

Strategies for freight train integrated ECP braking plus distributed power

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Summary

This paper explores convergence among train-technology-related drivers in the global freight railway industry. It examines insights from the integrated electronically controlled pneumatic (ECP) braking plus distributed power pilot scheme on the Ermelo-Richards Bay heavy haul line, probing beyond observable technical and economic benefits, to examine what competitive and strategic advances may be leveraged off these technologies, as well as the related *Elektronische Brems-Abfrage und -Steuerung* (EBAS) concept.

These technologies address two key areas of train technology, namely compressed air brake systems, as well as coupling automatability and -strength. Applicable global state-of-the-art train technologies include separate ECP braking and radio-based remote control of locomotives, and now cable-based integrated ECP braking plus distributed power, as well as EBAS that also integrates braking and propulsion control.

Besides the established heavy-haul domain, continental- and intercontinental corridors are extending the eminent domain of freight railways. Interoperability and interchangeability have become important considerations. Braking and propulsion technology bears heavily on the ability of railways to meet customer capacity- and scheduling requirements. The notion Scalability addresses how they apply it to match demand and capacity. Braking-and-propulsion technology now exists, that is scalable from the smallest self-propelled railway vehicle to the largest heavy-haul train, to leverage railways to a new level of competitiveness.

Key words: automation, braking, distributed power, ECP braking, propulsion, scalability, train handling.

Introduction

Future freight railway business

Heavy haul- and heavy intermodal trains, that exploit one or both strengths of single-degree-of-freedom-of-translation transport, namely precise application of vertical load and high speed, will sustain freight railways into the future. Where source competition prevails, bulk-commodity heavy hauls should continue on relatively short, essentially dedicated, routes. Where modal competition prevails, international consignments,

characterized by high added value and compact size, are looking to exploit long-haul continental- and intercontinental railway networks. Conveyed in containers for security, they may cross several countries between origin and destination.

To meet the challenges posed by international traffic, transport systems need to operate efficiently on a continental scale in perfect interoperability (UIC, 1999: 15). Beyond that, even intercontinental corridors are becoming topical. However, one observes differences among freight railways' economic achievement among major regional blocks — outperforming the stock market in North America (Foran 2001), but losing market share in, for example, Europe (Heinisch, 1997) and Japan (Kandatsu, 2001). This paper explores some associations between railways' market performances and differences in the train technologies that underpin them.

Major influencers

Information technology

When information technology affects an artefact, it changes it profoundly and forever. This paper examines and reframes learning from one such application, the integrated ECP braking plus distributed power pilot scheme on the Ermelo-Richards Bay coal export line. It probes beyond the evident technical and economic benefits, to explore its potential contribution to strategic adaptation of the railway transport mode.

Attributes of railways

Ships and aircraft, as units of transportation, are neither divisible nor scaleable, which necessitates transshipping at hubs where direct paths for full loads do not exist. Their hub-and-spoke transportation systems trade off flexibility against cost, the trend being toward bigger hubs connected by bigger load aggregates.

In contrast to competitive long-haul transport modes, freight trains are inherently both divisible and scaleable, capacity being variable at short notice, within wide limits, subject to appropriate technology support. Integrated ECP braking plus distributed power, as well as EBAS, offer just such support.

As aircraft, ships, and their service hubs become ever larger, and complementary feeder services become an essential adjunct, an opportunity is emerging to exploit the flexibility of railways to competitive advantage.

Potential for intervention

Some information technology interventions appear only to overlay information technology over a traditional railway. Among other, such interventions may position the rail transport mode in head-on competition with road hauliers, who also apply information technology to improve internal efficiency and manage customer relations. However, road access is ubiquitous, and rail access can never be, hence information technology alone can never position rail ahead of road. Railways therefore need also to differentiate and leverage their competence, through application of information technology to their unique, single-degree-of-freedom-of-translation transport technology, to gain invincible advantage vis-à-vis competitive transport modes whose technologies exploit two- or three degrees of freedom of translation.

Some key requirements

Service design

Many-to-many origin-destination pairs

One challenge for the rail mode is to transport all accepted consignments, of wagonload size or more, from many origins to many destinations, with, among other criteria, short transit time, freedom from congestion, and fast asset turnaround. The continental- and intercontinental scale of railway networks now coalescing intensifies that challenge. Notions such as block switching, train coupling and sharing, and hub-and-spoke arrangements underpin the modalities. In the limit, the objective has been to emulate the perceived ability of road hauliers to move a consignment, on demand, direct to destination. The trick is to emulate that without encumbering the service delivery process with elements that are expedient to the rail operator, such as shunting, but do not add value to the customer.

Capacity management

Another challenge, at the other end of the complexity spectrum, is to move large traffic volumes from stockpile to stockpile, in ordered flows, with heavy-haul unit trains. The trick is to scale the trains to deliver the precise capacity demanded by customers, within the train design fundamentals described next.

Train design

Essentials

Train design is concerned principally with train length- and mass, which involves the ability to propel and to brake a train reliably. Braking behaviour and coupler strength are therefore key issues. They in turn relate to the physical time constraints associated with braking response, and to the dynamic behaviour of trains interacting with infrastructure.

Braking

Two incompatible compressed air brake systems, which evolved in response to the requirements of their specific settings, presently dominate the freight railway industry. Both have desirable features as well as limitations.

The first, direct release braking, has worked well in its native North American setting of long, heavy trains. However, being an equalizing system, a given brake pipe reduction does not map to a unique brake cylinder pressure, but rather to the resultant of auxiliary reservoir volume, cylinder stroke, return spring strength, and mechanical friction, to mention some pertinent variables. It may therefore accentuate wheel temperature variance among vehicles on a train.

The second, graduated release braking, has worked well in its native European setting of short, light trains. It features controlled brake cylinder pressure, which attenuates wheel temperature variance among vehicles on a train, resulting in more uniform wheel temperatures. Graduated release is thus superior to direct release, regarding the average amount of heat that can be dissipated within a given temperature ceiling, by

friction braking at steady speed on long down gradients. Providing a filling pipe, for reservoir charging, achieves faster response, and perhaps slightly longer trains. In passenger service, as well as in occasional freight applications, electric overlay control has augmented this to give electro-pneumatic braking. Nevertheless, graduated release braking supports shorter trains than direct release braking, despite the filling pipe, because the brake pipe needs to restore pressure completely to achieve complete release.

Outside the abovementioned settings, alignment with complementary elements of train design, such as signalling and electric braking, where designers in the native settings have respected them, perhaps subliminally, needs explicit recognition. Unexpected problems may emerge when technologies, which are taken for granted in one setting, are deployed in systemic context outside that setting. Controlled brake cylinder pressure comes with a limitation on train length in graduated release braking. Direct release braking comes with a hidden brake-cylinder pressure variance when braking distance is constricted.

In principle, ECP braking (as distinct from electro-pneumatic braking) and EBAS eliminate the abovementioned incompatibilities and limitations, and replace them with the union of the best features of both existing compressed air braking systems, first by separating the charging and control functions, and second by informationalizing control to achieve instantaneous and simultaneous response on all vehicles.

Propulsion

Effective control of dynamic longitudinal forces may mitigate extreme loading, but couplers do ultimately break, and so limit train length and mass. Around the world, two coupling configurations dominate — the relatively weak screw-and-link coupler with side buffers, and the relatively robust automatic centre coupler. Weak couplers imply short and/or light trains; thus, graduated release braking is sufficient. Robust couplers imply long and/or heavy trains; thus, direct release braking is required. One could therefore regard the distinctions between graduated release- and direct release braking to be systemic bonding issues, rather than those of purpose.

The weaker the coupling configuration, the more attractive some form of distributed power becomes. The latter effectively regulates coupler forces within acceptable limits, but at the cost of additional equipment and operating complexity. The presence of intra-train communications for ECP braking may mitigate the cost and so reduce the incremental cost of distributed power. Placing locomotive consists at the front- and rear ends of a train can minimize operating complexities.

Two additional benefits also accrue to distributed power. First, for those railways that do not enjoy multiple-unit capability to North American standards of harmonization, distributed power offers an elegant protocol through which to multiple-unit otherwise incompatible locomotives. Second, the longer a route, the greater the probable range of topography, and the less a constant number of locomotives will suffice. Where there is an expectation of adding and removing locomotives en route, within a setting that challenges coupler strength, distributed power offers attractive solutions.

Mission reliability

Long continental- and intercontinental railway hauls must muster high mission reliability to compete against other long haul transport modes. Hardening train design

against catastrophic- and mission critical failure is therefore an important objective. Among other, available intra-train communication can render it possible to monitor individual vehicles regarding journal bearings, draft systems, suspension systems, and structural integrity, as well as vehicle performance indications above and beyond brake system status, such as ride-quality, leakage of hazardous materials, security breaches of valuable consignments, and high- or low temperature alarms for perishable goods (Lundgren, 1999).

Present lineside monitoring of malfunctions, such as hot bearings and -wheels, and dragging equipment, which may be adequate on relatively short heavy-haul railways, could prove inadequate on some transcontinental hauls, if for no other reason than compounding interoperability requirements and accountability for consequential damage. Subject to economic justification, it is preferable to monitor train borne equipment on board, rather than from the lineside. As a minimum, derailment detection, applied handbrake, and stuck brakes, are desirable.

Interchangeability and interoperability

In principle ...

The ability to move individual vehicles, on the one hand, and complete trains, on the other hand, among and across railway networks depends on the physical and operational compatibilities among them. Where insuperable physical constraints, such as loading gauge, prevent individual vehicles passing from one railway network to another, transshipment is the only way out. Transshipment may however marginalize, or even disintermediate, the railway industry, because transshipment to a competitive transport mode may prove to be more attractive. Where physical constraints are harmonized, but operational constraints are not, railways may interchange vehicles, but not complete trains. Where both physical- and operational constraints are harmonized, interoperation is workable. Interchange is therefore both a subset of, and a precondition for, interoperability. The intersection between interchange and interoperation may be all but complete, as in North America, or it may be partial, as in Europe.

In practice ...

As the horizons for railway freight traffic broaden, to continental and intercontinental, freight trains are embracing more extensive territory than in their historical national- or even regional domains. The inevitable interoperability issues that currently arise will need resolving in settings that do not have time-honoured interchange histories.

Where interchangeability exists as a minimum, but complete interoperability is absent, one may realize workable interoperability in three stages. First, adapt the physical attributes of vehicles temporarily. This relates to situations such as, for example, transition coupling arrangements between RoadRailers and conventional wagons, or bogie changing between different track gauges. Second, change vehicles at network discontinuities. Some interoperability elements, for example energy provisioning and movement authorization, associate with locomotives only. Operators can hereby minimise the initial cost of interoperability, but at additional operating cost due to inconvenience. Third, provide all relevant rolling stock with multiple network- or system ability. Variable-gauge wheelsets are an example. The requisite multiple system capability may be provided either at initial build, or retrofitted. The

crucial issue is establishing the value of the multiple system capability and justifying the associated expenditure.

Unless participants establish harmonization across fleets as an inaugural tenet, it comes later at a cost premium that undermines the competitiveness of railways vis-à-vis transport modes that are not so encumbered.

Core interchange requirements

There remain parameters that affect all vehicles, motored and trailing, irrespective of the stage of interoperability. The author terms these *core interchange requirements*. This category includes some rigid constraints, such as permissible loading gauge and axle load, which are not amenable to resolution by transitional arrangements or multiple functionalities. The parameters of train braking systems are arguably a subset of core interchange requirements. However, braking characteristics have generally been regarded as immutable, until the present.

Graduated release- and direct release compressed air braking are incompatible, because they trade off their mutually exclusive hallmarks, respectively inexhaustibility and responsiveness, against each other. It is therefore difficult to conceive of an elegant transitional arrangement. Equipping all vehicles with both direct release and graduated release braking is perhaps possible, but is unlikely to be affordable.

As the freight railway industry globalises, only one technology set can ultimately dominate. Regarding braking and propulsion, what will that be? Does a unifying technology set exist?

Technology answers

State-of-the-art train technology

Global developments: Braking

ECP braking emerged in the United States in the mid 1990s, first on heavy unit trains and later in intermodal service. Subsequent exploratory applications, around the world, have remained in these two quadrants. Initial contention, recently resolved, between cable-based and radio-based communication technologies may have retarded ensuing progress.

EBAS emerged in Germany in the context of intelligent freight wagons (Sonder, 1998). Similar in principle to ECP braking, by virtue of networked control, and local intelligence on each vehicle, EBAS extended the functionality set to comprehensive automation of brake testing, and remote uncoupling. Demonstration of economic viability of the sensors and actuators required for comprehensive brake test automation is awaited.

At the level of pure technology, i.e. at a business level of thinking, the benefits of ECP braking may appear marginal in general freight service. The modalities of equipping an entire wagon fleet are a major obstacle (Lee, 1997). Issues relating to timing, rate of conversion, and low economic return on partially fitted vehicles and infrequently used equipment, mean that ECP braking might be destined to serve a niche market. Taking a strategic view may yield broader insight.

Both examples also support distributed power, as will be addressed in the next section.

Global developments: Distributed power

Radio-based distributed power control emerged in North America, and eventually spread to South America, Australia, and ultimately to Europe. At time of invention, intra-train cables were apparently a bugbear; hence, radio transmission became an integral part of distributed power lore. Distributed power addressed both nuisances of long, heavy trains, namely high head-end coupler forces, and steep brake-pipe pressure gradient, the latter particularly in cold weather. To the extent that loss-free radio communication was available during brake applications, distributed power also speeded up brake system response. However, its logic had, among other, to circumvent inevitable communication losses.

The advent of ECP braking and EBAS facilitated a new mindset. There is no compelling reason why intra-train communication should not also carry distributed power control. Quite the contrary, there are compelling reasons to carry all intra-train communication on the same channel, particularly when it is sufficiently reliable to dispense with logic to deal with sporadic communications loss.

Technology intersection

Further understanding comes from examining differences among the above technologies, and noting that they differ in execution, rather than in principle.

Integrated ECP braking plus distributed power, and EBAS, are similar in that both are predicated on networked control of braking and propulsion. They differ regarding the number of nodes that they support without repeaters (respectively 220 versus 60), and the length of train that they support (respectively 3600m versus 1500m).

Both technologies tend to combine vehicles. For example, CargoSprinter and North American stack cars unitise five platforms; and even though individual wagons in heavy unit trains are typically nearly identical, operators frequently drawbar-couple them in rakes of two or more, for economic, maintenance, or technical reasons. It makes sense for railways to differentiate themselves from road hauliers, by semi-permanently coupling vehicles to raise minimum load-unit size, to avoid head-on competition by positioning rail between road hauliers and other long-haul transport modes, such as shipping.

The relatively many remote power units in the CargoSprinter concept (two per five platforms) (Dorn, 1997), contrasts with the relatively few in North American-style distributed power (two-, or at most three, locomotive consists per train). This seems related to the most distinct difference, namely automatic uncoupling functionality. Justification for this difference is dependent on the propensity to change the composition of a train, with respect to the frequency, number, and size, of concatenations and cuts. The need for automatic uncoupling seems to relate to the positioning of the rail transport mode within a logistics superset: The closer to high value–low volume traffic, the more the need; the closer to low value–high volume traffic, the less the need.

One might question whether the abovementioned differences perhaps threaten the less-developed technology. Is there space for rail across the logistics opportunities

scale, or does it gravitate to the low value, high volume end? In network economics, dominance goes to the technology that first attains critical mass in the market.

Insights from Ermelo-Richards Bay pilot scheme

Systemic drivers

The Ermelo-Richards Bay coal export line operates 200-wagon trains of up to 20800 tonnes gross mass, using head end power and direct release air brakes. The braking respected a design requirement to harmonize with European-oriented signalling, that provides 1200 meters maximum braking distance. This necessitated brake ratios higher than in the native setting, which led to relatively uneven wagon-to-wagon brake block forces. The wheel temperature distribution on long down gradients, where brake applications last some 40 minutes, reflects this variance. Furthermore, relatively slow propagation of brake applications can induce high transient in-train forces under certain conditions. The head-end power configuration also resulted in coupler forces occasionally being higher than intended. Once new train technology appeared on the horizon, these problems were sufficient to prompt an evaluation thereof.

A high-level description

The capabilities of ECP braking seemed to address the fundamental physical limitations of air brakes. Once the initial contention between cable-based and radio-based ECP braking had been resolved in favour of cable, it also made sense to address the high longitudinal forces by using the intra-train cable to communicate distributed power control. The facility to support distributed power at modest incremental cost rather than as major capital commitment, is attractive because it makes distributed power possible where the investment might otherwise have been prohibitive.

A 200-wagon-train cable-based integrated ECP braking plus distributed power pilot scheme was therefore commissioned in July 2000, to evaluate its abilities in revenue service. The intent was to thoroughly assess the equipment, and if found to eliminate the systemic problems, to proceed with a fleet conversion. Kull (1999), Saarinen (2000), and Van der Meulen & Cortie (2000), have described the pilot scheme and its equipment in detail.

Fundamental learning

The positive findings at technical- and systemic levels (Van der Meulen, 2001) have been encouraging. For the purpose of this paper, the author emphasizes one particular aspect, namely ease of handling long, heavy trains with integrated ECP braking plus distributed power, which has important strategic ramifications for leveraging the competitiveness of freight railways.

An impressive attribute of integrated ECP braking plus distributed power is that one can configure a train to respond essentially as a single vehicle. More correctly, in braking it responds precisely as a single vehicle, and in propulsion approximately as a single vehicle. Regarding propulsion, locomotives at both ends influence an entire train, enhancing the approximation to a single vehicle: Locomotives at the head end and somewhere else within the train leave a loose rear end, diminishing the approximation to a single vehicle. A long, heavy train may stretch over several gradient changes, and planning for slow pneumatic-brake responses typically

subsumes major topographical features that incur time commitments of around thirty minutes. Quite simply, appropriate train configuration plus integrated ECP braking and distributed power place train driving in a different realm, not very different from driving a road vehicle. While people who are accustomed to short trains may not appreciate the import of this finding, the implications for long, heavy trains are profound.

The pilot scheme was intended to address the limitations of air brakes and head-end power. However, its solid competence has exposed other strategic insights, as follows.

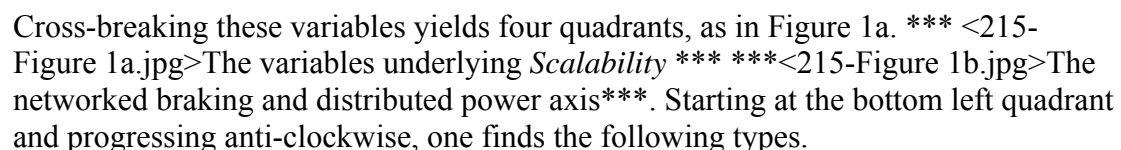
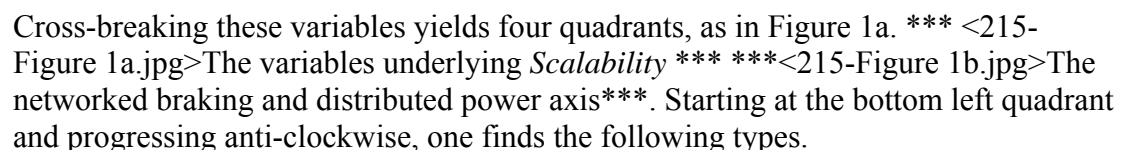
Some challenges for the future

Scalability

The author has found the notion *Scalability* useful to describe adapting trains to customer requirements, by expanding them to whatever tonnage and length is appropriate. He operationally defines it in terms of the following two variables.

First, *Traffic Nature*, which describes the type of freight traffic available to a railway. It varies on a continuum, from relatively chaotic, as in the output from a mass-customized manufacturing facility, to relatively ordered, as in the throughput of raw materials from a source (e.g. a mine) to a destination (e.g. a port).

Second, *Capacity Management*, which describes the approach railways take to managing capacity vis-à-vis aggregate demand. It varies on a continuum, from varying inventory magnitude at origin and destination through regular traffic flow, to varying train magnitude in unison with customer requirements for minimum inventory in the supply chain. These poles represent respectively railway-centred and customer-centred approaches: Logistics considerations inform the choice between them.

Cross-breaking these variables yields four quadrants, as in Figure 1a. The variables underlying *Scalability* The networked braking and distributed power axis. Starting at the bottom left quadrant and progressing anti-clockwise, one finds the following types.

First, traditional railway practice, that accepts chaotic traffic and orders it through a process of collection from consignors' sidings to a marshalling yard, sorting per route, line hauling to intermediate or final marshalling yards, and distribution to consignees' sidings. Other than movement over the shortest route, such processes add no value from a customer's perspective; hence, railways have come under threat in this quadrant.

Second (bottom right quadrant), long, heavy trains, that convey ordered traffic to a regular schedule — the job that railways do well. The traffic tends to be bulk commodities or intermodal freight. Operators can expand train length and tonnage to whatever they need, by using distributed power where head-end power would exceed permissible coupler loading.

Third (top right quadrant), predictable service, that makes freight reservations on scheduled trains. To the extent that customers can plan, it works, but where they prefer a spot market, it flounders. This quadrant is the antithesis of the traditional freight railway, and represents contemporary thought in several railways (Derocher & Foran, 2001).

Fourth (top left quadrant), customized service, that sets out to accept spontaneous consignments and move them immediately. It represents an effort to adapt railways (Dreier, 1996) to compete in the market for sophisticated logistics services. The concept has emerged so far in Germany, in the form of the CargoSprinter.

Note that the diagonal axes represent solutions continua. The axis linking bottom left- and top right quadrants represents traditional general freight service and enhancements thereto, using head-end-powered trains. Although freight railways have their roots in these quadrants, they are no longer vibrant. The axis linking bottom right- and top left quadrants represents networked braking and distributed power. Railways have experienced conceptual development and actual growth along this axis in recent years, as in Figure 1b. The commercially viable critical mass seems to reside in the bottom right quadrant. One may ask how far outside this quadrant advanced train technology will support the role that railways can play in the global transport market.

Automation

Automation of long hauls is routine for modes with which railways compete, such as air- and maritime transport. Recall however, that, on the one hand, integrated ECP braking plus distributed power makes train handling very easy, which opposes the propensity to automate. On the other hand, in contrast to direct release braking, the graduated release characteristic of ECP braking makes automation feasible, which favours the propensity to automate. This ambiguity could relegate resolution of the industry's position on automation to the middle future, rather than the near future.

Nevertheless, the author has experimented with a 300-wagon, 31 000-tonne train (Van der Meulen & Cortie, 1998), using segmented control of braking and propulsion, to explore what it might take to automate a long, heavy train. He found that train handling could indeed be independent of train length and weight. Note that this concept also lay on the axis of networked braking and distributed power. It means that one can conceive of automating freight trains, from the smallest to the largest, using a common technology set.

Concluding perspectives

First steps

Integrated ECP braking plus distributed power is, subjectively, more than the sum of its parts. It offers a quantum leap in railway competitiveness, through elevating the vision of what a train can achieve, to a new domain. However, railway operators will probably not perceive the full benefit of such advanced train technology until they have had a close encounter.

EBAS appears to have stemmed from rational analysis of what railway service could be. ECP braking came about because of trying to work around the physical limitations of pneumatic brakes. However, the preceding analysis and discussion suggest that they address the same fundamental issues.

There is probably not space in the global market place for two non-interoperable networked braking and propulsion systems. Either they will converge, or one must fall by the wayside. The author's experience suggests that the attractive attributes of ECP braking are no compromise, but rather combine and extend the best features of both

direct release and graduated release pneumatic brakes. This paper is a challenge to the industry to work toward a unified global train technology.

The fate of general freight

Heavy haul- and double-stack intermodal trains exploit one or both of the inherent advantages of single degree of freedom of translation transport, and can therefore support investment in new technology. However, general freight railway business is, at best, marginally competitive against road hauliers, therefore it will attract investment in new technology with difficulty.

Equipping all rolling stock with an interoperable braking and propulsion system would be a worthy objective. However, amending interoperability standards is notoriously difficult, and costly to boot. One might even conceive of a mechatronics device that could emulate either direct release or graduated release as required, but it would not get to the nub of interoperability. High investment requirements for train technology might thus trigger a bifurcation of destiny between heavy haul and heavy intermodal traffic on the one hand, and general freight traffic on the other hand.

Note that EBAS appears oriented toward general freight, whereas integrated ECP braking plus distributed power appears oriented toward heavy haul. Integrated ECP braking plus distributed power might thus enhance heavy haul- and heavy intermodal railway competitiveness, but general freight trains not so equipped might be left behind.

Vision

A braking-and-propulsion technology now exists, that is scalable from the smallest self-propelled railway vehicle to the largest heavy-haul train. Operators can split and combine them at will. The industry ought now to work on harmonising all constituent elements into an interoperable, global set. Relevant technologies at both ends of the train-size spectrum have been explored. Is it a major conceptual leap to fill the remaining gap?

Both technology candidates have yet to find commercial application. ECP braking appears to be leading, because at time of writing the author's employer was processing a decision to commit to fleet conversion of the Ermelo-Richards Bay coal export operation.

Such commitment will convert the numerous expectations regarding networked braking and propulsion into the foundation for a new level of railway competitiveness.

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