development of interchange standards for ECP brake systems began in 1993 with meetings between railroad representatives, both traditional and non-traditional railroad equipment suppliers, and AAR/TTCI personnel. Ultimately, AAR standards set the requirements for interoperability of equipment that will be interchanged between railroads and will allow for seamless pass-through service of rail vehicles.
The overall program goal was to enhance the brake system performance using available technologies. The chosen technology is referred to as Electronically Controlled Pneumatic or ECP braking. ECP braking enhances performance by using an electronic signal for communication while maintaining the pneumatic system to supply the braking energy.

**DESCRIPTION/BENEFITS OF ECP BRAKE SYSTEMS**

Basic ECP specifications are written for systems to provide brake system control using an electronic communication media operating at nearly the speed of light; thereby providing enhanced braking capability over that of traditional U.S. single-line air-only equipment. The specifications also include system capabilities for Trailing Locomotive Control (replacement of the 27 pin MU cable for control of locomotives/consists anywhere in the train) and onboard wagon health monitoring (on an exception or exceedence basis). The benefit of each of these capabilities is described in more detail.

- The benefits of ECP brakes over conventional North American equalization type pneumatically controlled brake systems begin with reduced stopping distances. Tests have indicated reductions in stop distance over that of conventional equipment by 30 to 70 percent depending on initial conditions and track gradient.

  Graduated or incremental release of a brake application is a major benefit in North America where existing equalization type systems are direct release only. Graduated release provides improved performance and speed control on downgrades. Full train stops due to “over braking” are no longer required, and the need to power brake is virtually eliminated.

  With ECP systems, brake applications occur simultaneously, or nearly so, throughout the length of the train. This results in significantly reduced train action (in-train forces caused by brake applications propagating from the front of the train toward the rear), and the aforementioned shorter stopping distance. Reduced component wear (wheels, brake shoes, draft gear, wagon body structure) is realized through better brake control and the ability to adjust the brakes incrementally to the required level. Brake shoes at the front of the train are worn at the same rate as those at the back of the train.
Brake system health feedback, such as train-line continuity, brake system health (the number of operating brakes) and wagon ordering are realized with ECP systems. U.S. freight trains cannot depart an initial terminal with less than 100 percent operative brakes and are required to cease or limit operation when the train has less than 85 percent operative brakes. This type of brake system health feedback is a standard ECP feature.

Fuel savings may be realized due to better brake control resulting in shorter trip times and more efficient operations. As stated previously, graduated release sharply reduces the need to power brake. Additionally, compressor requirements and cycling are decreased with the continuously charging train line.

- **Trailing Locomotive Control (TLC)** of locomotives and/or locomotive consists distributed throughout a train equipped with ECP systems is included in the specifications. TLC commands are passed along the same electronic medium as the brake commands. Continuous status of trailing locomotive operation (e.g., tractive and dynamic braking effort, engine status) is displayed.

  Economics of operating larger trains with the ability to limit in-train forces will determine the need for TLC by various railroads. The lead locomotive of each consist is required to be equipped with TLC equipment while adjacent trailing units can be controlled through conventional 27-pin Multiple Unit (MU) equipment.

- **Onboard wagon and locomotive health monitoring** is also available with the ECP Intra-train Communication (ITC) backbone. As with all monitoring functions of the ECP system, the concept of exception-based messaging is used. Only exception messages or diagnostic failures are passed along to the operator.

  Few onboard sensor systems have been developed to date. However, with the implementation of more revenue service trains with ECP systems, more types of onboard monitoring are foreseen. The first type of sensor expected would likely monitor hand brake application status. Numerous other sensor types monitoring ride quality, derailment, wagon component status (side bearing condition, cushioned draft-gear condition), sub-system status (refrigerators, security), and more have been suggested. Economics and sensor/system reliability will clearly drive such developments.
ECP Components

The components of a complete implementation using the Intra-train communication network include the items discussed below. Figure 1 offers a basic diagram of both a cable-based and a radio-based ECP brake system:

The **Head-End Unit (HEU)** is the operator interface and network manager that will be active in the lead locomotive. It consists of a display and the man-machine or operator interface to control the electronic brake system. Brake commands are sent throughout the ECP system from the HEU and information about the health status of the system is displayed to the operator.

![System Diagrams for Cable-Based and Radio-Based ECP Systems](image)

**Figure 1: System Diagrams for Cable-Based and Radio-Based ECP Systems**

The **Car (wagon) Control Device (CCD)** is the network connection found on each wagon (1 CCD per wagon). The CCD is a smart device capable of controlling the braking for each vehicle based on the brake command from the HEU or on local inputs in case of emergencies. The CCD acts as a pass through connection for onboard health monitoring equipment. Figures 2 and 3 show CCD’s Cable-based and a Radio-based CCDs.
The **End of Train Device (EOT)** is located on the last wagon in the train and is used to verify system continuity for both communications and air supply.

The **Head End Power Supply** is shown on the lead locomotive for the cable-based system. Cable-based ECP systems use a 230 VDC power supply with approximately 10 watts per wagon down the length of the ECP train-line. The head-end power supply is interlocked with the EOT.
and with the front locomotive cable connection for safety of operation. The cable-based ECP system uses continuous cable down the length of each wagon with an inter-wagon connector between each of them (Figure 4).

![End of Wagon Connectors, Inter-wagon Connector, Mated Inter-wagon Connectors](image)

**Figure 4: CECP End of Wagon and Inter-Wagon Connectors**

The radio-based systems require an onboard power supply on each rail vehicle. Developmental RECP systems used end-of-axle generators on each wagon. An air operated generator system (using train-line air) is proposed by one vendor for their newer generation RECP system. This proposal is awaiting submittal to the AAR Braking Systems Committee for consideration.

Locomotives used in distributed power service will be equipped with TLC equipment described earlier. TLC equipment will be used to control locomotives along the ITC network, as a replacement for the 27-pin MU cable.

**Developmental and Revenue Service Systems**

Since 1995, tests and commercial operation of ECP systems have occurred on at least three Class 1 and two short line railroads in the U.S., as well as on one railroad each in Canada, Australia, and South Africa. Early testing on U.S. roads with cable-based systems included the use of “overlay” ECP systems wherein the train wagons operate in either the ECP or the conventional mode. In most cases, the emergency control valve portions from the standard air brake system were maintained.

Canadian railroad Quebec-Cartier Mining implemented the first “stand-alone” or pure ECP system in North America. This captive system has been operating since April 1998 and much of the economic data gathered on ECP trains comes from the QCM system. QCM has accumulated approximately 94 million wagon kilometers (58 million wagon miles) of ECP operation to date.
BHP in northwestern Australia operated a developmental stand-alone Radio-based ECP train for some 18 months of service on a captive revenue iron-ore operation. Evaluation of that system has been completed and the equipment has been removed. Spoornet, South Africa, is operating the first AAR-compliant ECP overlay system and has accumulated some 26 million wagon kilometers (16 million wagon miles) of service to date.

FMECA ANALYSIS

At the end of the industry’s review of the cable-based specification, the U.S. Federal Railroad Administration (FRA) suggested that a Failure Modes Effects and Criticality Analysis (FMECA) be conducted for ECP specifications and equipment. As a result, an FMECA on the cable-based specification (S-4200) was completed in 1999. An FMECA is currently being conducted on the radio-based specification (S-4300).

ECP BRAKE SPECIFICATION DEVELOPMENT: STATUS

The purpose of the AAR specification development effort was to provide mandatory industry standards for the interchange of railroad equipment. With that in mind, the specifications are included in AAR Manual of Standards and Recommended Practices, Section E (Brakes and Brake Equipment), upon acceptance first by the AAR Brake Systems Committee (BSC), then by the appropriate technical and policy oversight committees. The cable-based ECP brake specifications were adopted in 2000 and are being revised with some technical changes. The radio-based specification will be submitted for adoption at the completion of the FMECA process and industry review.

CECP BRAKE STANDARDS

The cable-based ECP Specifications consist of the following documents:

- S-4200 – “Performance Requirement for ECP Cable-Based Freight Brake Systems”
- S-4210 – “Performance Specifications for ECP Brake System Cable, Connectors and Junction Boxes”
- S-4220 – “Performance Specification for ECP Brake DC (Head End) Power Supply”
- S-4230 – “Intra-Train Communication Specification”
• S-4240 – “Performance Requirement for ECP Trailing Locomotive Control” (under development)

RECP BRAKE STANDARDS

The Radio-Based ECP Specifications consist of the following documents:

• S-4300 – “Performance Requirement for ECP Radio-Based Freight Brake Systems”
• S-4310 – “Cable and Connector Environmental Requirements”
• S-4320 – “On-Wagon Power Environmental Requirements”
• S-4330 – “Intra-Train Communication Specification”
• S-4340 – “Radio and Antenna Performance”

ECP APPLICATION/IMPLEMENTATION PATHS AND ECONOMICS

Application of ECP systems is envisioned in three basic forms: overlay systems, emulator systems, and stand-alone systems. Early cable-based systems were applied as overlay systems with both original pneumatic and add on electronics and manifolds. These types of systems allow for either standard pneumatic or ECP braking operations but require redundant hardware.

Emulator systems provide the capability to operate in both standard pneumatic or in ECP brake mode. Emulator systems generally require some type of onboard power generation capability to operate. Both cable and radio based emulator valves are being tested.

Stand-alone systems only operate in ECP mode. At least one cable-based stand-alone ECP system is in operation in North America. Stand-alone systems can only be operated with like equipment and only by properly equipped locomotives.

A result of having multiple options is that a single implementation path is not clearly defined for all types of freight service in North America. Economic issues including the amount, type, and ownership of equipment, annual accrued mileage, and whether the fleet is captive or intended for interchange account for some of the variables that need to be considered.

Several implementation paths for ECP systems are possible including the use of overlay and emulator valves that can be passed down through the fleet as equipment is purchased to allow the wagons to operate in either ECP or standard pneumatic mode. The most aggressive approach is
to equip wagons with stand-alone systems. However, that type of system has yet to be approved by the FRA for use in the U.S.

The timing of implementation of an ECP system will be driven by the type of system chosen (cable or radio) as an interchange standard, as well as the economic analysis that determines if the benefits justify the capital investment.

Since specifications for two types of systems are being developed, it is foreseen that the marketplace will ultimately determine how and when implementation of ECP equipment will occur. The implementation of ECP brakes is seen as a long-term process. With approximately 1.6 million railcars in the U.S. and Canada, of which some 30 percent of the wagons accrue approximately 70 percent of the mileage, it is likely that high mileage unit-train and intermodal wagons will be equipped first. Other less utilized or special-purpose wagons are unlikely to be upgraded until sometime in the future. Another implementation factor is the fact that private companies rather than railroads own more than 60 percent of the wagons. This complicates the economic issues of who pays for the equipment versus who benefits from the use of the equipment.

Figure 5 demonstrates one potential economic payback scenario for unit-train service if ECP equipment is installed as a stand-alone system. Equipment suppliers with trains running in captive service suggest similar payback schedules. General service applications in North America are not as clearly defined.

![Figure 5: ECP Investment Recovery based on Stand-alone Unit-Train Installation](image)
QCM DATA

Quebec Cartier Mining Company has been operating a stand-alone cable-based ECP trainset since April 1998. Originally, the train had 156 wagon but due to the low air consumption of ECP brakes the train length was increased to approximately 175 wagons. QCM has also been able to eliminate the use of compressor wagons during winter months; again because of low air consumption and reduced valve leakage. QCM has been cooperating with TTCI and the New York Air Brake Co. (Knorr) by reporting operating data since the startup of ECP operations.

The QCM operation consists of iron ore trains operating over an 853-kilometer round trip. The loaded trains operate at about 21,000 metric tons. The railroad is relatively flat except for the last 97 kilometers, which is downgrade at 1.3 percent to Port Cartier, Quebec. The loaded trains negotiating this downgrade normally use dynamic braking and the graduated brake release feature of the ECP brake to control speed. The conventional trains make a medium air brake application and use the dynamic brake to control speed. Because of the faster response of ECP brakes, the ECP trains can normally run closer to the track speed limit and reduce the operating time on the downgrade segment by about five minutes.

Table 1 shows the test data collected through October 2000 comparing the ECP and conventional train operations.
Table 1. QCM Test Data

<table>
<thead>
<tr>
<th></th>
<th>ECP</th>
<th>Conv.</th>
<th>Change</th>
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<tbody>
<tr>
<td>Fuel Consumption (Liters/1,000 m. ton kms)</td>
<td>2.652</td>
<td>2.793</td>
<td>5.1 percent decrease</td>
</tr>
<tr>
<td>Undesired Emergency Brake Applications</td>
<td>0</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td>Kilometers per brake block</td>
<td>56,511</td>
<td>44,853</td>
<td>126 percent increase</td>
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Table 2 shows the enroute train delays per wagon/mile due to brake related problems. Cable disconnections while enroute virtually ceased when the wagon-to-wagon cable connectors were changed in September 1999 from a pre-specification design to the AAR standard design. Also, by mid-1999 the initial developmental problems of the ECP system had been corrected. The ECP system is now marginally more reliable than the conventional system it replaced. There should be further improvements when the current ECP engineering prototypes are replaced with production units in 2002.

Table 2. Train Delay Minutes per Wagon Mile

<table>
<thead>
<tr>
<th></th>
<th>April 1998 – September 1999</th>
<th>October 1999 – October 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECP</td>
<td>.172</td>
<td>.031</td>
</tr>
<tr>
<td>Conventional</td>
<td>.033</td>
<td></td>
</tr>
</tbody>
</table>

SUMMARY

The ECP brake program has progressed significantly since 1993. As a result of AAR, railroad, equipment owner, and supplier efforts, interchange specifications will be adopted for both cable- and radio-based systems. Ultimately, the economics of the North American rail industry and the continuing need for operational and safety efficiency improvements will be the driving forces behind implementation of new technologies and equipment.

With the completion of technical updates to the cable-based ECP specification, and the completion and expected adoption of the radio-based FMECA, it is likely that more ECP brake systems will be used in U.S. revenue service trains in the near future.
The migration from pneumatic brake systems to ECP brake systems offers revolutionary changes similar to that experienced in the late 1800’s to the operation of freight trains. Economics will again determine if this is a worthwhile technology for the rail industry.

Acknowledgements

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