

# Selected heavy haul insights: Some South African perspectives

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## 1 Introduction

This paper presents perspectives from long exposure to heavy haul railways in South Africa. Some of them may seem controversial, to challenge existing mindsets and to stimulate discussion. It offers insights which the author believes might add value to positioning railways in Russia. It also steers clear of areas where indigenous competence is manifest—e.g. wheel-rail interface, in which field an International Heavy Haul Association Specialist Technical Session was held in Moscow in 1999, and its Best Practice Manual has been translated to and printed in Russian. To relate the perspectives in this paper to the Russian background, four applicable papers from the most recent two International Heavy Haul Association events were consulted, namely Besedin & Muginshtein (2005), Muginshtein & Pyasik (2007), Muginshtein, Rakhmaninov, Pyasik & Yabko (2005), and Zakharov, Bogdanov, & Zharov (2007).

This paper draws on selected developments on the 860km Sishen-Saldanha iron ore export railway, and the 420km Ermelo-Richards Bay coal export railway, both of which were commissioned in 1976, with throughputs of 15 million tonnes per annum (Mtpa). The Sishen-Saldanha railway originally deployed 202-wagon trains at 26 tonnes/axle. It was upgraded to 30 tonnes/axle in 2001, with throughput approaching 30Mtpa. It is currently being expanded and upgraded to deploy 342-wagon trains for a throughput of 67Mtpa. The Ermelo-Richards Bay line originally deployed 50-wagon trains at 20 tonnes/axle. It serves some 40 mines in the Mpumalanga coalfields, the furthest being 160km from Ermelo. It was expanded and upgraded to deploy 200-wagon trains at 26 tonnes/axle for 65Mtpa, in the mid 1980s. Plans for further expansion to 91Mtpa are currently under consideration.

The author addresses increasing train length- weight-, and speed: Heavy haul railway throughput is a function of the number of wagons per train, their axle load and hence their payload, and cycle time. The latter is of course a function of train speed: Note nevertheless that several cycle time elements involve slow movement (e.g. loading and unloading) or even no movement at all (e.g. inspection and testing), and are therefore insensitive to speed.

## 2 Freight rail positioning

### 2.1 *Railway genetic technologies*

Steel-wheel-on-steel-rail transport competence is closely linked to the abilities of its wheel-rail interface. The vertical and lateral components of wheel-rail interaction support two of rail's three genetic technologies, respectively Bearing (the ability to carry heavy axle loads), and Guiding (the ability to run at high speeds). Coupling (the ability to couple many vehicles into a train) is the third genetic technology. Together, they support the railway mode, and distinguish it from all other transport modes. The references indicate that Russian researchers are also working in these fields.

The genetic technologies give railways distinctive competitive strengths: Representing them as three mutually orthogonal axes yields the following four archetypal applications, in which railways are naturally competitive. First, Bearing and Coupling support heavy haul railways. Second, Guiding and Coupling support high-speed intercity passenger railways. Third, Bearing, Guiding, and Coupling support heavy intermodal<sup>1</sup> railways, which convey double-stacked containers. Fourth, Coupling on its own supports urban railways. This paper addresses two of the archetypal applications, namely heavy haul- and heavy intermodal railways.

### 2.2 *Railway corporate citizenship*

Corporate citizenship concerns a railway's contribution to society through its core business, social investment, and engagement in public policy. Multivariate statistical research has revealed a railway corporate citizenship factor named Positioning Freight Rail (Van der Meulen & Möller, 2008). It suggested that sustainable freight railway positioning was driven by the presence of Heavy Intermodal, Distributed Power, and Heavy Haul, in the context of Infrastructure Ownership Locus, Relative Maximum Axle Load, and Infrastructure Operator Diversity. This paper therefore addresses the essence of freight railways, namely heavy freight, either bulk commodities or double stacked containers, heavy axle load, and long trains in the context of those drivers.

The abovementioned research also identified a separate though similar railway corporate citizenship factor named Positioning Passenger Rail, which reflected underlying drivers that differed from those of freight rail. Russia's vast railway network supports both freight and passenger traffic, and it will be interesting to observe how it resolves their contending requirements into the future.

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<sup>1</sup> The author uses the term heavy intermodal to distinguish double stacked container trains from single stacked container trains. While the latter may indeed be classified as intermodal, in the strict sense that they connect with one or more other modes, their axle load is too low to position them competitively, and they are generally not successful in free markets.

## **3 Application to heavy haul and heavy intermodal**

### **3.1 Trains**

#### **3.1.1 Tonnage**

Heavy haul trains should ideally be long and heavy, to maximize payload per train, and hence to maximize throughput with respect to line capacity constraints. Therefore they combine heavy axle load from the Bearing genetic technology with long length from the Coupling genetic technology. In addition, they should be as fast as reasonably practical. Consignments of bulk commodities are by nature not generally urgent, so high speed is not a fundamental requirement. Nevertheless, cycle time drives rolling stock fleet size, so the Guiding technology also contributes value. In the author's experience, the following insights help to fit heavy haul trains into the broader railway setting.

#### **3.1.2 Insights**

##### *3.1.2.1 Coupling and slack*

The total amount of coupler slack in a long train can be substantial, and inappropriate or injudicious train handling may cause jerks due to run-in or run-out. However, when properly managed, slack can accommodate gradient changes, and consequent speed changes, with low coupler forces. This includes accommodating gradual redistribution of tractive forces between distributed locomotives as the train passes over crests and through sags, and when making a transition from synchronous- to asynchronous control, and vice-versa.

Efforts were made to eliminate or minimize slack action by using slack-free couplers. However, while normal operation was found to be comparatively smooth, one unintended consequence was that the scale of derailments escalated. It appeared that the energy absorption capacity of conventional drawgears reduced the number of collaterally derailed wagons, and that reducing the longitudinal energy absorption capacity therefore increased the number of collaterally derailed wagons. This phenomenon was named the Slackless Bogeyman (Van der Meulen, 2001) after research into the causes and outcomes of heavy haul derailments on the Ermelo-Richards Bay line.

##### *3.1.2.2 Human factors*

A train driver's perception of his or her control of their task can influence their capability and productivity. During the course of heavy haul development on the Coal Line, through successive generations of new locomotives and wagons, it was appreciated that sensory feedback to train drivers in respect of modulation of locomotive power and -braking controls contributed significantly to raising their perceived competence, and ultimately their actual competence. The following aspects were progressively optimized: Indication of acceleration; response to control lever movement; brake block material and friction characteristics; wagon brake ratios; relations among electric (rheostatic or regenerative) braking, friction braking, and down gradient

variations<sup>2</sup>; time delays between traction and braking set-up; ramp rates for traction and braking effort; and shape of tractive and braking curves (Van der Meulen, 1993). They were related to common train handling situations, namely starting from standstill, passing over sags and crests, descending long grades, and precise stopping. Ultimately, it was possible to make a 200-wagon train handle more easily than the original 50-wagon trains on the same route.

### *3.1.2.3 Distributed power*

As trains become longer and heavier, and locomotive tractive effort increases with advances in wheelslip control, heavy haul railways eventually find themselves at the limit of coupler strength. Further increases of tractive effort require consideration of distributed power (DP), to reduce coupler forces at any particular point in a train, and in some instances also to enhance brake system response by applying and recharging simultaneously from multiple positions in a train. The ideal is to place locomotives only at the ends (front and rear) of a train: Motive power changes can then easily be accomplished, and the conceptual basis for driver training is simple. For very long and heavy trains, such as the 342-wagon trains being implemented on the Sishen-Saldanha line, more than two locomotive consists may be required (Veldsman & Mulder, 2005).

Commercially available DP systems support synchronous- or asynchronous control of locomotive consists, with the proviso that under asynchronous control, consists ahead of the fence cannot apply traction while consists behind it apply braking, to mitigate against breaking a train in two.

When a train is fully on up- or down gradients, the distributed locomotive consists may be operated synchronously. When a train passes over a crest, a fence can be placed behind the leading consist to enable it to go into electric braking, while consists behind the fence remain pushing, until they also need to apply electric braking. In the case of more than two locomotive consists, the fence can be moved progressively rearwards: When passing through a sag, the front consist gradually reduces electric braking, while the rear consist gradually increases traction: This controls slack in a relatively high-speed energy-saving maneuver.

In addition to reducing coupler forces, DP also allows diesel locomotives to be added to electrically hauled trains in situations where overhead traction supply is inadequate. Ideally they are added at the rear, to give stability against train break in twos during overhead power fluctuations.

Uniformity of train loading should also be considered. For uniformly loaded trains, such as those that convey coal or ore, the rear end can accept high tractive effort, because adhesion is good and compressive forces do not break couplers. However, less DP is typically applied at the rear of container trains, because the natural variance in wagon loads increases the risk that wheel unloading together with high compressive forces may lead to derailment of lightly loaded wagons.

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<sup>2</sup> Note that at that time AAR direct release air braking was the only viable braking system option. Electronically controlled pneumatic (ECP) braking, which supports graduated release, was not yet on the horizon.

#### *3.1.2.4 A world record*

The foregoing work accumulated a substantial body of knowledge regarding train dynamics, particularly in the comparatively rugged terrain of the Ermelo-Richards Bay line. Over time, curiosity arose regarding what ultimate limits on train size might exist. Eventually, it was decided to answer the question by transferring know-how from the Ermelo-Richards Bay line to the Sishen-Saldanha line. Hence, on 26 and 27 August 1989, a 660-wagon ore train, with gross mass of 71000 tonnes, was hauled by sixteen locomotives, in three consists coordinated by voice radio, over the full 861km length of the Sishen-Saldanha line (Robinson, 1990). While the outcome did not have immediate relevance, it did provide a framework within which to conceive further South African heavy haul developments.

#### *3.1.2.5 Integrated braking and distributed power*

Given adequately stable bogies<sup>3</sup>, braking becomes the next constraint on increasing train size. Conventional direct release pneumatic braking has served heavy haul railways well, but it does compromise performance at wagon level to improve performance at train level. The ideal, of course, is instantaneous and uniform response throughout a train. In addition, the heating variance among wheels on long down grades<sup>4</sup> can result in failure of outliers.

When electronically controlled pneumatic (ECP) braking became available in the late 1990s, Spoornet implemented a pilot scheme to quantify the benefits of the new technology. The instantaneous response reduced braking distance, which allowed higher over-the-road speeds, while the uniform brake cylinder pressure gave uniform wheel temperatures, which allowed higher speeds on steep down gradients within existing wheel thermal loading limits (Van der Meulen, 2001).

The presence of a cable throughout the length of the train had obvious attractions for DP as well: This functionality was specified, and Spoornet's pilot scheme became the world's first integrated ECP braking and wire DP train. ECP braking supports graduated release, which together with DP provides intuitively easy train handling. It provides a solution that, for new applications, is scalable to whatever challenges a heavy haul or heavy intermodal railway is likely to face (Van der Meulen, 2004).

#### *3.1.2.6 Automation*

Driving heavy trains remains a demanding job, despite technological advances. Furthermore, nowadays many people are averse to irregular hours and shift working. The ultimate objective is thus automation or unmanned trains. In the lead-up to the ECP pilot train, Van der Meulen & Cortie (1998) explored some conceptual train driving automation issues on a 300-wagon train on the Ermelo-Richards Bay line. The networked control of ECP braking has the potential to address individual wagons, and the question therefore was whether it was possible to configure a train such that portions on up

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<sup>3</sup> Heavy haul state-of-the-art maximum speed is currently in the vicinity of 80km/h.

<sup>4</sup> Direct release air brakes develop brake cylinder pressure by equalizing brake pipe pressure and auxiliary reservoir pressure, by passing air from auxiliary reservoir to brake cylinder. Resultant brake cylinder pressure, which depends on piston stroke and return spring strength, can vary from wagon to wagon.

gradients could power, and portions on down gradients could brake. The concept was attractive because applying traction or braking as necessary to particular wagons or train segments would simplify modeling an automated train. The configuration was approximated by combining three 100-wagon trains into a single train, with the brake pipe isolated between each of them. Brake pressures and coupler forces were measured at selected locations. The three sections were powered and braked independently, informed by accelerometers on each locomotive consist, to test the hypothesis that strong central command was not required. It was encouraging to find that the train handled easily, held no surprises, and drivers quickly grasped the new paradigm, thereby supporting the hypothesis.

It is significant to note that Rio Tinto has announced that it plans to automate its iron ore railway in the Australian Pilbara ([www.railpage.com.au](http://www.railpage.com.au) on 27 September 2008).

## **3.2 Infrastructure**

### **3.2.1 Life cycle considerations**

Greenfields heavy haul routes offer opportunities to apply the best current insight into infrastructure design. However, existing lines frequently need to carry more and/or heavier traffic, with limited or perhaps even no incremental investment. The author has found the following insights to ease the fit. Of course, the principles apply also to greenfields projects.

### **3.2.2 Gradients**

#### *3.2.2.1 Asymmetry*

It is possible to construct dedicated heavy haul lines with asymmetrical ruling gradients, such that loaded trains face flatter gradients than empty trains. This applies both to new lines, where steeper downgrades may reduce construction costs, and to upgrading existing lines, where reducing only long up grades similarly reduces construction costs. For example, the Sishen Saldanha line was originally constructed with 4‰ up gradients and 10‰ down gradients, while the Ermelo-Richards Bay line was originally constructed with symmetrical up- and down gradients of 15.2‰, but up gradients were subsequently reduced to 6.25‰ when 200-wagon trains were introduced. Two issues need care when providing asymmetrical gradients.

The locomotive regenerative- or rheostatic braking capacity is determined by the number of locomotives required to haul the train on up grades, while total braking energy dissipation (locomotive electric braking plus train friction braking) on long down grades would be higher than on symmetrical grades. This means that the amount of energy dissipated in train wheels could reach critical values, and appropriate speed limits need to be applied and enforced.

When the difference between up and down gradients is sufficiently large, and trains are very long, it may not be possible to recharge the train brake after stopping on a down grade before the train reaches the prescribed speed on that downgrade. This situation occurs on the Ermelo-Richards Bay line, where the number of locomotives required to haul a 200-wagon train on a 6.25‰ up grade cannot hold it with the locomotive independent brake on a 15.2‰ down grade. It was necessary to fit a holding brake, which is coupled through the

first 100 wagons, to retain brake cylinder pressure while recharging the brake pipe. ECP braking, which charges reservoirs continuously, avoids this issue.

#### *3.2.2.2 Inflections*

It is sensible to avoid more than one gradient change of sign under a train, if possible. That is, one portion of a long train should not be on say an up gradient, followed by another portion on a down gradient, followed by yet another portion on an up gradient. It is difficult for a driver to plan train handling in such situations. Inflections, where the gradient changes to zero but does not change sign, are acceptable. Inflections are acceptable without reservation on up gradients, because braking is absent. However, on down gradient inflections, direct release braking may cause problems with excessive thermal load on wheels: Where there is insufficient recharge time, train drivers tend to either power against the train brake, or allow train speed to rise ahead of the inflection. ECP braking also avoids this issue.

### **3.2.3 Track maintenance**

#### *3.2.3.1 Longitudinal forces*

It is important to appreciate the relation between energy consumption and track maintenance. In particular, the difference between minimum possible energy consumption and any higher energy consumption must be dissipated in the track structure. Traction and braking forces are applied longitudinally to the track, and excess energy consumption manifests itself as longitudinal damage, such as buckling, rail breaks, and sleeper movement. It is thus important to minimize energy consumption, and also preferable, to the extent possible, to impart energy to a train at high speed and low tractive effort rather than at low speed with high tractive effort (Van der Meulen, 1991).

#### *3.2.3.2 Superelevation*

Long trains ideally transfer potential energy from down gradients to following up gradients by means of kinetic energy, to reduce overall energy consumption. At a particular point on the track in a sag, the speed of a long train can thus vary considerably, by as much as 50% between maximum and minimum speed. This makes it difficult to determine the ideal superelevation. Possible solutions are to avoid curves in sags, or to provide a large radius where curves are unavoidable.

### **3.2.4 Power supply**

With several reasons for concentrating locomotives at the rear of a train with DP, such as minimizing the risk of break-in-two and possibly stable tractive effort if they are diesels, it is important to consider the forces applied to the track. Adhesion is good within a train, so there is a tendency to concentrate forces. If overhead power supply is not sufficient to operate locomotives at their designed balancing speed, it is possible that unequal load sharing between consists can apply forces that are sufficiently high to move the track longitudinally. This essential difference between diesel traction and electric traction should be appreciated.

## **4 Potential applicability to railways in Russia**

The following views on potential applicability of the foregoing material are offered humbly, to a very large country, based on the author's heavy haul experience in a much smaller country.

Research has revealed a railway corporate citizenship factor named Exploiting Opportunities (Van der Meulen & Möller, 2008). It indicated association among Railway Network Coverage, Country Population, Employment Creation, Total Road Network, Passenger Traffic Volume, Country Physical Size, and Freight Traffic Volume. Russia scored high on all the foregoing variables except Total Road Network. This suggested relatively low exposure to road competition, which stimulates high railway performance. The same research found further that, in terms of railway corporate citizenship, Russia is one of the world's top five railway countries.

Russia, and the contiguous states with 1520mm gauge railways, indeed have huge networking opportunities, without even leaving their broad-gauge territory. Looking further afield, Russia's strategic location between East and West, places it in a strong position to leverage its railway competencies even further. In addition to existing heavy coal and oil traffic, one now looks forward to significant participation in intercontinental container traffic. Very long hauls fit excellently with the competitive strengths derived from rail's genetic technologies. The recent container trains moving from China via Russia, Belarus, and Poland to Germany provide a sound foundation for forthcoming traffic growth. The intense competitiveness required to overtake the incumbent maritime transport is likely to drive double stacking.

This in turn brings new challenges. An axle load of around 32½ tonnes seems to be emerging as a global standard for such applications, using four axles per double container. The challenges of operating such heavy axle loads in low temperatures will need to be overcome. Double stacking under catenary is another. While double stacking emerged in diesel territory, and perhaps emerged there because there was no catenary, the solution is becoming attractive in countries where electrification already exists, or where energy sensitivities are driving electrification. Initial solutions have already emerged. The electrified Northeast Corridor in the United States carries double stack container trains, and China Railways also double-stacks containers under wire, albeit not 2 x 9'6" containers. India is set to be next with its electrified dedicated freight corridors that will convey double stacked containers. High reach pantographs do exist, and broad gauge reduces the associated stability issues.

## **5 Conclusion**

Heavy haul and heavy intermodal are undoubtedly the foundation of future freight railways. Russia has the natural resources and vast distances to support very interesting applications of both. The Far Eastern Region has further unique railway potential. Given the formidable railways of both Russia and North America, is it too much to imagine linking them by railway via the Bering Strait?

## **6 References**

Besedin, I.S. & Muginshtein, L.A. 2005. Technical and economic challenges and decisions for heavy haul operations in Russia under conditions of



- combined traffic of freight and passenger trains. *Proc. 8<sup>th</sup> International Heavy Haul Conference*, Rio de Janeiro.
- Muginshtein, L.A. & Pyasik, M.S. 2007. Intellectual system for automated driving of trains of increased mass and length by locomotives distributed along the length of the train. *Proc. Specialist Technical Session*. Kiruna: International Heavy Haul Assoc.
- Muginshtein, L.A., Rakhmaninov, V.I., Pyasik, M.S. & Yabko, L.A. 2005. System for remote measurement of longitudinal – dynamic forces in long trains. *Proc. 8<sup>th</sup> International Heavy Haul Conference*, Rio de Janeiro.
- Robinson, B. 1990. Sishen-Saldanha record breaker. *South African Mechanical Engineer*.
- Van der Meulen, R.D. & Cortie, A.L. 1998. Towards the next level of train handling technology. *Proc. 90<sup>th</sup> Annual Convention*, Chicago: Air Brake Association.
- Van der Meulen, R.D. & Möller, L.C. 2008. Ultimate interoperability: Line-haul railways as global corporate citizens. *Proc. 8<sup>th</sup> World Congress on Railway Research*, Seoul.
- Van der Meulen, R.D. 1991. Optimisation of the economic relation between train handling and track maintenance. *Proc. Specialist Technical Session*. Vancouver: International Heavy Haul Assoc.
- Van der Meulen, R.D. 1993. Safer, faster, heavier trains by optimising sensory feedback to drivers. *Proc. 5<sup>th</sup> International Heavy Haul Railway Conference*, Beijing.
- Van der Meulen, R.D. 2001. Progress with evaluation of cable-based ECP braking and distributed power. *Proc. 7<sup>th</sup> International Heavy Haul Conference*, Brisbane.
- Van der Meulen, R.D. 2001. Soft science and heavy haul: Multivariate statistics and systemic drivers. *Proc. 7<sup>th</sup> International Heavy Haul Conference*, Brisbane.
- Van der Meulen, R.D. 2004. A systemic approach to modulating train braking and -traction. *Proc. 96<sup>th</sup> Annual Convention*, Chicago: Air Brake Association.
- Veldsman, A. & Mulder, M. 2005. Progress on the roll-out of ECPB/WDP and RDP systems on Spoornet. *Proc. 8<sup>th</sup> International Heavy Haul Conference*, Rio de Janeiro.
- Zakharov, S.M., Bogdanov, V. & Zharov, I.A. 2007. Wheel and rail profiles optimization: Problems and possible solutions for heavy haul lines in the Russian Railways. *Proc. Specialist Technical Session*. Kiruna: International Heavy Haul Assoc.