A SYSTEMIC APPROACH TO MODULATING TRAIN BRAKING AND -TRACTION

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INTRODUCTION

Positioning the topic

This paper examines issues relating to modulating train braking and -traction, within a framework developed in a previous publication (Van der Meulen, 2003). In this context, modulation means technologies to vary braking- and tractive effort to handle a train within authorized- or prudent limits. It takes stock at a time when new train technologies are finding their way into the market: It therefore also examines which carry-over technologies from the past still make sense, and what new concepts should be explored and positioned.

The paper addresses technologies applicable to Heavy Haul and Heavy Intermodal trains. It is set in a time frame when key railroad competitiveness parameters, developed after US railroad deregulation, have attracted railroads elsewhere in the world that are less fortunately positioned. If those railroads are to make a difference to the transport task in their countries, regions, and continents, they will also need to develop an appreciation of the technologies that support heavy freight railroading.

Terminology

The term *Heavy Haul* widely connotes long unit trains, with heavy axle load when loaded, and light axle load when empty. The term *Intermodal* connotes a looser understanding. To the industry as a whole, it means conveying containers and/or trailers with at least one change of mode. To a smaller subset, it means conveying containers on double-stack cars also with at least one change of mode. As will become evident later, double stack cars leverage a basic strength of the rail mode, namely the ability to carry heavy axle loads, by stacking containers two-high. To distinguish the latter from lighter examples of intermodal, the author has defined *Heavy Intermodal* to mean conveying containers in double stack trains.

SOME HIGH-LEVEL OBJECTIVES OF MODULATING TRAIN BRAKING- AND TRACTION

An introduction to genetic railroad technologies

One must begin at the technologies that make a railroad a railroad, namely those genetic technologies that distinguish railroads from other transport modes. An examination of their degrees of freedom of translation, or movement, yields a useful understanding of differences among transport modes.

- *Spatial transport* (typically aerial and submarine) features three degrees of freedom—vertical, lateral, longitudinal: It offers high mobility, but at relatively high cost.
- *Unguided surface transport* (typically wheeled- or tracked vehicles, and maritime) features two degrees of freedom: It sacrifices the vertical degree of freedom to become more affordable, and still offers moderate mobility.
- *Guided surface transport* (typically railroads and maglev) features one degree of freedom: In further sacrificing the lateral degree of freedom, it offers only limited mobility (back-and-forth on the same

guideway), but compensates by offering distinct competitive strengths.

These strengths derive from the nature of guidance, namely the ability to apply and to react loads at precisely defined *points* (a railway line is of course an infinite series of such points). This in turn facilitates design of cost-effective structural components, because the loading conditions are accurately known. Compare this situation to pavement and tire design: Pavements must support loads over less precisely defined *areas*, hence compromising their economic bearing capacity, and tires must operate on a diversity of surfaces, which compromises their performance. The author has named the genetic railroad technologies as follows:

- *Bearing*, the set of technologies that give railroads the ability to carry heavy axle loads.
- *Guiding*, the set of technologies that enable locomotive- and wagon wheels to deliver economically-viable life under aggressive loading conditions.
- *Coupling*, the set of technologies that leverage Bearing and Guiding, by combining vehicles together, or scaling train size, to deliver high capacity.

Maximizing competitiveness of railroads requires leveraging these genetic technologies to maximize their key parameters, respectively permissible axle load, permissible speed, and permissible train length. With respect to technologies for modulating train braking and -traction, this paper necessarily emphasises the Coupling genetic technology set, while nevertheless recognizing inseparable relations to Bearing and Guiding. Heavy railroad operations, Heavy Haul and Heavy Intermodal, which combine long trains and high axle loads, impact as follows on the three genetic technologies.

Criteria of success

Unique to Bearing

Increasing axle load enhances freight rail's competitiveness, and in so doing proportionately increases the braking thermal load on car wheels. Long air braked trains require direct release: Because it is an equalizing system, brake cylinder pressure is indirectly related to brake pipe reduction, under the influence of variables such as piston stroke and rigging elasticity. Consequently, a given brake pipe reduction may result in car-to-car brake cylinder pressure variance. Under high aggregate thermal loading, the temperatures of some wheels may exceed the acceptable limit, and any particular wheel to which outlier thermal stress is applied becomes a safety risk. This phenomenon in turn influences the maximum axle load that can be safely carried. One objective of train braking- and traction modulation technology is thus to apply equal thermal loading to all car wheels, to raise the average thermal load without individual wheels exceeding the acceptable limit, thereby supporting higher axle load.

Unique to Guiding

A link between Guiding and motive power placement may seem tenuous, but it is nevertheless important in a systemic approach. When running free, i.e. with no longitudinal in-train forces, curving of individual vehicles is a function of vehicle-track parameters only. However, longitudinal in-train forces, more particularly traction, may disturb free running. In curves, the lateral components of longitudinal tensile coupler forces pull cars in the direction of the centre of the curve, thereby forcing wheel sets to deviate from the path on which they would run absent such forces. In the case of conventional trucks, this increases the angle of attack between leading wheel flange and outer rail, thereby increasing running resistance. In the case of radial trucks, where curve resistance is normally negligible, the lateral components cause additional creep forces between wheel and rail, which also increase curve resistance. Another objective of train braking- and traction modulation technology is thus to reduce curving forces, through reducing longitudinal forces, by distributing power, thereby supporting heavier trains. This applies more particularly where coupler forces with only head-end power are approaching limiting values.

Unique to Coupling

Coupling combines individual vehicles into trains, to leverage the strengths of heavy axle load and high speed, and so distinguish railroads from other transport modes. However, that strength also contains the seeds of weakness, and introduces one of the major technological challenges of railroading. Traditional pneumatic brake signal propagation along a train can not be faster than the speed of sound. That relatively slow response at *train level*, which leads to compressive run-in forces, is countered by retarding flow from auxiliary reservoir to brake cylinder at *vehicle level*. The compromise had to be introduced to make control of long trains possible, because it is not possible to alleviate technological limitations by application of the same level of technology. Furthermore, when a train becomes heavy enough, the tractive force required to move it may approach the limits of coupler strength, thereby introducing a new Coupling-related issue. Yet another objective of train braking- and traction modulation technology is thus to eliminate train-length-related constraints, to scale train services to meet traffic throughput requirements, to accelerate braking response, and to eliminate train break-in-twos.

TYPES OF INTRA-TRAIN COMMUNICATION

Established technologies

Air braking

Although it is well established, air braking is not customarily regarded as a communication medium. Nevertheless, the brake pipe both charges the system and communicates a complex message set (amount and rate of pressure change, initial condition, transient response, with both engineer initiation and local initiation). In the present context, it is important to appreciate that an automatic air brake system also provides vital communication under abnormal conditions. Direct release air brakes have done a worthy job over many years in respect of heavy trains: However, their physical limitations, mentioned above, must eventually drive operators and suppliers to seek superior solutions to continuously enhance their competitiveness.

Radio distributed power

Radio distributed power has also been around for many years. It represents the first application of electronics to tackle some of the inherent physical limitations of air brakes and long trains. It addresses issues related to train length, namely:

- High coupler forces as train length and train tonnage increase. The technology facilitates distribution of locomotives within trains, to enable heavier trains than would be workable using head end power only.
- Reduced brake system responsiveness and stability due to higher brake system air leakage as train length increases. The technology supports multiple feed valves to enable responsive, stable braking on long trains.
- Increased air leakage from the brake system as temperature falls, which sometimes necessitates reducing train length or application of other measures in extremely cold weather. The technology facilitates multiple feed valves, which reduces the length of train that must be fed from any one of them.

However, radio is an interruptible communication medium, so overall system design needs to ensure that applicable safety requirements are met even during interruptions. Interruptions may be of long duration, but occur in situations where system logic can work around them (as when traversing long grades where braking and/or traction are modulated only infrequently); or of short duration, but occur in situations that may compromise train handling (as when initiating a train brake application while passing over a crest). It is therefore important to appreciate that radio distributed power can only provide non-vital communication. If a particular situation demands vital communication, and radio communication is interrupted at that moment, vital communication reverts to pneumatic signals via the brake pipe.

Emerging technologies

Electronically controlled pneumatic braking and its intra-train communication system

New electronic communication technologies have emerged, that ask for an integrated approach to the issues raised in this paper. Their attractions are high speed and uniform response. Cable-based intra-train communication first emerged in the US, as the foundation of electronically controlled pneumatic (ECP) braking. Subsequently it spread to a few other heavy haul sites, and seems to be establishing itself as an industry standard, with applications underway in Australia, Canada, South Africa, and the US, with interest being shown elsewhere too. Radio-based intra-train communication initially appeared to offer strategic advantage for converting large fleets of non-captive cars to ECP braking. However, that advantage has not materialized in practice, and market forces seem to have favored cable. Both alternatives have thus far been confined to heavy haul operations, where the benefits of electronic control are taken as read.

Wireline distributed power

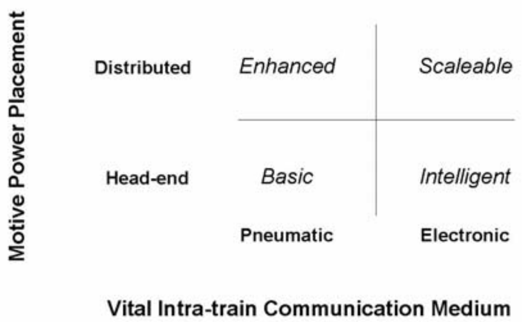
Whatever the intra-train communication medium for ECP braking, its presence provides an attractive path for distributed power control. The incremental cost on top of ECP braking is relatively small, so wireline distributed power could potentially offer cost-effective solutions to issues already discussed. Of course, several other costs also associate with distributed power, in particular due to more complex operating arrangements, to cut in motive power at more than one position in a train, and to set-up and/or test the communication link, both of which increase the cycle time of the operation. Distributed power should probably not become the motive power placement of choice, until other economically viable alternatives have been exhausted. The following section proposes analytical tools with which to make informed decisions.

A CASE FOR INTEGRATED MODULATION

A hierarchy of modes

From the foregoing discussion, one can identify two nominal variables that should inform train technology selection decisions. First, Vital Intra-train Communication Medium, which may be either Pneumatic or Electronic. In the present context, Electronic may mean either cable or radio—the essential distinction between Pneumatic and Electronic centres on propagation attributes. With respect to the cars in a long train, Pneumatic communication is serial and slow, Electronic communication is instantaneous and simultaneous. Second, Motive Power Placement, which may be either Head-end or Distributed. Cross-breaking these two variables constructs the four quadrants in Figure 1.

Figure 1: Modulation mode



The *Basic* quadrant represents a classic train, with head-end power and pneumatic braking: It is subject both to the physical limitations of direct release air brakes (brake signal propagation speed, non-uniform car wheel thermal loading, and system charging ability), and to the limit of coupler strength on maximum train tonnage. The *Enhanced* quadrant represents a pneumatic braked train with radio distributed power: It eases limitations related to train length, namely brake signal propagation speed, system charging ability, and the limit of coupler strength on maximum train tonnage, but retains the risks associated with non-uniform car wheel thermal loading, . The *Intelligent* quadrant represents an ECP-braked train with head-end power: It eliminates all pneumatic braking limitations, but is still subject to the limit of coupler strength on maximum train tonnage. The *Scaleable* quadrant represents a train with ECP braking plus distributed power integrated with the intra-train communication system: It is scaleable, because for any reasonable train length and –tonnage, it is not subject to a limit on brake signal propagation speed, to non-uniform car wheel thermal loading, and to the limit of coupler strength on maximum train tonnage.

Strategic intent

Distinguish between objectives and vision

One can rank the foregoing four quadrants hierarchically. Clearly Basic would be at the bottom, and Scaleable would be at the top. The relative ranking of second and third places will doubtless stimulate contention: The insight with which to resolve it is found in strategic intent.

A need to rank the quadrants will usually arise in the context of investment to address existing- or fresh challenges. A first question should test the immediate objective—is it to leverage an existing operation, or to initiate a greenfields development? A second question should test the vision—is the ultimate objective only a marginal increment to an existing operation, or is it a first step in an open-ended development, where the ultimate parameters regarding permissible axle load, speed, train length and throughput are speculative?

Greenfields developments are relatively rare in the railroad industry, if for no other reason than that extension of established networks conveniently supports most incremental transport requirements. Therefore, most investment decisions will relate to leveraging existing operations, often from the Basic quadrant, as follows.

Towards the Enhanced quadrant

A railroad operation that is approaching train length related limitations (high coupler loading and sluggish pneumatic braking performance) might be naturally attracted to radio distributed power, i.e. to the Enhanced quadrant. This option concentrates the incremental investment on the locomotives, and possibly on fixed repeaters as well, but avoids the cost of equipping all cars with additional- or new braking equipment. Free interoperability within a larger system is an added attraction. However, following that path may preempt progression to the Scaleable quadrant, because the incremental benefit of upgrading later to integrated ECP braking plus distributed power, namely elimination of non-uniform car wheel thermal loading, will require investment in a full intra-train communication package plus the ECP braking equipment itself. Thus the vision question is important.

Towards the Intelligent quadrant

A railroad operation that is approaching the same limitations, but with potential for substantial future growth, might be attracted to the Intelligent quadrant. That path will eliminate the physical limitations of direct release air brakes (brake signal propagation speed, non-uniform car wheel thermal loading, and system charging ability) from the outset. In addition, when the limit of coupler strength constrains maximum train tonnage, the system will support subsequent migration to vital distributed power at small incremental cost, thereby positioning the railroad for Scaleable growth to any reasonable train length and tonnage. Such positioning will give it confidence to grasp whatever opportunities, or deal with whatever challenges, may arise in future.

Towards the Scaleable quadrant

The foregoing reasoning leads to instances where new applications do not need to build on or interoperate with legacy investments. The first all-new locomotive- and car fleet ECP braking roll-out is underway in Australia's Hunter Valley. It will be interesting to observe how other greenfields railroad applications choose their brake- or intra-train communication systems: Is there still any advantage in a pneumatic system in settings where interoperability with legacy equipment is no longer an essential requirement?

In particular, Asia-Europe landbridge services hold fascinating prospects. A stage is being set for expansion of Heavy Haul- and Heavy Intermodal technologies into long haul intercontinental traffic. Suitable traffic is already moving in single stack container trains, and growing substantially year-on-year. On the one hand, it seems inevitable that, as competition increases over time, that double stack intermodal will become part of that scene. On the other hand, braking systems have disparate characteristics—direct release in the east, and graduated release in the west, so brake system compatibility must eventually become an issue. The emerging electronic intra-train communication technologies offer elegant solutions to such challenges.

CONCLUSIONS

Application of established train braking and –traction modulating technologies, namely pneumatic braking and radio distributed power, will probably continue as long as railroads routinely replace equipment or add incremental capacity to existing systems. This paper does not question the course of that process, but instead has explored what attractions may present themselves when opportunities for major new investment do arise.

This paper has identified four modes of braking- and traction modulation, namely Basic, Enhanced, Intelligent, and Scaleable, which map onto existing- and emerging train technologies in a way that suggests a ranking. Commencing with traditional practice, that suffers many inherent limitations, it ends with highly competitive new train technologies, which leverage the railroad genetic technologies to permit higher axle load, higher speed, and longer trains, to offer high performance and robust reliability.

Less than full exploitation of genetic railroad technologies sacrifices competitiveness to other sources (in the case of Heavy Haul), or to other modes (in the case of Heavy Intermodal), so migration to the emerging vital electronic technologies seems inevitable. The industry should therefore be wary that short term expediency does not preclude longer term competitiveness.

REFERENCES

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