ELECTRONICALLY CONTROLLED PNEUMATIC (ECP) BRAKES: MOVING THE INDUSTRY THROUGH THE 21ST CENTURY

RAILROAD SAFETY WHITE PAPER

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ACKNOWLEDGEMENTS

As before, the writer claims no specific technical expertise in railway braking systems. However, the writer engaged with the subject matter as a senior executive with the Federal Railroad Administration (FRA). Now long ago retired, my intent is to inform and, if possible, to persuade, in order to encourage industry acceptance and to advance public policy.

The writer is grateful for the comments and suggestions offered by several expert reviewers. Their insights have been important to the final product; but, as always, the writer is responsible for any errors or misunderstandings. Readers are invited to respond with corrections, criticisms, or suggestions. The writer will endeavor to incorporate or respond in any subsequent versions of this White Paper.

INTRODUCTION AND APOLOGIA

This series began with multiple versions of a White Paper titled "Management of In-Train Forces." The conclusions regarding the factors underlying the problem may have been controversial, but the theme was not. Likely the White Paper had minimal effect, but the consequences of the documented behavior seem to have resulted in rethinking operating practices, at least in some quarters. Scrutiny by the National Academy Committee on very long trains[1] may have prompted some internal discussion. FRA's advisories may be helping, as well. Best of all, there is evidence of real effort to build better trains among several of the major railroads.

The second White Paper in this series declared, first, that the data being reported to FRA on pedestrian/trespass casualties was wrong and could be readily corrected with some enforcement action. At last report, the agency was not responding coherently to the critique. The second point in that White Paper was that safety at private crossings was still unacceptable, and that there were actions that could be taken to address the subject. At this date, nobody seems to have noticed, despite distribution on line and among members and friends of the relevant Transportation Research Board committees. There is scant comfort that nobody has stepped forward to suggest that the two points made in this second White Paper were ill founded.

ECP brakes are a different kettle of fish. This topic is well worn, and most folks, including major railroads, had thought it was a dead issue.

Consider that I speak for the dearly departed (ECP), and pray for a resurrection. I recognize the difficulty of my task.

There is no pretense here that the presentation will be dispositive, but we need to keep ECP in play for the future of the industry and the nations of North America. It is encouraging that FRA has tasked the Railroad Safety Advisory Committee (RSAC) with exploring "Train Brake Modernization," albeit with a heavy focus on trains carrying hazardous materials. One must be anxious that such an approach will run aground like the "high hazard" train rulemaking did during the previous Administrations. Putting a few ECP trains on the railroad amid overlong and underpowered conventional trains will not make the network more fluid. Limiting ECP brakes to trains of certain lengths, or trains employing distributed power, would not be feasible given the requirements for interoperability. There needs to be a broader commitment.

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[1] Information on this effort is available at https://www.nationalacademies.org/our-work/impacts-of-trains-longer-than-7500-feet.

BENEFITS OF ECP BRAKES

Technical Benefits

Much of the case for ECP brakes was initially described in a report commissioned by the FRA Office of Safety and developed with the help of an expert industry panel. This excellent "Booz Allen Hamilton report" remains available on FRA's web site.[2] The basic architecture and functions of ECP brakes were also described in the White Paper on "Management of In-Train Forces." The recent FIRST ADDENDUM to that paper bemoaned the prevailing lack of attention to the future of the technology, while calling out additional derailments that might have been prevented with its use.[3]

A closer look from a more contemporary perspective seems to be warranted. First, a brief on the essentials.

Conventional train air brakes depend on changes in air pressure, transmitted through a trainlined brake pipe at less than the speed of sound, to apply and release brakes. ECP brakes respond to electronic signal sent through the ECP train line, almost immediately, to command the application or release of the brakes. The following table compares and contrasts the two systems:

Attribute	Conventional	ECP	Comment
Charge pneumatic system	Brake pipe and reservoirs on each car are charged from the lead locomotive and one or more DPUs.		ECP brakes allow for continuous charging of the train air line; cannot inadvertently deplete brake pipe and lose control.
Service application	Reduction in brake pipe pressure signals valves on each car, progressively.	Electronic command to valves on each car, simultaneously.	Permits stopping distances 40-60% shorter for ECP trains; reduced in-train force from run-ins means fewer "train handling" derailments.

2 https://railroads.dot.gov/elibrary/ecp-brake-system-freight-services

3 White Paper version 3.0 and a First Addendum are available at https://www.railwayage.com/?s=cothen+white+paper. After its publication, a vendor has pointed out that derailments due to excessive slack from end of car cushioning might be addressed with new non-hydraulic cushioning units that are presently in field test following initial validation on the test track. Certainly, those efforts should be advanced to meet immediate needs. *See* "Managing Slack in Trains," *Railway Track and Structures* (Sept. 2023).

Attribute	Conventional	ECP	Comment
Brake release and brake application	Direct (all or nothing).	Graduated (can reduce or apply braking incrementally), with near instantaneous response at each car. ECP allows continuous adjustment of braking effort without exhausting air supply.	ECP reduces wheel wear and fuel use associated with "power braking" that may be required to control speed and in-train forces in certain terrain. Engineer can apply exactly the amount of braking desired at any given time and for any grade or train condition.
Emergency application, commanded	Venting of brake pipe to atmosphere from lead locomotive, EOTD, and DPUs if so equipped.	Electronic command to valves on each car, simultaneously.	Stopping distance reduced by approx. 10% with ECP, and with no risk of run-in leading to derailment. ECP provides confidence to use full service or emergency application to mitigate obstruction accidents without fear of derailment.
Emergency application due to train separation (e.g., pull apart or derailment)	Break in train line vents system to atmosphere, (which is repeated along the train line by other cars).	Same as conventional, but in addition break in ECP electronic continuity automatically calls for immediate application on each car.	There is uncertainty here regarding the marginal benefit of ECP in this scenario,[4] but remaining energy will be reduced, which may mitigate derailment consequences.

[4] LETTER REPORT ON A REVIEW OF THE DEPARTMENT OF TRANSPORTATION TESTING AND ANALYSIS RESULTS FOR ELECTRONICALLY CONTROLLED PNEUMATIC BRAKES, Phase 2, TRB (National Academy), Sept. 2017.

Attribute	Conventional	ECP	Comment
Undesired emergency application due to valve malfunction	A single defective "kicker" or "dynamiter" valve can produce an emergency application without warning. Less common than previously, but still a problem. Industry research continues.[5]	Not expected.	Depending on the circumstances, UDEs can result in derailments from in-train forces. Recovery from any undesired emergency (UDE) is an exhaustive process, requiring at attempt at identification and isolation of the car causing the event.
Function with EOTD[6] when brake pipe is obstructed	Requires continuous radio telemetry or rendered useless.	ECP system does not depend on EOTD or the air line to apply brakes from rear. (A termination unit is applied that may also carry the required rear end marker.)	ECP will prevent run-away train events.
Function with DPUs	If data radio communication fails, DPUs will initially continue to provide tractive effort or brake as previously instructed, but after a set (previously programmed) time or upon receipt of a service brake application from the head end, will go to idle.	ECP train line provides a secure and timely means of communication with DPUs, ensuring prompt response to commands for throttle adjustment and use of dynamic brakes. No reliance on radio telemetry or potentially ambiguous changes in brake pipe pressure.	ECP significantly improves management of in-train forces in many scenarios, reducing derailment risk from buff and slack in the train. Continuity of communication adds assured timeliness in addressing individual DPU consists in the train. May reduce need for repeaters.

[5] *See*, e.g., Cummings, S., and Keylin, A., "Train Handling Prior to Undesired Emergency Brake Applications in Warm Weather" (TTCI TD-16-019, June 2016).

[6] Two-way end-of-train telemetry device, as required by FRA on most freight trains. 49 CFR part 232, subpart E.

Attribute	Conventional	ECP	Comment
Cold weather performance (higher leakage conditions)	Brake pipe cannot be charged while the brakes are applied.	Continuous charging while brakes are applied and in lap. Maintains brake pipe pressure without excessive flow and quickly restores individual car reservoirs. Train stopped on grade less likely to move, since car reservoirs will continue to be charged, offsetting leakage.	ECP permits use of longer trains (or segments between power consists) during cold weather. Continuous charging could reduce the risk of loss of braking effort without the ability to recover.
Monitor system state	The engineer can see the pressure at the head end, the air flow rate (compensating for leakage) and, with the EOTD in communication, the pressure at the rear.	In addition to the information available for conventional brakes, the engineer can determine the state of each brake valve and reservoir in the train.	Optimal use of energy management systems in automatic mode will require a valid information flow from the train air brakes. ECP would provide the current information required.

The unique attributes of ECP technology appear to offer many advantages in the interest of safety, reliability, train speed, and system capacity. These are not the product of a bureaucrat's fantasy (the writer being the bureaucrat), but were widely touted by industry technologists who participated in the system's development. As we discuss below, the system must work in the field, as designed, for benefits to be realized.

No doubt there have been issues related to reliability in the initial applications domestically. However, ECP brakes are used in several services internationally, and the air brake suppliers report that their customers are pleased.[7] The benefits promised by the architecture are manifold, and the notion that the technology should be allowed to just slip away would be wasteful.

Let it first be noted that railroads do not rely as much today on train air brakes. There is a good reason for that: today's extended range dynamic brakes can handle many of the territories on the railroad, with just the addition of the independent locomotive brake to come to a full stop. With distributed power locomotives (DPUs), long trains can be handled well in many of these territories without "touching the air."

There is another, not so good reason: conventional air brakes are a cause of many delays, wheel problems, and even derailments. Brakes can apply when they should not, stay applied when told

[7] Responses to questions posed by the National Academy committee on very long trains, July 13, 2023.

to release, and release without notice when it is intended that they stay applied.[8] Railroads and shippers spend hundreds of millions each year maintaining, testing, and inspecting these brakes annually. But engineers are allowed to use them only in limited situations where it is necessary to negotiate descending grades or keep the train stretched. Then they must be careful not to deplete the air line in situations where the dynamic brakes provide insufficient retarding force.[9]

Heavy reliance on dynamic braking would not end with ECP brakes, of course. However, the responsiveness and resilience of ECP brakes could significantly reduce train handling challenges in an industry that has reported many failures. ECP brakes would also offer better options for train handling where train make-up is marginal (avoidable at initial terminal, but difficult after industry switching and pick ups at interchange with other railroads). With proper training and supervision, engineers (or their energy management systems) would learn the beauty of graduated release and save fuel and wheel wear in territories where train brakes are a necessity.

Practical Benefits

What practical benefits should implementation of this technology yield? We can discern several distinct tiers of benefits, some of which flow to the railroads, some to customers, and others to society "as a whole."

1. Improved safety.
2. Platform flexibility.
3. Fewer operational problems resulting in delayed trains and shipments.
4. More reliable service as realized by existing shippers (resulting in efficiency and lower costs), promoting retention of business (for shippers not wholly captive to rail service).
5. More rail volume reclaimed or newly gained (most diverted from trucks) in carload and intermodal markets, resulting in a resumption of rail volume growth, with benefits to railroads, shippers, and the general public.

Let us admit at the outset that only a portion of these benefits would result from ECP brakes alone. As some Class I CEOs seem to be acknowledging, the days of artificially low operating ratios, issuance of cheap debt instruments, and arguably excessive payouts to Wall Street have run their course. Railroads need to get back to business with a view to the future. The nations of North America need them to do that. ECP brakes can play a role, but getting there will be painful. Let us save for the last a further complication.

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[8] The recent TSB report on a CP derailment at Partridge B.C. in 2019 provides an example of the extreme sensitivity of pneumatic brakes to variations in brake pipe pressure. Transportation Safety Board of Canada, Rail Transportation Safety Investigation Report R19V0002 (released July 19, 2023). Available at https://www.tsb.gc.ca/eng/rapports-reports/rail/2019/r19v0002/r19v0002.html .

[9] Dynamic brakes are increasing reliable, but locomotives are subject to unexpected loss of power and in this regard do not "fail safe." Train air brakes are required to be capable of bringing the train to a safe stop within speed limitations and signal spacing.

Safety

What safety benefits should the technology yield?

- **Shorter stopping distances**. There is ample evidence that ECP provides a 40-60% reduction in stopping distances with a full-service application. Perhaps more importantly, ECP brakes provide the confidence to employ emergency brakes when an impact or derailment seems certain, even when the train is stretched. There are lives to be saved with this functionality.

- **Mitigation of highway-rail crossing risk.**
  - Collisions between trains and heavy trucks, often with deadly consequences for truck occupants or railroad crew, are tragically frequent.[10] Some of these may be avoidable, but locomotive engineers are often left to choose between avoiding or mitigating a collision, on the one hand, or using dynamic or train brakes in such a way that the train derails, on the other.[11] ECP brakes would provide the confidence to bring the train to a stop, or at least reduce impact forces, without first bunching the consist and while employing an emergency application.

  - Collisions involving motor vehicles "stored" on crossings due to traffic congestion may be avoided or (more likely) mitigated in severity in the same way. *Train speed at impact is a major determinant of motor vehicle occupant injury severity.* Granted, in most cases "the train can't stop," but that does not mean some reduction in impact force is not possible in many situations, without endangering the larger community.

- **Reduction in other obstruction risks.** Derailments due to obstructions such as fallen rocks, mud slides, washouts, sun kinks, and fouling construction equipment present similar challenges. Even where significant preview is available for the train crew, a derailment may not be avoided; however, the seriousness of the event may be reduced. Note that derailments attributed to climate-related causes appear to be on the increase. Although deployment of sensors may be effective where feasible, all the tools in the tool kit will be needed to address this growing concern. Derailments at mis-aligned switches outside of Positive Train Control (PTC) territory may also be mitigated to some degree, particularly where the rate of approach to the switch is relatively moderate.

- **Reduction in derailments due to in-train forces.** As noted in the initial White Paper of this series, a significant number of derailments are caused by buff and draft forces that result in wheel climb, rail roll-over, and string-lining. Pull-aparts from broken draft gear will also result in derailments from the ensuing emergency brake application in some

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[10] See, e.g., https://939theeagle.com/highway-24-near-mid-missouris-madison-expected-to-reopen-wednesday/, NS derailment in Monroe County, MO, truck driver fatality, May 21, 2023.

[11] See, e.g., https://www.wdrb.com/glendale-train-derailment---3-16-2023---courtesy-jerry-lawson-3-png/image_37a50e8e-c437-11ed-a65e-c700a7c3984c.html, CSXT derailment at Glendale Kentucky, March 16, due to "successful" avoidance of truck hung up on crossing.

cases. Not every one of these events is necessarily avoidable with ECP brakes. However, a train handled with ECP brakes will be less susceptible to excessive in-train forces in many situations, reducing events caused by both train handling and less-than-optimal train builds. The initial White Paper and FIRST ADDENDUM call out several recent events where outcomes may have been different, including some in terminals.

- **Train line integrity.** Kinked train lines remain a threat to safe train operations when EOTDs are not in communication with the head end. This scenario resulted in a major collision with two crew member deaths at Granite Canyon, WY. The NTSB has noted that ECP brakes would have prevented this accident.[12]

- **Security.** Vandalism leading to a train separation may be detected by the train crew using existing procedures, but distraction may lead to error and loss of control over a divided consist, particularly with DPU consists operating under radio control.[13] ECP brakes reveal any loss of train line integrity and ensure against uncontrolled movement.

- **Improved management of extreme situations.** Cold weather operations and unexpected stalls or loss of control on heavy descending grades can challenge train crews with currently unmanageable situations. Crew members can temporarily address these challenges by applying the brakes in emergency and setting hand brakes, if they can act before air bleeds off. But those hand brakes will have to come off to avoid tread build up,[14] and there may be limited confidence that the train's situation has been stabilized. ECP brakes will provide a much better view of air brake system state than can be gleaned from the rudimentary information available with conventional brakes. Brakes can be modulated, charging is continuous, and reliance on the train air will dampen rather than exacerbate in-train forces. Even in the most extreme cases, ECP brakes also offer much improved odds that a running recovery of the air brakes will be successful in regaining control of the movement.[15] It is easy to say that these kinds of situations should not be allowed to develop, which is correct. But, thus far, they do.

  The Union Pacific derailment on Cima Hill, near Kelso, CA, on March 27, 2023, presents an interesting case. The run-away occurred following a train separation at the top of the extended grade. The train separation resulted in application of the emergency brakes, of course. However, the conductor is said to have closed the angle cock at the rear of the first section of train, having failed to set hand brakes. The result was air flow into the train line that began to kick off the brakes, car by car. The engineer evidently realized what had happened and exited the locomotive, evidently concluding that the dynamic brakes would not be sufficient to prevent a dangerous overspeed and derailment. There

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[12] Collision of Union Pacific Railroad Train MGRCY04 on October 4, 2018 (NTSB/RAR-20/05), available at https://www.ntsb.gov/investigations/Pages/RRD19FR001.aspx.
[13] *See*, e.g., FRA HQ-2020-1401 BNSF Railway derailment, Custer, WA, Dec. 22, 2020 (resulting in derailment, fire, evacuation, and loss of crude oil).
[14] As in the case of the now very familiar CSX derailment at Hyndman, PA, on Aug. 2, 2017.
[15] See, e.g., Transportation Safety Board of Canada, RAIL TRANSPORTATION SAFETY INVESTIGATION REPORT R19C0015, UNCONTROLLED MOVEMENT OF ROLLING STOCK AND MAIN-TRACK TRAIN DERAILMENT, Canadian Pacific Railway Company Freight train 301-349, Yoho, British Columbia, Feb. 4, 2019.

> would have been little chance of recharging the brake line and re-applying the brakes in time. The result was a spectacular derailment at over 100 mph (UP admits to just 60), with the derailment scene appearing more like a bomb crater. https://www.8newsnow.com/news/local-news/train-derails-southeast-of-baker-hazmat-crews-respond/ The railroad reported damages to equipment and track of $3.9 million (exclusive, as always, of wreck clearance, loss of lading, and expenses due to train delays and re-routings). Thankfully, the site was away from the parallel interstate highway and all development. As the writer understands the functioning of ECP brakes, even the conductor's compounding mistakes (if that is what occurred) would not have resulted in the brakes releasing in the first instance.

So confident were the major railroads that ECP brakes would make a major difference for safety and efficiency, they mandated the use of ECP brakes on trains carrying spent nuclear fuel and other high-level nuclear waste in 2003.[16] The Association of American Railroads (AAR) standard explained:

> This will improve stopping distances, possibly preventing some grade crossing accidents….An ECP system will….accommodate transmitting vital safety related information back to the locomotive or passenger car real-time. Examples include brake pressure, roller bearing temperature, and vibration level. These data should allow the train crew to stop in the event of equipment failure, preventing a derailment.[17]

The current version of the AAR Standard is dated 2017, and the ECP brake requirement was removed at that time, evidently due to the controversy over High-Hazard Flammable Unit Trains.

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[16] AAR Manual of Standards and Recommended Practices, Car Construction Fundamentals and Details, Standard S-2043, Performance Specification for Trains Used to Carry High-Level Radioactive Material (Effective: May 1, 2003).
[17] Id. at 13.

MORE TO COME

Robert Lauby, who started his railroad career as an engineer with a major air brake company, worked as a freight railroad mechanical officer, led rail accident investigations for the National Transportation Safety Board, and served as FRA's Chief Safety Officer, among other postings, offered these forward-looking insights:

"ECP Brakes provide improved stopping distance solely by applying the brakes faster. The 40-60% reduction in service brake stopping distance that ECP brakes currently provide is a powerful safety benefit but is only the tip of the iceberg. One of the inherent problems with conventional brakes is that there are many inaccuracies in setting up the resulting brake cylinder pressure on each car. For example, at a minimum, the BC [brake cylinder] pressure depends on the brake pipe pressure at the car's location in the train, the condition of the brake valve, and the ambient temperature or weather conditions. The braking ratio used in freight cars is very low because of the inaccuracies of the pneumatic control system and the need to prevent wheel slides on the worst actors in the tolerance band.

"Once you have a consistent and reliable brake cylinder pressure - which ECP can provide - you can ask for better performance and higher brake rates out of the existing system. Transit specifications for steel wheel on steel rail light rail vehicles typically ask for service rates of 3.0 to 3.5 ph/s. These rail cars have anti slide systems but there is still room for improvement between freight train deceleration rates and transit deceleration rates. [A]nd some form of rudimentary slide protection may be possible once you have power on each freight car.

"I think that stopping distance could be further improved on an ECP train with little chance of sliding wheels. Stopping distance with an emergency application could also be markedly improved, consistent with the ability of the track structure to withstand the longitudinal forces. And, of course, better stopping distance enables capacity improvements through less train separation or higher train speeds. Better stopping distance also allows you to optimize virtual block operation."

Platform Flexibility

One cannot build anything else on the train air brake system of today. The only innovation in this regard was tapping the train air line for an air flow generator that powers end-of-train device batteries (initially implemented under waivers approved by the writer). The system has reached its limits.

As noted in the AAR quotation, above, the ECP train line, by contrast, provides a platform for a wide range of potential applications. It carries both energy and information.

ECP train lines can transmit safety-related data to the head end, and the “add-ons” considered practical are extensive.

- Manufacturers report the following sensors in use today:
  - Handbrake status (preventing wheel flats and rail wear)
  - Empty/load
  - Hatch/door status
- The East Palestine accident sparked discussions regarding bearing sensors (which could be acoustic, vibration or thermal).
- Work has been done on devices that might apply and release hand brakes using power initially provided over the ECP train line, saving scores of injuries to ground personnel and lots of time assembling trains. This approach could be applied to introduction of parking brakes, which is backed by a recommendation from the Canada’s Transportation Safety Board,[18] yielding many benefits for safety and efficiency.
- Vibration sensors and accelerometers could be used to detect derailed axles or truck hunting.

A variety of other sensors might be integrated with ECP, both for safety and business reasons. Enormous amounts of effort are being expended or planned to apply GPS tracking devices and specialized sensors on refrigerator cars, tank cars carrying heat or pressure sensitive commodities, and other cars carrying high value freight. Information will be sent back to the shipper via cell data networks, where available.[19] Much of that could be avoided by placing sensors on the cars and tying them into the ECP train line, with message sets that would be read at the controlling locomotive and forwarded through Railinc channels to the shipper (on a periodic or exception basis). Knowing where shipments are would not depend on cell coverage, since ECP knows what cars are in train and on-board PTC knows where the train is at any given time (even outside of PTC territory). This would not solve every problem, but in rail logistics simplification carries a high value.

Operational Efficiency

Railroads may scale back their use of very long trains for mixed freight service due to the difficulties associated with achieving proper train placement, handling long trains in certain territories, and dealing with communities affected by block crossings during switching that requires use of main tracks or when trains stall or break apart in populated areas. However, very long trains will remain a fixture for single commodity service (unit trains) in many corridors. Moving bulk commodities in long unit trains, augmented by distributed power locomotives, will continue to make sense in many contexts.

Major railroads report emerging success in maintaining DPU communications through use of new technology that uses relays within the train with help from the wayside PTC data radio network. This works optimally, of course, only where PTC is installed on the wayside; and much

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[18] https://www.tsb.gc.ca/eng/recommandations-recommendations/rail/2022/rec-r2202.html.

[19] *See*, e.g., Vantuono, W., “Telematics: Tell-All Tracking” (Railway Age May 2023). Vantuono quotes a research firm to the effect that “the global railway telematics market is projected to exceed $13 billion by 2033,” with the U.S. market representing a 18.5% market share (U.S. 2023 revenue estimated at $1.2 billion).

of the rail network (~45% by route mile) still lacks that capability. The ECP train line can command DPUs authoritatively and will promptly recognize any discontinuity in control to the rear of the train. The control system will work much more reliably, providing the potential for further refinements in control of in-train forces and avoidance of inefficient train braking in undulating territory.

Existing air brake technology is greatly advanced in its sophistication. However, it is still based on the use of pneumatic signals that must be distinguished from noise, as well as sensitive valves that may not see a single car test for several years. Longer train lines (between locomotive consists) mean more leakage and less reliability. There are no data available from the railroads regarding the resulting pull-aparts and undesired emergency brake applications, but there is ample reporting from the field of broken knuckles, replacement knuckles placed at field locations in anticipation of trouble, and persistent issues with dynamiters to know there are very substantial costs involved.[20] Rail service needs to be reliable if it is to be relied upon. Costs are not reduced by re-crews and the need to dispatch mechanical forces to diagnose train line problems. More reliable braking systems that have performance characteristics more transparent to locomotive engineers and on-board energy management systems are *part of the solution*. Taken with other reasonable steps, ECP brakes fulfill those requirements.

ECP fits with other electronic systems.[21] Because the ECP train line verifies consist integrity, there would be no reason to continue the decade-long research effort designed to determine end-of-train location in PTC. ECP knows that the train is intact, what cars are in the train, and therefore where the end of the train is. With this information secured, PTC 2.0 (moving block) is one step closer to reality. And, indeed, the greater confidence provided with respect to the PTC braking algorithm for the specific train (not the biggest on the railroad) will facilitate elegant routing at the tactical level.

Quality of Service

As evidenced in the dockets of the Surface Transportation Board, in recent years many rail shippers have been very unhappy with the quality of service that they have been receiving. In fact, in some cases shipments have been embargoed. Poor service leads to retention of larger inventories, at a cost to shippers and their customers. Factories and refineries may have to pause operations with parts or feedstocks are not delivered on time. The productive energy of their workers is lost. Supply chain disruptions can ripple through the system creating more inefficiencies. This is economic waste, and the mechanisms for transferring this cost to the railroads are broken.

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[20] FRA now proposes to collect better data on train size and performance (88 FR 47233; July 21, 2023). This information collection would gather useful information, but not by any means all the data needed to evaluate the drag on industry performance presented by current air brake technology.

[21] *See* Ditmeyer, S., "Network-Centric Railway Operations Utilizing Intelligent Railway Systems," Journal of Transportation Law, Logistics, and Policy, Third Quarter 2010, Vol. 77, No. 3; Cothen, G., "Integration of Railway Electronic Systems to Achieve Safety and Efficiency," Proceedings of the 2012 Joint Rail Conference (JRC2012-74025).

Railroads do pay for damage to lading in transit, but thus far that seems not to have motivated better behavior on the part of some.

Over the last decade, railroads have suffered a decline in coal traffic, as the energy sector has shifted to natural gas and renewables. Since coal mines often sit at the periphery of the network and gross tonnages drive maintenance and capital requirements on those lines, the railroads can adjust to this change. Putting aside coal, though, the railroads have not managed to grow their volumes over the past decade, while truck tonnage has grown by a quarter.

ECP brakes are, arguably, a necessary *part of the solution*. Greater reliability over the line of road translates into more system fluidity, holding down cost, and on-time delivery—which is what rail customers want.

Optimizing the Modal Choice

The nations of North America need freight rail in the mix. Railroads play a critical role in transporting bulk commodities and specialty shipments, particularly over long distances. Rail can play a key role in intermodal transportation, moving boxes from ports and loading docks to inland terminals where they are dispersed via drayage. Short line and regional railroads continue to demonstrate that rail carload traffic is a valued option for many shippers.

The writer appreciates the difficulty of drawing a straight line between ECP brakes, quality of service, and specific effects on choice of mode. Nevertheless, any gain (or retention) of rail market share will yield enormous public benefits in the form of highway safety, reduced freight impacts on public infrastructure, and congestion that affects both truck transportation and time demands on working people.

For instance, "in 2021 there were 5,788 people killed and an estimated 154,993 people injured in traffic crashes involving large trucks. An estimated 523,796 large trucks were involved in police-reported traffic crashes nationwide during 2021."[22] Consider the potential savings to the public associated with diversion of just 5 or 10% of this traffic to the rail system. Unfortunately, over the past decade railroads have been ceding market share to trucks.

Estimating the Monetary Value of Total Benefits

Should it be necessary for FRA to mandate the implementation of ECP brakes, more than one industry economist will have to be assigned to the project. Technical help will be solicited from a variety of sources within the Federal government. Railroads will be requested to provide data regarding the current disbenefits associated with existing pneumatic brakes, and they will likely demur—leaving FRA to estimate, following which the estimates will be challenged. Projections will be required with respect to impacts on a variety of industries and sectors of better service and rail market share gains (with rippling effects of a positive nature for our roads, highways, and those who use and pay to maintain them).

[22] *Traffic Safety Facts, Large Trucks*, National Highway Traffic Safety Administration (DOT HS 813 452 June 2023 (Revised)), available at https://crashstats.nhtsa.dot.gov/#!/ .

Very fortunately, the writer is retired. This modest paper endeavors to call out the types of benefits that should be available. We do not pretend to quantify the benefits, but it seems clear that, *order of magnitude*, the benefits over 20 or more years[23] to the national economy here in the U.S. should easily exceed the costs. There are two problems. First, the benefits will not come early, and particularly so if the railroads do not find ways to accelerate the process. Second, many of the benefits will redound to the benefit of the public (as further discussed below).

COSTS OF IMPLEMENTATION

There are three principal categories of costs associated with a transition to ECP brakes. The first category will include any additional re-engineering of the applied technology to reduce causes of disruption claimed by the railroads—principally connector failure, crosstalk, and battery problems. The air brake suppliers have reported to the National Academy Committee on very long trains that these problems have been addressed in international service, apparently since the last ECP revenue demonstration train was removed from service by BNSF in 2018.[24]

Although ECP brakes are not used in freight service domestically, the air brake manufacturers reported to the RSAC working group on advanced braking technologies that international use continues, with the technology operational on about 2,300 locomotives and 43,000 cars. The manufacturers also briefed RSAC participants on improvements in ECP technology since 2018, contributing to better reliability and increased capabilities.

Resolving any remaining interoperability issues between the two major suppliers will also be required, or railroads will have to rely on a single vendor (which would have its own consequences with the respect to lost competition). The writer has no information on the status of that effort.

The second set of costs will pertain to managing both cars that are equipped and those not yet equipped, particularly for mixed freight service. For the transition period, dual equipping of most of the fleet, by "overlay," will likely be a practical necessity. This will result in early reliance on the older technology as a default, delaying recovery of investment in ECP brakes, but also provide a "backstop" if problems with a particular ECP train's equipment prevents its use until repairs can be accomplished.

The third set of costs is application and maintenance of the hardware. These costs will be also be higher during the period of transition, as locomotives and cars will have to be equipped with both conventional pneumatic and ECP equipment.

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[23] Executive branch regulatory evaluations normally use 20 years as the window for discounting costs and benefits. There would be a good case here for going out to 25 or more years, given the lengthy implementation phase.

[24] This reassurance was repeated in a joint presentation by the suppliers to an RSAC working group this month.

Emulation ECP

Advocates of ECP have posited that, during the fleet transition period, emulation ECP brakes might be employed. These ECP brakes would have the capability to operate as conventional brakes, without the additional pneumatic portion, in a conventional train. FRA's R&D office has described the technology in "Electronically Controlled Pneumatic Brake Device with Pneumatic Brake Emulation – Field Demonstration" (DOT/FRA/ORD-22/12 March 2022). Modified equipment from the supplies of a former ECP developer was subjected to limited field testing. FRA reported that the equipment responded properly in both the ECP and pneumatic modes.

This paper does not assume use of emulation technology because of the limited information available concerning the maturity of the technology and the readiness of current suppliers to provide it.

Appendix A to this paper details the costs discussed in previous economic analysis of the ECP technology. It should be noted that there has never been a benefit/cost study for application of ECP technology to the entire locomotive and rail car fleets. Previous discussions have centered around coal fleets (FRA 2006) and application to so-called high-hazard flammable unit trains. In the latter case, the industry contended that many more locomotives would have to be equipped, and many more employees would have to be trained, than estimated by the Pipeline and Hazardous Materials Safety Administration (PHMSA) and FRA. This is a distinctly different discussion.

So, who would pay?

Major railroads will bear the costs of applying the technology to their locomotives and carrier-owned cars, as well as ensuring the successful integration of the technology. They claim that barriers to cost-effective implementation of ECP brakes are insuperable, mirroring their dire predictions regarding the introduction of PTC. After being late out of the gate from 2008 to 2015 (at which point certain major freight and commuter railroads hoped the mandate would be repealed), railroads have now successfully deployed the interoperable PTC technology on a majority of their lines—which is to say, all those required. Further, BNSF Railway is continuing to cut over PTC on additional subdivisions, beyond what is required. PTC communications infrastructure is already being used to backstop head-end to DPU and EOT communication, fostering more confident operation of very long and heavy unit trains. PTC data flows are being employed to sharpen dispatching strategies and solve other problems. Major railroads claimed that the cost of PTC would result in diversion of capital funds needed for other purposes. Apparently, that turned out not to be the case, given the generous payouts to investors over the period.

This is not to say that the transition will be easy. Like PTC, ECP brakes rely on software; and software is subject to periodic updating, with revision control constituting a practical challenge in the field. We suspect that, if automobile manufacturers can do it, railroads can as well.

Private fleet owners, generally consisting of lessors and shippers, will bear the cost of equipping their own freight cars. They own about two-thirds of the freight car fleet. With respect to new car construction, it appears ECP brakes, as overlay, may add about seven percent (7%) to the cost. However, as "fleet saturation" is achieved, those cars will no longer have to be equipped with conventional pneumatic valves. Further, if improved cycle times are realized, as should be the case given reduced field inspection requirements, fewer cars will be required to carry the same amount of product.

Short line and regional railroads will bear the burden to equip their locomotives and cars. These Class II and III railroads originate or terminate about a quarter of rail traffic, and a larger share of carload traffic. Their older locomotives may be more difficult to equip. In some cases, they own more freight cars than they require for their business as carriers (making them effectively private car owners).

Providing sufficient time for the fleet transition should avoid disruptions in availability of locomotives and cars. In the wake of "Precision Scheduled Railroading" (PSR), several hundred thousand cars are in storage and several thousand locomotives, as well. These assets need to be exercised in any event. The regulator should be able to provide targeted relief if "pinch points" arise in specific traffic categories.

SOURCES OF FUNDING

As noted, the principal entities affected by a mandate would be Class I railroads, fleet owners (lessors, shippers), and Class II/III railroads. Class I railroads have been extremely profitable for the past two decades and have returned huge amounts of cash to their shareholders in the form of dividends and stock buy-backs. Still, they claim that their reinvestment in the enterprise has been robust (a claim subject to some skepticism from some outside observers, but nevertheless their claim).

Appendix B details the cash distributions of the six surviving Class I freight railroads over the past 10 years, consisting of stock dividends and stock buy-backs. They aggregate to over $200 billion, or an average of $20 billion per year. The rate of payouts has increased during the so-called PSR era, with the average for 2018-2022 coming in at about $25 billion per year for the group.

Let us admit that the sums reported in the Appendix may not in every case fairly reflect the long-term profitability of the enterprise. Costs were cut sharply during much of period, with ensuing attempts to recover staffing almost immediately following. In some cases, long-term debt was accumulated, seemingly coincident with cash going out to investors in stock buy-backs. The writer has encouraged public authorities to conduct serious financial analysis regarding the effects of these practices and the forecast for the industry health going forward. Still, this is how the industry has presented itself to Wall Street, and many dedicated capitalists have reassured us that all is well.

From this experience, there would seem to be no reason why Class I railroads could not, as a group, afford $700-800 million annually for a bit more than a decade to implement ECP brakes, even while otherwise increasing their rate of reinvestment in the existing enterprise. There is no reason to expect a single railroad to proceed unilaterally, of course. (See discussion of market failures, below.) *We say we place the highest value on safety, and this is a good opportunity to show it, as an industry.*

Fleet owners consist of lessors (that are often car builders, as well) and shippers. ECP brakes would add about 7% to the initial cost of a freight car (less after fleet saturation). Freight cars can last up to 50 years. Much more onerous requirements (e.g., tank car crashworthiness costs) tend to be met with a shrug in this market. Shippers ultimately bear the costs, and they may be passed on to customers in increments not likely to be noticed. Indeed, over the longer term those costs may be handsomely offset by the consequences of more reliable and efficient rail service.

Class II and III railroads make up a heterogeneous group. Many are part of large corporate families with significant borrowing capability, while others are very modest operations that may even be locally owned. There would seem to be no reason why, in the interest of keeping as much traffic on the railroads as reasonably possible, USDOT and FRA would not employ their substantial loan and grant programs to assist smaller railroads in the transition. These railroads, acting through the American Short Line and Regional Railroad Association, have also claimed substantial tax credits (~$5B to date) for physical improvements to their properties. Similar relief might be arranged for the ECP transition, given the public benefits involved.

MARKET FAILURE

The Office of Management and Budget, ever vigilant to ensure that regulations are cost effective, will want to know why, if this is such a fine idea, the private market is not pursuing it without the need for regulatory intervention. The first answer to that is, well, they were. Major railroads and suppliers spent significant effort to develop the technology and demonstrate its utility. They importuned the regulator (which in this case was highly receptive) to get relief from regulatory burdens, considering the superior safety characteristics of ECP brakes.

After commissioning a safety analysis of the technology, FRA granted substantial relief from existing power brake regulations for ECP trains. Waivers were followed by a proposed and final rule, and still more waivers.[25]

So, what happened? The major railroads report that they tried, but the expected benefits did not appear. Indeed, the technology was really glitchy. “Couldn’t depend on it.” There is no argument here about the architecture, really, just the implementation.

There are those who watched this closely and have a slightly different take. Several railroads did launch ECP revenue demonstrations (no, they were not “test trains”) with the best of intentions. A major power company (shipper, fleet owner) participated.

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[25] See, e.g., 73 FR 61612 (Oct. 16, 2008), 49 CFR part 232, subpart G.

It may be that some railroads soured on trouble-shooting ECP brakes when the 2008 PTC mandate came along. Technologists can only sell so much to the "C suite" at any given time, and PTC was certainly a substantial lift. It is also undoubtedly true that ECP technology, as implemented in the field, presented major challenges.

Most critically, the return-on-investment period was very likely to be extended beyond the tenure of the CEOs and CFOs presented with the decisions. Wall Street was looking for cash, and anything that might interfere with good dividends and (particularly) big stock repurchases was out of the question. It probably did not help that the initial market sector targeted for ECP, western coal, began to decline with the growing appreciation of the need to combat climate change.

One might have thought the so-called high-hazard flammable unit trains (HHFUTs) would have been a natural for ECP brakes. The advent of large-scale ethanol service and then Bakken Shale crude oil transportation began a long string of fiery derailments. PHMSA and FRA stepped up to the plate and demanded better tank cars and ECP brakes on certain trains. Car owners were going to have to retrofit or replace not only the old DOT 111's, but also the compromise AAR car (CPC-1232) which turned out, unsurprisingly, to be too fragile in a derailment, as well.

Requiring the fleet owners and shippers to pay for the fleet, with ECP as an overlay, should have been attractive to the railroads. But they found dozens of reasons to say no, including the ***vast number*** of locomotives they would have to equip and employees they would have to train to avoid dedicating locomotives and crews to the service. Well, guess what? By equipping just a few more locomotives and training a few more people, we could get ECP brakes on across the entire fleet.

It is always a risk to tell business people they should do something they do not want to do. But times change. If you listen carefully to the pronouncements of some newer CEOs in 2023, the great tide of Precision Scheduled Railroading, with its cult of the operating ratio, is now at least partly passé. The industry may be reeling from a decade during which their volumes were essentially static, despite robust growth in trucking and the national economy, even discounting the secular decline of coal traffic.[26]

Whether it was shipper complaints, lost market opportunities, congressional criticism, fear of renewed economic regulation, the bad press from East Palestine, or serious self-examination, there may be, over time, a broader recognition in the industry of the synergy between growing the market and a greater public good.

However, we would be naive just to wait for the light to dawn. Individual railroads cannot undertake a transition to ECP without feeling competitive pressures and without confidence that the rest of the industry will follow. Just one major North American railroad hanging back would be enough to kill progress. That is a market failure, brought on by the structure of the market.

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[26] *See* Bill Stephens' excellent summary entitled "Can railroads come back from a dismal decade?" (*Trains* August 2023).

Then there are the externalities. Public policy intervenes when costs external to the producer or consumer result from the conduct of business. Environmental regulations are an obvious example.

But the failure to deliver good service can affect the nation in many ways, as well. We do not have to imagine many of them, because the "Freight Rail Works" commercials are in our face all the time.[27] For traffic that belongs on the railroad, the benefits to the public in terms of reduced emissions, fewer traffic delays and accidents on the roadway, and a generally more vital economy driven by efficiency are real. But these very real benefits redound mostly to the benefit of the public at large, not railroad shareholders. Shareholders are happy if the profits are shared generously with them, and the fact that more burdens are placed on public highways and more emissions are generated by growing truck traffic is not their problem.

The urgency of addressing climate change is with us daily. There is no reason to expect shareholders (in their capacity as shareholders) to bend over backwards to advance these purposes. Yet, when the railroad is not serving the customer effectively, the public suffers. That is a classic market failure.

There are even market failures on the safety side. Private individuals and small businesses likely suffer significant economic harm when they or their family members or employees are involved in grade crossing accidents. Although on occasion juries make outrageously large rewards in tort actions involving the railroads, most of those are subject to adjustment on or prior to appeal. In many other cases, no action is brought because the law assigns full responsibility to the motorist or pedestrian whose negligence contributes to the injury. Railroads would get little benefit in this regard from avoiding or mitigating collisions, but the public would.

One can look at the East Palestine situation[28] and see that the very publicly visible nature of the injury has prompted major promises of financial recompense from the railroad, accompanied by significant initial outlays,[29] tremendous support to the community from public agencies and private donors, and lavish attention by elected officials. Class action lawyers have smelled the vinyl chloride and descended *en masse*. However, <u>that is the outlier</u>. In most cases railroads do provide mitigation of damage and compensation to emergency response agencies and property owners directly affected by significant derailments. But many others, impacted by significant restrictions on mobility, loss of business and other indirect costs, may be forced to bear those costs on their own. Citizens who cannot get to work or school because a train has stalled out from leaking air brakes and blocked every crossing in town have no effective recourse, and even if they did the economy would have suffered pure economic waste. Once again, here is a market failure indicating the need for public policy intervention.

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[27] As a complete aside, we are very grateful for the public information campaign, which tells a true story. Many of my colleagues had advocated for a more aggressive industry posture for many years.

[28] There is no claim here that ECP brakes were necessary to prevent the East Palestine derailment. There is time for talk later about any mitigation of severity or the ability of the ECP train line to carry sensor information, should bearings have been equipped.

[29] As of the end of the August 2023, NS had announced charges exceeding $800 million for the accident.

Railroads will bear a substantial part of the costs for ECP brakes, and the promise of market growth and safety benefits may seem distant to current top executives. Indeed, as the railroads have demonstrated in the past 7 or 8 years, it is possible to create the service conditions under which market growth will not occur and safety knowledge long ago acquired is not put to good use (e.g., building trains properly, assigning adequate power, helping employees get ready for change).

Public policy, however, must proceed on the assumption of future success, looking to the best interest of the nations of North American as a whole. We need to trust that railroads will recover from their recent infatuation with cutting costs, and in fact during 2022 and early 2023 there has been more and more talk about doing just that. That will still not eliminate the market failures associated with the failure to move forward with ECP brakes. More than a nudge will likely be needed in this case.

CONCLUSION

Reasonable minds can differ with respect to the implementation of ECP brakes across the North American rail network, given the costs and logistical challenges. However, without question successful implementation would put to bed many of the limitations of current train braking technology and provide a platform for additional advances in efficiency and safety. Railroads could show good faith in this regard by applying ECP brakes, initially on an overlay basis, to intermodal trains—and provide these trains the priority on the railroad that they need to compete. Success with this portion of the fleet would provide confidence to move forward with a broader implementation. If the railroads do not show leadership, the regulator will need to act.[30] Very possibly, given the retrograde nature of current administrative law, FRA will need explicit legislative direction to make a mandate stick, notwithstanding the agency's clear statutory authority over "every area of railroad safety" (49 U.S.C. § 20103).

BUT, WAIT…

Nothing would please the writer more than ending the production of White Papers with this stretch piece and feeling that the duty was discharged. However, there remains a topic that is even more urgent and, alas, more obvious than those thus far addressed. Our public authorities need to address, yesterday, the forthcoming crisis in climate policy now being previewed in (where else) California regarding the source of motive power for the railroads' future.

For now, let us just skip to the bottom line and note that major rail lines will need to be electrified soon, perhaps supplemented by use of hydrogen fuel cells (or H_2 as an internal combustion fuel), with battery tenders in the mix as required, ending centuries of reliance on fossil fuel. The railroads note with justifiable pride the fact that they are more energy efficient

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[30] Transport Canada, as well as officials in Mexico, will need to be part of the discussion to ensure harmonization. However, the fact that AAR Interchange Rules already effectively govern the technical aspects of freight service across all of North America ensures an available path to interoperability.

than their truck competitors, and that is accompanied by lesser emissions of greenhouse gases. They are, of course, working on ways to make the situation better, but in the meantime, they are buying no new locomotives. Even the locomotives they are rebuilding will emit carbon dioxide, nitrous oxides, and diesel particulates in significant quantities for decades to come. When the competition has gone electric, the contrast will be stark.

The subject deserves proper treatment, ideally by the Department of Energy and Department of Transportation, in consultation with the Environmental Protection Agency and others. Barring that, somebody will have to try to spark interest in the public policy aspects of the transition, a topic that is dominated, as before, by market failures and transportation externalities. The Federal agencies are conducting research on aspects of this problem, but no coherent policy strategy appears to have emerged.

In the meantime, technically innocent readers like this writer can check out Michael Iden's excellent articles in *Railway Age*, which describe a path forward for the candidate technologies.[31]

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[31] Iden, Michael, "Follow the Megawatt-Hours: Hydrogen Fuel Cells, Batteries and Electric Propulsion" (*Railway Age* March 2023 at 41); and "Mind the (Hydrogen) Gaps" (*Railway Age* July 2023 at 30). *Railway Age* digital editions are available without charge at https://www.railwayage.com/digital-edition/

APPENDIX A—COST DETAILS

ECP BRAKES COSTS -- SYSTEM-WIDE IMPLEMENTATION
TIME PERIOD -- NOT MORE THAN 12 YEARS FOLLOWING EFFECTIVE DATE

ASSUMPTIONS:

> All cars and locomotives are dual equipped until fleet or sub-fleet saturation, after which conventional equipment is removed

> Most equipping of locomotives is retrofit or at rebuild, in either case at a time mechanical attention or annual inspection is otherwise required

> Most controlling and distributed power locomotives will be equipped in the first 4-6 years, allowing flexibility in handling unit train service; non-equipped head-end locomotives can be bypassed by cables at railroad's election

>As confidence builds, railroads will equip carrier-owned intermodal cars (including TTX cars), carrier-owned coal and grain cars, accelerating the realization of benefits

> New cars will be dual equipped until fleet or sub-fleet saturation, after which pneumatic valves will be discontinued

> Existing cars will be equipped when in the shop for wheel replacement or other major work

> Work trains may be excluded from mandatory equipping

> Class III railroads (other than switching/terminal RRs) may retain conventional brakes for local service if they find it in their interest to do so

> Passenger, historic and excursion railroads excluded

COST ELEMENT	UNITS	PER UNIT	ITEM TOTAL	SUBTOTAL	SOURCE	NOTES
RAILROAD COSTS						
Locomotive, equip	26,000	$ 88,300	$ 2,295,800,000		Unit cost from Oliver Wyman, Note 1 below	Unit cost is likely excessive for all but the oldest locomotives.
Freight car, equip	539,151	$ 9,655	$ 5,205,502,905		Ditto for cost. Railroad share of fleet assumed to include TTX at about 33% of total	The Oliver Wyman estimate was for tank cars and buffer cars and considerably higher than the earlier USDOT estimate. Average new rail car cost is around $130,000, so ECP would add about 7% to the cost of the car until fleet saturation.
Training, locomotive engineers	31,000	$ 5,848	$ 181,288,000		Populations estimated based on dual qualifications for about half of the employees; cost from Oliver Wyman (80 x $73.10)	In March of 2023, Class I railroads employed about 51,000 T&E employees. Class II and III railroads employed about 17,000 employees total, and we have assumed that about 11,000 of these require qualifications as engineers or conductors. No increase in wage rates has been taken for recent agreements; however, Class II/III employee training has been charged at the same rates as Class I, which is conservative.
Training, conductors	31,000	$ 995	$ 30,845,000		Population estimated based on dual qualifications for about half of the employees; cost from AAR (16 x $62.16)	
Training, Mechanical/Electrical	21,000	$ 3,728	$ 78,288,000		Population is March 2023 employment for Class I plus est. for Class II/III; cost and hours from Oliver Wyman (80 x 46.60)	
Maintenance; and additional stores, parts (12 years)			$ 200,000,000		Est.	Need to maintain dual stores ends with fleet saturation in year 13; pneumatic valves may be removed and need not be maintained
ECP-related delays in initial years plus Investments in system reliability			$ 200,000,000			Railroads have complained of issues with connectors, crosstalk and battery life, among other issues. These problems can be overcome with early attention to resolution, but no doubt would persist through the first 2-3 years. Note that, over a century later, railroads continue to complain of sticking brakes, brakes that fail to apply and other problems capable of being reduced or eliminated with ECP brakes.
Subtotal, railroad incurred costs				$ 8,191,723,905		
PRIVATE CAR OWNER COSTS						
Freight car, equip	1,094,641	$ 9,655	$ 10,568,758,855		Remainder of fleet total from AAR Fact Book	Private entities own a large majority of rail cars and maintain them in AAR-approved shops. When components fail en route, railroad shops may claim the work, including wheel set replacements
Freight car, maintain			$ 300,000,000		Est.	Although they own the larger portion of the fleet, preventive and periodic maintenance is more centralized. Field maintenance is more likely to be performed by the railroads, and that charge is included on this line.
Subtotal, private car owner incurred costs				$ 10,868,758,855		
Total costs				$ 19,060,482,760		These are costs are likely greatly exagerated values but have been accepted to demonstrate the order of magnitude effects.

NOTES:
1- OLIVER WYMAN, "Assessment of Enhanced Braking Requirements in Hazardous Materials: Enhanced Tank Car Standards and Operational Controls for High-Hazard Flammable Trains Final Rule of May 1, 2015" (June 15, 2015). This was a report commissioned by the rail industry to oppose the HHFUT mandate. Like a similar report a decade earlier on Positive Train Control, much of the assigned cost and diminished benefits was based on interviews with railroad personnel who presumably understood their companies did not wish to proceed with the safety upgrades. Costs may be exaggerated.

APPENDIX B—CLASS I RAILROAD CASH DISTRIBUTIONS

	(Values in $millions)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10 yrs.
BNSF												
	Distributions to Berkshire (est.)	4,000	3,500	4,000	2,500	4,575	5,450	4,425	4,830	3,800	5,000	42,080
CN												
	Repurchase of common stock	1,317.8	1,299.6	1,329.0	1,572.1	1,712.5	1,542.1	1,390.1	353.7	1,322.2	3,605.7	
	Dividends (common/pref.)	681.5	706.3	717.8	863.1	985.5	976.6	1,189.1	1,284.2	1,376.0	1,480.1	
	Total repurchase/dividends	1,999.3	2,005.9	2,046.8	2,435.2	2,698.0	2,518.7	2,579.2	1,637.9	2,698.2	5,085.8	25,705
CP												
	Repurchase of common stock	-	1,770.2	2,008.7	901.1	303.1	808.1	873.3	1,185.9	-	-	
	Dividends (common/pref.)	229.7	210.7	162.9	189.9	246.6	254.9	317.3	367.0	400.9	522.2	
	Total repurchase/dividends	229.7	1,980.9	2,171.6	1,091.0	549.7	1,063.0	1,190.6	1,552.9	400.9	522.2	10,752.5
CSX												
	Repurchase of common stock	353	517	804	1,056	1,970	4,671	3,373	867	2,886	4,731	
	Dividends (common/pref.)	600	629	686	680	708	751	763	797	839	852	
	Total repurchase/dividends	953	1,146	1,490	1,736	2,678	5,422	4,136	1,664	3,725	5,583	28,533
NS												
	Repurchase of common stock	627	318	1075	803	1,012	2,781	2,099	1,439	3,390	3,114	
	Dividends (common/pref.)	637	687	713	695	703	844	949	960	1,028	1,167	
	Total repurchase/dividends	1,264	1,005	1,788	1,498	1,715	3,625	3,048	2,399	4,418	4,281	25,041
UP												
	Repurchase of common stock	2,218	3,225	3,465	3,105	4,013	8,225	5,804	3,705	7,291	6,282	
	Dividends (common/pref.)	1,333	1,632	2,344	1,879	1,982	2,299	2,598	2,626	2,800	3,159	
	Total repurchase/dividends	3,551	4,857	5,809	4,984	5,995	10,524	8,402	6,331	10,091	9,441	69,985
		2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**10 yrs.**
	TOTAL CASH DISTRIBUTIONS, 6 CLASS I RRs (millions), 2013-2022											**$202,096.5**

Sources:
BNSF -- published estimates based on Bershire Reports
Others -- SEC 10-K data or equivalent from SeekingAlpha.com circa 7/2023