GLOBALISATION AND OPEN ARCHITECTURE FOR RAILWAYS: A ROLE FOR INTEGRATED ECP BRAKING PLUS DISTRIBUTED POWER

Dr. Dave van der Meulen

Chief Engineer (Systemic Rail Solutions), Spoornet, South Africa

E-mail dave-vdm@telkomsa.net, Telephone +27 12 345 2017

Abstract

The paper compares railway technical architecture to that of other transport modes, and the information technology industry, to examine their relative freedom to adapt to market forces and to prosper. It reviews the genetic technologies that characterize railways, and their contribution, on the one hand to competitive advantage, and on the other hand to interoperability- and intraoperability constraints. The author applies information engineering to model relations among technical attributes and service offerings, to examine whether appropriate classification of service domains can ameliorate interoperability constraints and promote intraoperability benefits. It examines the prospects of ECP braking and distributed power in that context. The conclusion is that there is value in a railway meta-model, to enhance railway industry competitiveness through opening its architecture. This should optimize interoperability within the railway industry itself, as well as leverage interoperability with service providers in the larger logistics industry to advantage.

KEY WORDS: Distributed power, ECP braking, freight railways, interoperability, intraoperability, open architecture.

1.   Should railways have a meta-model?

1.1.   Legacy outcomes

The sustainability challenges that confront many railways today frequently stem from their adaptation legacies. State ownership, external regulation, opaque governance, etcetera, shielded them from market forces, and circumscribed opportunities to adapt voluntarily. This resulted in stunted development, rendering them fragmented and insular. Recognize nevertheless that such impediments have not applied to all railways, or always, and that counter examples exist, which attest to the worth of encouraging unfettered adaptation to market forces.

Mostly, the sequence has been; free founding, then politically driven regulation, followed in recent decades by gradual though sporadic liberalization. Examples exist at all stages. Therefore, in many respects, railways are anything but a global industry. In comparison with other transport modes—whose members grow steadily, without protection or stimulation—many railways need external subvention. Even the most successful of railways, those in the USA, are marginal with respect to earning their

cost of capital (AAR makes, 2003, p. 311). Railways seem to need a meta-model, to guide development towards a vibrant, competitive, globalized industry.

1.2. Some weaknesses vis-à-vis key benchmarks

1.2.1. A technical architecture perspective

One can approach industry comparisons from many perspectives: The author predicated this paper on prima facie differences between the technical architecture of railways, and that of other transport modes and of other industries.

1.2.2. Vis-à-vis other transport modes

As an old industry, railways are steeped in tradition. Founding investments date from long before harmonization was valued. By contrast, rival modes seem to have enjoyed better harmonization from the outset. Their constraints are arguably fewer, because they tend to concentrate on ports, but open waters and -skies have never known interoperability constraints comparable to those of railways. Road transport harmonization is reasonable in respect of scientifically founded parameters such as maximum axle load (but not in respect of value founded parameters, such as maximum combination length and gross vehicle mass, and, most conspicuously, not with respect to rule-of-the-road). Where transport on water is challenged, it is for the same reason as railways, namely physical constraints that impede interoperability, such as canals and locks that could not accommodate larger vessels. Railways have made significant inroads into water transport, where interoperability constraints have marginalized or eliminated all but an interoperable remnant.

The relatively open technical architectures of rival modes show up the relatively proprietary technical architectures of most railways. Exceptions do exist: North American railways are one. However, as open as their technical architecture is, it is regional, not global. This example nevertheless underscores a theme this paper will develop. North American railway equipment is generally not *interoperable* elsewhere, due mainly to its axle load- and loading gauge parameters. However, sub-systems, such as braking, bogies, couplers, and drawgear, are *intraoperable* in many of the world's heavy haul railways, on broad and narrow gauge.

1.2.3. Vis-à-vis other industries

The author chose the information technology industry as underscoring the benefits of open technical architecture—affordability, adaptability, capability, maintainability, and ubiquity. Railway customers expect comparable seamless service, from any origin to any destination, plus intermodal transfers where necessary to support comprehensive logistics networks.

Since fusion of information technology and telecommunications in the 1990s, the 25-30 percent per year performance/price increase that prevailed has led to a surge of competition from their products and services (Bradley, Hausman, & Nolan, 1993, p.7). It is salutary to reflect on what such an accomplishment could do for the railway industry. This paper examines intelligence from information technology- and telecommunications technical architectures, with a view to mapping it to railways. Business-to-business relationships, and the technology to support them, are beyond the scope of this paper.

1.3.   *Towards sustaining competitive advantage*

Technology drives, and is driven by, globalization. The fusion of information technology and telecommunications has affected the competitive environment, creating new industries, and restructuring existing industries. Restructuring means changing the bases of competitive advantage in an industry, and the ways in which buyers, suppliers, and rivals compete, cooperate, and interact (Bradley, Hausman, & Nolan, 1993, pp. 3, 6). In a world where industries globalize one after the other to survive, railways appear to have no alternative but to do likewise.

The author argues that, to globalize, the railway industry must consider opening its technical architecture, to participate in what, for it, has been restructured into a logistics environment. With the Gulf War II demonstration of formidable information-technology-driven logistics in mind, the author looked to the technology that supported it. What follows deconstructs railway technology using information technology tools, to promote understanding, reengineering, and opening its architecture. The author examines the supporting role of emerging information-based railway technologies; more particularly electronically controlled pneumatic (ECP) braking and distributed power.

2.   What makes a railway a railway?

2.1.   *Genetic technologies*

2.1.1.   A single degree of freedom of translation

To examine the architecture of railways, one needs to consider the genetic technologies that characterize them. That is, what makes a transport mode a railway, and not some other mode? The author argues that one may approach open architecture and globalization through the applicable genetic technologies.

Guided surface transport, of which the railway mode is an example, rests on a single-degree-of-freedom-of-translation, which distinguishes it from rival modes, which boast two- and three degrees of freedom of translation. Unguided surface transport features two degrees of freedom, which enables the door-to-door access valued in logistics solutions. Aerial- and submarine transport feature three degrees of freedom, which maximize utility, but at a premium. A single degree of freedom of translation transport mode requires the following three genetic technologies.

2.1.2.   Bearing, guiding, and coupling

Bearing enables heavy axle loads, through precise alignment between load and support. Railways have come to dominate this attribute. It rests on wheel/rail contact technologies, the management of which is topical in the open access versus vertical integration controversy. Some argue that wheel/rail contact is so intimate that one cannot optimize it without unitary management of both mating surfaces. Nevertheless, recognize also that heavy axle loads and free interchange coexist successfully in North America. While unitary management might optimize, satisficing is arguably all that is required.

Guiding enables high-speed transport on land. Railways have dominated this attribute since their founding. While acknowledging that Guiding also rests on wheel/rail contact, the technology set underlies interoperability issues that relate to track gauges and differences among them.

Coupling leverages Bearing and Guiding, creating capacity. It unitizes individual vehicles into trains, distinct from the random vehicle movements that characterize rival modes. Originally Coupling was just that. Continuous braking came later, followed by intra-train communication, to support distributed braking, propelling, and other functionalities. The technology set must therefore support physical trains and logical trains.

2.1.3.   A caution

The foregoing genetic technologies enable railways to deliver heavy loads, high speeds, and high throughput, effectively. However, it will appear later that they may also impose constraints if their relationships to other entities are ill conceived.

2.2.   *Enabling technologies*

2.2.1.   Introduction

The following technologies are not unique to railways, although their railway manifestations are usually proprietary. They enable railways to function, but are subsets of technologies that extend beyond railways.

2.2.2.   Propelling (and braking)

Propelling enables trains to move: In this paper, it includes both motoring and braking, because braking is simply negative motoring. Propelling includes two technology subsets, namely supplying, how energy is provided to a train, and controlling, how its flow is modulated. The following issues influence technical architecture: A railway is a net consumer, but it may also dissipate or regenerate energy. Energy supplies may not be interoperable, but it is feasible to change locomotives at break points. Control may be more complex, because it may associate with the set of Coupling technologies.

2.2.3.   Authorizing

Authorizing enables many trains to safely share a network. It includes signaling- and train control systems, plus production systems and capacity management (ERRAC, 2002, p.8). At its lowest level, where a human train driver receives authority and acts accordingly, Authorizing technology is highly interoperable but less than perfectly safe. As technology displaces fallible humans to enhance safety, inter- and intraoperability issues escalate.

3.   Selected architecture considerations

3.1.   *Technical architecture*

3.1.1.   A frame of reference

Railway technology and information technology arguably represent the poles of a continuum from proprietary- to open architecture. It is instructive to note that information technology has not always been so open. It progressed through integration, to satisfy accountability, dissolution of technological barriers, computerization of technologies that contained no electronic logic, and networks that eliminated barriers around traditional domains (Sprague & McNurlin, 1993, pp. 5-6). As in the case of railways, the different information technology sectors had developed

strong traditions during their thirty fragmented years: The speed with which their architecture opened is noteworthy. A Google search on railway technical architecture, -interoperability, and -intraoperability yielded no coherent philosophy. As already mentioned, military systems offer well-grounded insights into technical architecture. The following sections paraphrase some key quotations, to establish a frame of reference within which to examine railways.

3.1.2. Some definitions

For different systems to interoperate with each other, or to potentially intraoperate, that is share subsystems, one must define the following:

> *Technical architecture*, a minimal set of rules governing the arrangement, interaction, and interdependence of the elements, identifying the services, interfaces, standards, and their relationships (JACG/AESB, 1997; OUSD, 2002, p.7).

> *Interoperability*, the ability of systems to provide services to and accept services from other systems, using the services so exchanged to enable them to operate effectively together (JACG/AESB, 1997).

> *Intraoperability*, the extent to which architectural attributes apply throughout a system, to enable economy or efficiency. It depends on establishing an area of interest, and creating a technical architecture within that boundary (JACG/AESB, 1997).

These definitions seem to apply to railways no differently than to their native domain.

3.1.3. The significance of interoperability and intraoperability

Though greatly improving interoperability of systems by eliminating proprietary interfaces, technical architectures alone are insufficient to support interoperability and intraoperability: An application layer architecture is also required (OUSD, 2002, p. 7). The latter requirement suggests why interoperability issues, and more recently intraoperability issues, have afflicted railways. The application layer, which should drive railways as a global industry, has not yet developed the stature to dominate subordinate interests, for the reasons mentioned in Paragraph 1.1.

A technical architecture supports acquisition of systems, by reducing life cycle costs and by providing a framework for technology insertion. It defines a set of reusable components and their interfaces, to reduce the maintenance costs of a system as well as the development costs of follow-on systems. It also allows porting components developed for one system to another system. Technology insertion is achievable when the architecture is scaleable. As a system evolves, the analysis and architecture can support more advanced capabilities (OUSD, 2002, p.8). The author will indicate how railway technical architecture could benefit from the foregoing principles.

3.1.4. Palliatives and solutions

As in the case of railways, interoperability and intraoperability in information technology is not perfect. Nevertheless, software solutions can often work around whatever barriers exist. Sprague & McNurlin (1993, p. 187) identify the following examples. First *bridges*, interconnecting networks that use different physical media. Second, *routers*, determining the most efficient route between networks. Third, *gateways*, linking local area- networks to long-haul networks. Last, *smart hubs*,

handling a variety of bridging, routing, and gateway functions. Their transferability to railways is self-evident, particularly in a logistics context. However, railways are less fortunate, because comparable hardware solutions are not trivial. The examples nevertheless point to where railways should anticipate equivalents. The author revisits these issues later. The potential for railways to realize interoperability and intraoperability is the resultant of the following unifying drivers and countervailing constraints.

3.2. Unifying drivers

3.2.1. Network integration

The worldwide telephone system already enables any user to connect with any other user (Sprague & McNurlin, 1993, p. 185). Computer users are not far behind. The exponential increase in value to all users, of networking standalone systems, is not lost on railways. In the northern hemisphere alone, the following fragmented network route kilometerage can potentially coalesce: Western Europe 180 000 (standard gauge), Eastern Europe and Central Asia 155 000 (1520 mm gauge), China and Eastern Asia 70 000 (standard gauge), and North America 265 000 (standard gauge). Less than one percent remains to link them into a 670 000 km network.

The drivers are already at work. The North American Free Trade Area added a north-south dimension to North American railways. The Trans-European Rail Freight Network opened on March 15, 2003, to qualifying operators. Europe's Strategic Rail Research Agenda 2020 envisions cost effective interoperability between standard and non-standard gauge networks, especially in the Iberian Peninsula, Finland, and the Community of Independent States (ERRAC, 2002, p. 12). The Transport Corridor Europe-Caucasus-Asia has been underway for some years. A Northern East West Freight Corridor is under consideration (Sharma, 2003). Note that these are essentially freight corridors: People generally do not want such long hauls. Expect intense pressure on interoperability and intraoperability issues.

3.2.2. Industry restructuring

The railway industry is restructuring rapidly. Separation of infrastructure and -operations is accelerating; as stakeholders appreciate that unbundling them may unlock value that exceeds their vertically integrated value. Bedding in of major railroad mergers in the United States has stimulated intermodal traffic growth (Stagl, 2003, p. 33). The nature of competition for freight by railways is changing in Europe (Freight customers, 2003). In the supplier industry, mergers among system integrators have left only a few global participants.

In information technology industry restructuring, open architecture led to more and better solutions. No single company could manage the pace of technology, and standards formation occurred too late to matter: Software's increasing role in providing integration and functionality, rendered the demise of standards unlikely to affect customers or markets adversely (Bradley, Hausman, & Nolan, 1993, p. 29). The expectation that manufacturing industry will implement technical interoperability requirements (ERRAC, 2002, p. 9) is a precursor in the railway industry.

3.2.3. Advancing mechatronics

Mechatronics is the synergistic integration of mechanical engineering with electronics and intelligent computer control, in the design of systems. It separates functionalities,

previously embedded in an integrated physical whole, into hardware, actuators, and information. For example, one may regard the most elementary subsystem of railway technology, the wheelset and track, as a set of load bearing elements (wheels and rail), guiding elements (wheel- and rail profiles), force distributing elements (wheels and axle, rails and track structure), and information on their relationships (wheel/rail contact technology). Where trams required removal of a vital element, the axle, to facilitate a low floor, mechatronics technologies reintegrated the remaining elements to steer by controlling traction motor torque—an electronic axle. Expect mechatronics to play a significant role in ameliorating the impact of hardware constraints on interoperability.

3.3. *Countervailing constraints*

3.3.1. Introduction

Interoperability constraints, which inhere in the way in which railways deploy the genetic single-degree-of-freedom-of-translation technologies that generated them in the first instance, may threaten their competitiveness. The following list is not exhaustive, but addresses those that relate most directly to the genetic technologies. Note that railways may work around interoperability constraints either by associative relationships (smart), or by redundant functionality (expensive). The author highlights examples of each.

3.3.2. Bearing constraints

Bearing constraints relate to differences between Dynamic Axle Load and Permissible Axle Load. They may present a serious interoperability impasse with respect to axle load requirements for heavy freight- and high-speed passenger trains, which differ distinctly and might not even intersect. Furthermore, heavy haul railways even regard axle load as a competitive advantage rather than as a constraint, with the result that it generally increases over time.

Railways may work around this constraint to some extent with track-friendly bogies, and/or by accepting a higher track degradation rate as axle load increases. When the US Class 1 railways upgraded permissible gross wagon mass to 286000 pounds, the marginalizing effect on short lines was salutary (Stagl, 2002, p. 27). One should expect this constraint to direct attention to sustainability—interoperate heavy, competitive trains on a lean network; or slide into penury on an extensive but lightly loaded network.

3.3.3. Guiding constraints

Guiding constraints relate to differences between Track Gauge and Wheelset Gauge, which may hinder interoperability among networks. One can gauge their dominant influence by noting how the associative relationship of variable gauge wheelsets facilitated interoperability for trains so equipped between Spain and France, and how introduction of standard gauge transformed railways in Spain, by enlarging the potential interoperability intersection with neighbours. Railways also work around this constraint with redundancy, by changing bogies at gauge breaks: Dual-gauge track may be an alternative over short distances.

3.3.4. Coupling constraints

Coupling constraints relate to differences among Coupler Type, Coupler Strength, Intra-train Communication, and Brake Release. They may preclude interoperability between standard trains and heavy trains. Physical coupling may be foremost, but increasingly one must recognize additional relationships: Coupling functionality may be so complex that it makes sense to integrate all connections—physical, pneumatic, electric, and electronic—but that limits interoperability to the same kind.

Coupling well illustrates the relational nature of constraints. As individual constraints are eased, trains tend to become heavier, and faster, imposing associated demands on coupler strength and brake signal propagation. Radio-based distributed power has facilitated such interoperability through an associative relationship for many years.

Redundant-functionality examples abound. The RoadRailer CouplerMate device interposes between RoadRailer's proprietary trailer coupler and whatever coupler the operator otherwise uses; the changeover rack in Spoornet's Blue Train enabled a vacuum-braked locomotive to control the graduated release air brake.

3.3.5. Propelling constraints

Propelling constraints stem from differences between Power Supply and Motive Power. Territoriality and technological progress have influenced energy supply frequencies and voltages, resulting in impeded interoperability among them. So-called autonomous traction, namely diesel locomotives, can facilitate associative relationships: Photographs of open access trains frequently show diesel locomotives under catenary. Evidently, they offer seamless movement from non-electrified origin to non-electrified destination, even though the intermediate line haul may follow an electrified route. Electric motive power manufacturers have provided redundant functionality by multi-system locomotives.

3.3.6. Authorizing constraints

Authorizing constraints stem from differences between Signaling Type and Train Control Type. Interoperability is most problematic where vertical integration within national- or territorial boundaries left proprietary interfaces. Communication based train control elevates functionality to a higher-level, and by executing it within information technology, can enhance interoperability. The European Rail Traffic Management System and North American Joint Positive Train Control initiatives exemplify the objective of associative relationships—in practice overlays—with legacy systems.

3.3.7. Clearance constraints

Clearance constraints stem from differences between Load Height and Vertical Clearance. They inhere neither in railways nor in their technologies, but relate to historical technical architecture decisions. Other modes have comparable interoperability constraints, for example aircraft wingspan versus airport bay. This constraint applies particularly to freight railways, where the inability to interoperate high loads, such as double stacked containers and piggyback trailers, on electrified routes, precludes realizing the full potential of heavy axle load, and hence of realizing the full competitive advantage of the rail mode. The rapid growth of open access operator rail4chem (Raith, 2003, p. 159) should thus not surprise: Its traffic is rail friendly, because the density of its chemicals traffic makes for substantial axle load

before encountering clearance constraints. Commodity density may thus facilitate an associative relationship between clearance-related attributes.

3.3.8. Internal consistency constraints

Note that constraints mentioned thus far have related to differences between sets of infrastructure- and vehicle attributes. They may equally originate as internal consistency constraints on interoperability. For example, light rail and heavy rail trains might not share infrastructure because they differ in End Strength, or heavy freight trains might not share a passenger train route because their permissible Ruling Gradient differs.

3.4. A way forward

3.4.1. On the nature of interoperability constraints

The constraints mentioned above may appear comparable to Maslow's hierarchy, where needs at one level remain subliminal until needs at subordinate levels are satisfied. Similarly, interoperability constraints at one level may seem to mask constraints at subordinate levels. For example, a power supply incompatibility may seem crucial only after eliminating border-crossing formalities, or brake system incompatibility may not seem to constrain interoperability while track gauge incompatibility is a super ordinate constraint. The author posits that considering multiple constraints as hierarchical is a flawed simplification of reality. Whether they are hierarchical or relational is thus a fundamental question. If they are indeed relational, it could lead to an understanding of how associative relationships could enhance interoperability.

3.4.2. Reconcilable- and irreconcilable constraints

The author defines a reconcilable constraint as one for which technologists can devise an interoperability solution. Reconcilable constraints tend to be programmable or systemic, because they relate to configuration or deployment of equipment. Irreconcilable constraints tend to be physical, because they relate to mating physical components. The fewer the functionalities that must physically interface, the greater is the probability of finding a reconcilable solution. For example, one can conceive of a mechatronic wheelset with programmable gauge: An integrated coupler with programmable contours and programmable air and electric connectors seems far-fetched.

Ideally, one would like to minimize the physical content (hardware), and maximize the programmable content (software). Advances in mechatronics hold the prospect of separating functionality from form, to gain interoperability through programmability. This establishes the notion of *associative relationships*, introduced in Section 3.3.1, which achieve interoperability by introducing hardware- or software solutions that establish one-to-one relationships between the pertinent attributes.

3.4.3. A relational perspective

Note that the interoperability constraints discussed here are no more than introductory, and that their possible number, and the relations among them, are too numerous to describe in words. An alternative approach to comprehend their complexity is therefore required. One can conceive of a database, that describes the set of all train systems and -subsystems, and the set of all infrastructure systems and -

subsystems, included in an interoperability and intraoperability domain of interest. An entity model view (an information engineering concept) graphically illustrates the business rules, embedded information, entities, relationships, and data attributes, which such a database should support.

The author developed a high-level entity model view in Annexure 1, as basis for further discussion. Appreciate that a single page can by no means be exhaustive. Note that the keys to the infrastructure- and vehicle attribute tables correspond to the interoperability constraints already discussed: Construction of a fully populated database would identify all possible constraints: Any attributes that do not match represent a constraint.

3.4.4.　　　Interoperability in practice

In Annexure 1, the author deliberately chose the relations depicted in colour, by cross-breaking the variables Axle Load (*light* and *heavy*) and Speed (*low* and *high*), which derive from the genetic technologies *Bearing* and *Guiding*. This yields the four railway archetype quadrants depicted: *Light* Axle Load and *low* Speed (Urban); *heavy* Axle Load and *low* Speed (Heavy Haul); *heavy* Axle Load and *high* Speed (Heavy Intermodal); and *light* Axle Load and *high* Speed (High-speed Intercity).

Interoperability in railways generally means operating diverse trains over contiguous networks: Operators frequently do not attain it seamlessly, or without associative- or redundant functionality. Inspection of the attribute tables reveals why: Generally, the attributes that associate with each of the four archetypes are distinct. This means that many constraints will impede interoperability among these quadrants. Each is therefore essentially a unique domain, although they share the same railway genetic technologies. This situation begs the question: What subset of ideal interoperability might suffice?

3.4.5.　　　Intraoperability in practice

The author found several distinct perspectives on railway intraoperability, so some aligning seems in order.

First, there is agreement that intraoperability reduces system life cycle cost, by re-using system elements across many systems. Some system elements are intrinsically intraoperable, for example, any brake system or any signaling system can support operation on non-interoperable track gauges. There are even opportunities to think outside of the box: Where technologies are not railway specific, economic benefit could accrue from intraoperability with other modes—for example, some diesel engines do duty in marine, mining, *and* railway applications.

Second, intraoperability means that some subsystems can operate over all systems in a domain: Railways traditionally call this *interchangeability*, and apply it to operation across contiguous networks. It is arguably a more attainable objective than full interoperability in many railway instances, at least in the medium term. Consider that coaches and wagons may interchange among railways, although the locomotives that haul them may not, because of constraints on propelling- and authorizing interoperability. In such instances there is compelling reason to keep trailing loads intact, while economic reality dictates changing locomotives at systemic discontinuities. Note that interchangeability may approach full interoperability, as in North America, in which case the terms are synonymous: However, even there, absolute interoperability remains elusive.

Third, intraoperability should facilitate technology development within a technical architecture. To illustrate, a railway has DC and AC locomotive classes that each operates on dedicated supply networks: Because they need not multiple unit, each class got its own, incompatible, control system. Now that technological advances have made dual system locomotives available, new locomotives that should multiple-unit with either existing class, will multiple-unit with neither. The value of identifying constraints that intraoperable subsystems may avoid is self-evident.

Fourth, the North American Joint Positive Train Control program uses the term *intraoperability* to describe fall back under failure conditions, or to run unequipped trains on equipped routes.

Intraoperability is a subset of interoperability, which the railway industry appears to have glimpsed but not fully exploited, because its technical architecture is not yet adequately developed.

4. Measures of progress

4.1. Some railway systemic objectives

4.1.1. Scope
The following key objectives in the drive for sustainability bear on railway technical architecture. They are indicative, and by no means exhaustive.

4.1.2. Increase throughput
Sustainable railways continually increase capacity on existing networks, by developing their genetic technologies to operate heavier axle loads, higher speeds, and longer trains. Each of these thrusts will test interoperability constraints against legacy systems.

4.1.3. Accommodate traffic diversity
Where freight- and passenger trains share the same infrastructure, the performance gap between them strains scheduling intraoperability. Ideally, they should run at same speed, stop in same distance, and fail to the same degraded state: Narrowing the gap between their performances has been a long-standing interoperability objective.

4.1.4. Enhance safety
Pressure to reduce railway accidents is mounting; therefore further investment in train control systems is probable. This issue has significant implications for both interoperability and intraoperability as network- and train operators establish their separate franchises.

4.1.5. Promote global reach
As networks coalesce, demand for interoperability will increase. Opening architecture on global scale is an overall objective that seems inevitable. Most likely, this will unify train and infrastructure attributes through an interplay among bridging devices, mechatronics applications, and domain segregation.

4.1.6. Enhance scalability

The genetic technology Coupling makes railways the most scalable transport mode, enabling it to dynamically adapt resources to demand. The resulting large-scale transformations may nevertheless shift operations into different, more demanding domains. Once again, a technical architecture is indispensable.

4.2. Thrusts and achievements

4.2.1. Introduction

Despite interoperability constraints from its fragmented past, the railway industry is opening its technical architecture. Analogous to information technology, the following examples illustrate the pragmatic thrusts that make business sense.

4.2.2. Railway *bridges*

The following equipment enables physically incompatible or non-mating devices to interoperate. Spoornet's forthcoming ECP braking specification calls for transition vehicles to interpose between air-braked locomotives and ECP-braked trains in feeder services; its forthcoming locomotive investment program makes provision for transformer cars, to operate 25kV locomotives on 50kV. The US high-speed non-electric locomotive technology program is a novel way to achieve performance interoperability by high-speed passenger trains, normally electrically propelled, on non-electrified routes (Federal Railroad Administration, 2002, p. 5-5).

4.2.3. Railway *routers*

To the extent that railways cannot offer ubiquitous door-to-door service, they need to align with road hauliers. North American railways understand the notion of working with trucks, and it underpins the growth in intermodal traffic (Stagl, 2003, p. 34). Europe expects a similar approach, forming alliances with partners from other modes (ERRAC, 2002, p.6). The revitalizing aspect of these developments is that routing initiative resides externally to railways, in logistics service providers.

4.2.4. Railway *gateways and smart hubs*

BNSF's Logistics Park in Chicago exemplifies the railway equivalent of this information technology concept, offering customers a new level of logistics integration. It enables BNSF to interchange directly with other Class 1 railways, instead of using an intermediary switching railway. It enables companies to consolidate all Chicago freight in one location. In future, it plans to add multi-user wagonload and trainload facilities, and warehouses (Multi-modal, 2002, p. 6). TFM has built a smaller, though correctly named, Automotive & Intermodal *Gateway* in Mexico (Foran, 2003, p. 15).

In the light of these developments, the author questions the ultimate mission of railway interoperability. Is it to keep traffic exclusively on rail, even if service quality does not meet customer expectations, or is it to interoperate in logistics chains to deliver high quality service? As logistics hubs and gateways emerge, the role of railways could well change from inter<u>m</u>odal to inter<u>n</u>odal.

4.3. A question of domain

Given the large number of possible interoperability constraints, one might question whether they need all be satisfied within a single domain, or whether there exist homogeneous Service Offering (see Annexure 1) subsets that railways may operate, or interoperate, more effectively in separate domains. The greater the variety of service offerings that must interoperate, the more heterogeneous the equipment- and infrastructure attributes, and the more costly or improbable their alignment will be.

It seems particularly apposite to examine freight- and passenger train homogeneity. Essentially, they are genetic variations of the same technologies set, whose attributes differ significantly. Separating their infrastructure might achieve more than aligning their performance. The value of separating local passenger services from other train services is already widely appreciated. Perhaps railways should extend the practice to all train archetypes.

5. ECP braking plus distributed power

5.1. Background

The author has been involved in Spoornet's cable-based ECP braking plus distributed power fleet conversion, for which a call for tenders was imminent at time of submission. He examined the potential of these technologies to open architecture, and found the following.

5.2. Contributions to open architecture

5.2.1. Pro interoperability

ECP braking unifies mutually exclusive direct release- and graduated release braking characteristics, lifting train length constraints associated with graduated release braking. This opens the way for interoperating long heavy trains on networks where that has not been possible before. Of course, physical train length constraints may remain.

As railways leverage their genetic technologies, trains become heavier, and existing locomotives aggregate into larger consists. Distributed power facilitates multiple unit operation of non-compatible locomotive classes, thereby enlarging the intersection of motive power interoperability. It also mitigates the associated interoperability constraint of low-strength couplers, because it reduces longitudinal in-train forces to below acceptable thresholds.

Both technologies reduce the performance differential between freight- and passenger trains, thereby facilitating scheduling interoperability to accommodate traffic diversity.

5.2.2. Pro intraoperability

ECP braking offers global brake system interoperability, through facilitating intraoperability across all existing pneumatic brake systems. This holds promise of reducing the life cycle cost of brake control systems.

Both technologies expand the application of mechatronics—separating hardware, actuation, and information. The case of ECP braking transition vehicles, which will have a pneumatic-information-pneumatic control sequence, is particularly interesting.

5.3. Impact of failure mode

One ECP braking failure mode, unlikely though it be, is pneumatic backup following total failure of electric- and electronic systems. This could introduce a new interoperability challenge: Whereas train control is usually predicated on brake systems that fail safe, pneumatic backup could lengthen stopping distance beyond normal (R. Bergstedt, private communication, June 2003). This condition would need to be recognized in interoperability relationships between Signalling Type and Train Control Type.

5.4. Industry standards formation

Cable-based ECP braking plus distributed power to AAR standards has the potential to emerge as the industry standard, simply because no other contender beat it to market. This illustrates how the information technology model could well take root in the railway industry. Furthermore, the suppliers played a significant role in forming standards, once again endorsing the information technology model.

6. Conclusions

6.1. Open technical architecture as meta-model

The author has shown that open technical architecture, interoperability, and intraoperability, can lay a foundation for mutually supportive relationships among train- and infrastructure operators within their industry, and for building rewarding relationships with partners in the larger logistics services industry. A meta-model to guide railway industry is ready to support those with the courage to apply it.

6.2. Value of ECP braking plus distributed power

ECP braking plus distributed power contribute significantly to intraoperability and interoperability, by strengthening the global reach of the genetic technology *Coupling*. Together with communication-based *Authorization*, they apply information-based technology to reconcile previously irreconcilable constraints, in support of continental- and intercontinental interoperability.

6.3. Interoperability and domain

Interoperability is a worthy objective, but difficult to realize. Regarding genetic technologies and interoperation, *Bearing* does not readily support it, and *Guiding* may require associative equipment: Tight definition of domain eases both constraints. If the railway industry overplays interoperability within its domain, it could become vulnerable to being marginalized by the larger logistics domain.

6.4. Exploiting intraoperability

Intraoperability appears to offer economic benefits, independently of interoperability, which the railway industry has hardly started exploiting. However, exploiting its potential requires a strategic vision of the industry's future: It may be more valuable to intraoperate with logistics partners than to interoperate with railway peers.

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8.   References

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