Why heavy haul?
Learning from the cost-effectiveness of heavy axle loads in South Africa

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Abstract: The paper reviews South African experience in heavy haul railways, with a view to understanding the context in which heavy haul may be successful. It examines the existence of a unique heavy haul identity, as well as some decreasing- and increasing cost drivers that apply in a heavy haul environment. It relates these to the fundamental drivers of railway competitiveness, heavy axle load and high speed, to reveal critical insights into heavy haul systemic architecture and transferring it into other environments. It concludes that such transfer is context-sensitive, and that a bold attitude is part of making heavy haul work.

1. Introduction

1.1. What is there to learn?

This paper sets out to facilitate projecting South African experience regarding the cost-effectiveness of heavy axle load into the European milieu. It seeks answers to the conference theme *Heavy Haul: The solution for Europe's future?* The systemic attributes of South Africa's railways resemble those of Europe in several respects, both as they exist now, and as they could well be in the future. The context within which heavy haul technology can deliver cost effectiveness and strategic positioning benefits ought thus to be of value to the Conference.

1.2. Heavy haul 101

One can address the theme of the conference very simply: Yes, heavy axle load works. The International Heavy Haul Association (2001) has even documented much of the expertise. Yes, heavy haul is economically viable. But …why does it work? Perhaps more importantly, when, and why, does it or might it not work? Examination of proceedings of International Heavy Haul Association (IHHA) conferences, representing a respected body of knowledge, reveals that the overwhelming majority of papers have addressed the *how* of heavy haul railroading. Few papers have addressed the *why*.

That situation suggests that some elements of understanding, and perhaps critical ones at that, may have been taken for granted. From an organization ecology perspective, the environments in which heavy axle loads originated were probably favourable for reasons that complemented heavy axle loads. It is also possible that, because early adopters did the right things, followers implemented a systemic package that worked, without fully comprehending, because there was no need to do so.

1.3. A search for context

The distinct identity of heavy haul railways was arguably recognized for the first time in a 1972 publication (Tracks to). What has become known as heavy haul emerged from customary or standard freight railway practice in North America. However, only after North American technology migrated to other, dedicated, sites did the term *heavy haul* acquire currency. The first international heavy haul conference was held in 1978 in Perth, Australia. Subsequently, a group of railway organisations from different countries agreed to an informal coalition to promote additional conferences every four years (International Heavy Haul Association, 2003). The resultant stream of proceedings is a valuable source of heavy haul knowledge. Over time, it has also broadly defined the field.

The conference organizer proposed the sub-title of this paper. However, the author considers it vital to distinguish between heavy axle load in isolation, and heavy haul as system architecture. Examples of heavy axle load in isolation are rare: It is therefore probably not a widely viable proposition. Hence, it is apposite to ask what additional systemic elements enable heavy axle load to support its superset, heavy haul. The author sets out to pose and address such questions.

The IHHA defines a heavy haul railway as one that meets at least two of the following criteria (International Heavy Haul Association, 1998). First, regular operation of trains of at least 5000 tonnes gross mass. Second, hauling at least 20 million tonnes per year over a line haul segment comprising at least 150km in length. Third, regular operation of equipment with an axle loading of 25 tonnes or more. The author sets out to establish a position, that recognizes and builds on the fundamental competitive advantages of the rail mode, by testing it against the strengths of a single degree of freedom of translation transport system, namely high axle load and high speed, from which one can examine the high-level systemic constituents that support heavy haul.

2. Some touchstones

2.1. Lessons in South Africa

Heavy haul railways have operated in South Africa since 1976, when both the Sishen-Saldanha iron ore export line, and the Ermelo-Richards Bay coal export line, were commissioned. The relevant investment decisions were taken at time when, on the one hand, the inherent competitiveness and ultimate survivability of railways in the face of intense competition from other modes was under earnest questioning and, on the other hand, major opportunities for coal and iron ore exports were beckoning.

In the event, vision prevailed over pessimism, and two new heavy haul railways were built. As newcomers to the field, the project sponsors liberally recognized other schemes in operation at that time. Although the axle load increase, from the prevailing maximum permissible 18½ tonnes/axle, to the proposed 26 tonnes/axle, was perceived as a major hurdle and an issue for thorough investigation, there was also appreciation of the necessity to address the supporting context. The author examines key issues that railway people in South Africa tackled to meet the challenge. In the present context, what learning is worth passing on?

2.2. Technology transferability

Europe has strongly influenced South Africa in respect of several technologies. In particular, European traction and signaling philosophies feature strongly. In addition, although exposure to passengers has declined in recent decades, South Africa remains a mixed freight-and-passenger setting. The author is therefore mindful that, in presenting an overview to a European conference, he must show where heavy haul has added value, as well as where blind spots may embarrass the unwary.

2.3. Statistical analysis

2.3.1. Route length analysis

The author has tabulated route lengths of twelve selected railways, which have been mentioned in IHHA and Air Brake Association proceedings, in Table 1. The selection includes railways that have a clearly distinguishable heavy haul identity, but excludes operations that share networks with other traffic, and where public domain data does not separate heavy haul from other traffic flows. Examples of the latter are North America, where many operations meet the axle load, train tonnage, and throughput definitions of heavy haul; and China, where traffic flows tend to comprise a complex mix. Statistical analysis found a mean of 661km, and a standard deviation of 333km.

The Ermelo-Richards Bay route at 580km, and the Sishen-Saldanha route at 861km, fit easily within this distribution. One can therefore regard South African experience and perspectives as reasonably aligned with those of the heavy haul industry as a whole. However, heavy intermodal double stack train routes, such as Chicago-Los Angeles, at 3000km, are clearly in a different league. This comparison underscores the need to adequately distinguish possible subsets of heavy haul when contemplating heavy axle loads and all that goes with them.

2.3.2. Cluster analysis

The author analyzed the World Bank railway database (World Bank Group, 2001) using cluster analysis. The analysis excluded fields and cases with empty cells, for which Railway Directory (2000) could not provide substitute data. Table 2 lists the fields and cases used. Several clusters emerged, that fairly reflect the state of the global railway industry.

However, at the highest levels of clustering it is evident that, other than being on the same planet, the railways of China, Russia, and the U.S. Class 1 railroads, share very little with each other or with their counterparts elsewhere in the world. It is significant that all three clusters are members of the IHHA, the U.S. as founder member, China and Russia having joined later.

Cluster analysis needs careful examination and comparison of the clusters to appreciate the underlying distinctions, which is beyond the scope of this paper. It stands to reason that the twenty-three fields used are not sufficiently exhaustive to explicitly measure attributes of systemic architecture. They are therefore complex, and implicitly aggregate relations among many underlying variables.

2.3.3. A unique heavy haul identity?

The author examined the above-mentioned statistics to categorize and understand differences among the systemic architectures of railways. At the level of discourse of the present paper, it is therefore sufficient to recognize the unique identity of heavy haul railways, as well as the seminal role of the U.S. Class 1 railroads. Can one now associate any requirements with it? The author argues that the distinct positioning of heavy haul that emerged, and subsets within that positioning (that he discusses in Paragraph 5.2.1), is sufficient cause to consider carefully the alignment between the system architecture, and the intended purpose of that system.

2.4. Creating a conducive environment

From the foregoing discussion, it should be evident that prospective entrants to heavy haul will need to align their axle load aspirations with a host of supporting considerations. What follows sets out to survey what conditions would allow the benefits of heavy haul to materialize.

3. Decreasing cost drivers

3.1. Higher productivity

Increasing axle load liberates an array of cost-decreasing drivers, key elements of which are discussed below. In general, they increase productivity, and hence render railways more cost effective. Notwithstanding cost decreases, there are also concomitant cost increases, discussed in Section 4.

It is also important to recognize that cost is not the only criterion in customers' decision-making processes. While cost may be significant in heavy hauls subject to source competition, where high-value manufactured goods in containers are heavy hauled subject to modal competition, service becomes the dominant criterion, and cost becomes a subordinate criterion. Cost effectiveness per se is insufficient to fully realize the competitive potential of the rail mode: Railways need to complement it by adequate performance on all dimensions that clients deem important.

3.2. Numerically smaller fleet size

Most obviously and directly, increasing axle load drives down the number of wagons to convey a given traffic throughput. It also drives positive spin-offs, such as fewer trains to schedule, fewer vehicles to maintain, fewer assets to manage.

3.3. Higher wagon load-to-tare-ratio

The mass of several wagon components is essentially independent of axle load—e.g. brake systems, couplers, and drawgear. This driver leverages increased axle load to advantage at individual wagon levels, because a larger body alone is usually sufficient to increase payload. Furthermore, several structural elements are sized with respect to life cycle considerations, such as abrasion- and corrosion resistance. When sized appropriately for those purposes, they may be relatively lightly stressed at low axle load. Increasing axle load can optimize the balance among various determinants of size. Consequently, increasing axle load tends to use functional- and structural design elements more efficiently, thereby raising load-to-tare ratio. In turn, this further reduces the fleet size required to convey a given amount of traffic.

3.4. Lower-cost rolling stock

3.4.1. Locomotives

Increased permissible axle load allows locomotives to haul heavier loads within given usable adhesion. The heavier permissible mass typically permits relaxed structural design and low-strength low-cost materials, rather than critical structural design and high-strength high-cost materials. Consequently, the cost per unit tractive effort is driven down.

3.4.2. Wagons

Increasing axle load for wagons drives advantages in two areas. First, for bulk commodities, increased axle load comes from volumetrically enlarging the body. Even though higher strength/mass materials may be indicated, the body structure nevertheless remains a relatively low cost/mass element of total wagon cost. Second, for containers, platforms may be articulated by carrying them on bogies between platforms. This eliminates almost one bogie per platform, a relatively high cost/mass element of total wagon cost. Consequently, the cost per unit payload decreases. In both cases, the cost of running gear design elements such as bogies, brake systems, couplers, and drawgear, tends to be relatively insensitive to axle load. Furthermore, running gear maintenance tends to be a significant operating cost item: Reducing equipment count reduces maintenance costs pro rata.

3.5. Reduced energy consumption

Rolling resistance decreases as axle load increases. Longer train length averages gradient over undulating terrain, thus enabling energy transfer between portions of the same train. Use of distributed power reduces string lining in curves and the concomitant off-tracking forces that contribute to curve resistance. Higher load-to-tare ratio reduces the dead mass hauled back and forth between mines and ports. These factors combine to drive energy consumption down.

3.6. Higher labour productivity

Increasing axle load drives train crew, yard crew, and maintenance team productivity upwards, for several reasons. First, output per task increases in proportion to payload increase, whether it be maintaining wagons, marshaling wagons, or driving trains. Second, heavy haul trains tend to operate between well-defined origin and destination pairs. This facilitates concentrating examination and repair, thereby increasing labour productivity. Third, fewer or no inspections are required en route, because trains can be maintained within a defined operational cycle.

3.7. Higher throughput, and a caveat

As applied until now, railways involved in heavy haul have tended to leverage the economic advantages of heavier axle load by operating long, heavy, unit trains. One needs to appreciate this practice, with a view to projecting heavier axle loads into other settings. While it exploits competitive advantages of the railway mode vis-à-vis competitive modes in moving traffic wholesale or in bulk between limited origin-destination pairs, it also introduces an implicit constraint on flexibility. One should therefore carefully consider the applicability of heavy axle loads and heavy haul to other environments or settings.

4. Increasing cost drivers

4.1. Systemic issues

Increasing cost drivers stem from the objective of wringing maximum throughput from a given asset base, personnel complement, and consumable resources, as axle load is increased. They need to be recognized, quantified, and offset against the decreasing cost drivers, to arrive at the net benefit of increasing axle load. Some relevant issues, as they have manifested themselves in South Africa, follow.

4.2. Premium components

One should regard implementation of heavy axle load as a way of life rather than an unchanging position. Competitive market forces tend to converge a heavy haul system against multiple constraints simultaneously. Furthermore, many components experience what one might regard as accelerated degradation in a normal railway environment. Continuous improvement is therefore always prominent in a heavy haul environment. It provides both the opportunity, and the driver, to implement successive generations of components as learning advances. For this reason, premium components have emerged. They set out to extend service life, or to reduce the rate of degradation, by promoting high strength materials, wear resistance, corrosion resistance, accuracy (wheel and rail profiles), reliability, and safety. So, for example, all South African heavy haul wagons have self-steering bogies. It is important to balance the quality of components, recognizing that an advance in one area may trigger unexpected degradation in another. South African experience indicates that strong engineering support is needed, either in-house or through the supply industry, but most likely both.

4.3. Routine maintenance

4.3.1. Infrastructure

The author here addresses only differences between heavy haul- and normal operations. Signaling is thus excluded. It is also worth noting that heavy haul publications rarely address electrification maintenance. This could be for two reasons. First, not many heavy haul lines are electrified, and hence there are few potential contributors. Second, electrification of heavy haul lines does not differ materially from that of other applications. The key issue with electrification is that of provisioning, which the author addresses in Paragraph 4.4.

While routine track maintenance addresses issues such as ballast cleaning, destressing, profile grinding, rail pad replacement, rerailing, resleepering, track surfacing, the challenges have arisen in other situations. For example, work has done in respect of; distress following longitudinal track movement (the so-called Paulpietersburg syndrome) (Maree, 1989); sinusoidal rail side wear (Kretzmann, 1997); formation rehabilitation (Lourens & Maree, 1997); and dipped rail joints following an increase of axle load to 30 tonnes. However, work on rail profiles cannot exist in isolation from the complementary wheel profile: The issue is therefore treated separately in Paragraph 4.3.5.

4.3.2. Locomotives

Wheel-rail forces become more critical as axle load is increased, and materials that are more wear-resistant enter service. Venter (1989) described problems relating to abnormally low locomotive wheel life following rerailing with harder rails, which development of new rail profiles and application of lubrication in curves resolved. Kretzmann (1997) described problems of extreme locomotive wheel wear, which were resolved by ensuring accurate bogie alignment.

Self-steering locomotive bogies hold the prospect of ameliorating this sort of problem, as they have done for wagons. South Africa has a small fleet of self-steering locomotives, which unfortunately have proven unreliable in service for reasons unrelated to their steering capability. The self-steering locomotive bogies that are becoming commercially available are attractive from a heavy haul perspective.

4.3.3. Wagons

South Africa has learned that heavy haul wagon maintenance should address two key objectives. First, ensure good running gear maintenance. Wayside condition monitoring systems are currently being rolled out to realize this (Tournay, 2001). Alignment accuracy (Kretzmann, 1997) and bogie tracking accuracy (Tournay, 2001) are key objectives. Second, in the case of bulk commodities, particularly coal, abrasion- and corrosion resistance are also important (Maxwell & Benadé, 1997).

4.3.4. Wheel-rail and train-track interaction

This field is the heart of heavy hauling. South Africa has learned that to manage it effectively requires a multidisciplinary, integrated approach. It comprises two constituents. First, optimize wheel-rail contact, which is the essence of increasing axle load. It subsumes wheel profiling, rail profiling, degradation modeling, wear limits, and lubrication. Kuys (1989), Durham (1997), Tournay (1993), and Howard, Fröhling, & Kayser (1997), have chronicled progress in this field. Second, optimize train-track interaction, which is the essence of multiplying individual axle capacity to design a system that delivers the required output. Van der Meulen (1990, 1991a and 1991b) has addressed the determinants of longitudinal forces applied by trains to the track. The integration of these two constituents extends heavy axle load to full heavy haul.

4.4. Energy provisioning

An electrified heavy haul railway moves away from a well-regulated supply network with relatively many light trains of approximately equal size, to a less-regulated network with relatively few heavy trains of possibly disparate sizes. The latter attribute peaks when trains in one direction run loaded, and return empty in the opposite direction, as in the case of many bulk commodity routes. Where heavy trains conveying high value goods in containers are involved, economic forces tend to minimize unbalanced traffic flows. When using electric traction, system design must recognize issues such as:

- Low scalability,
- Unpredictable external supply dynamics,
- Operation within, rather than at the limit of, the tractive effort-speed characteristic,
- Tractive effort interruptions, and
- The problematic nature of regenerative braking in freight service (Van der Meulen, 2000).

These issues are typically absent in a diesel-powered operation. They are not insuperable, but do need attention.

4.5. Train driver training

Drivers of heavy trains command recognition at a higher level of skill in South Africa. If not explicitly driven by remuneration, then by seniority, the selection process ensures that the feeder channel starts with experienced train drivers, and further training elevates the requisite skills. The advent of ECP braking and distributed power has however changed the requisite skills. As reported elsewhere (Van der Meulen, 2001), the new technology materially reduces the skill required to drive a heavy train. This closes the gap between run-of-the-mill trains and heavy trains, thereby leveling train driver skill requirements.

4.6. Unintended outcomes

South African experience rests on an environment of no passenger trains on dedicated heavy haul routes; few passenger trains on other heavy haul routes; and substantial single track. Many other heavy haul railways have similar settings. This means that the consequences of derailments, due to operating equipment at the limit, are typically limited to the equipment and crews directly involved.

Such derailments are attributable to causes such as wheel fracture (due to thermal overload and surface- or internal defects), rail fracture (due to impact loading and surface- or internal defects), and drawgear fracture (due to excessive tensile force and manufacturing defects or stress concentrations). Of course, other loading conditions and defects also result in failure, but their degradation is usually more gradual, they are less exposed to impact loading, and hence they are more likely to be detected during routine inspections.

The consequences of derailing a long, heavy train may be more severe than for a short light train. However, safety standards for heavy haul may be less stringent than for mixed traffic. These issues should feature in any argument for transferring technology from one setting to another.

5. Context for solutions

5.1. Locating a positive nexus

The relative balance between cost decrease drivers and cost increase drivers is context-sensitive. They can have a positive resultant in one set of circumstances, and a negative resultant in another. This section explores the preconditions for a positive nexus.

5.2. Four railway quadrants

5.2.1. A baseline reference

The author has found it useful to examine the advantages of heavy axle load and heavy haul by juxtaposing the drivers in sensible relation to each other. The rail mode is a single-degree-of-freedom-of-translation mode. This parameter distinguishes it from unguided surface transport, which can have two degrees of freedom of translation, and spatial transport, which can have three degrees of freedom of translation (some spacecraft, aircraft and underwater craft).

A single degree of freedom of translation confers both advantages and disadvantages. The disadvantages are well known, namely the inability to service directly sites not linked to the network, and the need to aggregate and disaggregate small consignments to build economic line haul loads. Much creative effort has gone into ameliorating these disadvantages, but ultimately they remain a weakness of railways. The advantages are equally well-known, namely precise application of load and accurate guidance. These advantages enable railways to carry heavy loads (axle loads in excess of 40 tonnes are rare in other surface transport modes) and operate at high speeds (speeds in excess of, say, 200km/h are rare in other surface transport modes).

However, the relations among these advantages and disadvantages seem to be grasped less well. Cross-breaking axle load and speed gives the four quadrants in Figure 1. Three of the four quadrants describe subsets of the railway mode that exploit one or both of the advantages of a single degree of freedom of translation mode, namely heavy axle load and high speed. Railways can hold their own against competitive modes in these three quadrants.

The remaining quadrant is outside the scope of this paper. Nevertheless, for the sake of completeness, note that railways in this quadrant exploit neither heavy axle load nor high speed. It accommodates the economic weaklings of the industry, namely urban-and suburban rail, traditional long-distance passenger trains, and general freight trains. These three examples are not economically sustainable. Either they require subsidies, or their technologies hybridize (to appropriate advantages from other modes, e.g. Bombardier's GLT and RoadRailer), or they succumb to competitive forces.

Where efforts to counter the disadvantages of a single degree of freedom transportation mode fail to elevate railways to competitive dominance, this cross break yields insight into why success was elusive. Alternatively, it suggests how to reposition railways to be more competitive in the first instance.

5.2.2. The Sperry Award

Many accolades for transportation exist. However, the Elmer A. Sperry Award, which shall be given in recognition of a distinguished engineering contribution, which through application, proved in actual service, has advanced the art of transportation, whether by land, sea, or air (SAE International, 2003), is, to the author's best knowledge, the only one to recognize significant contributions across the entire transportation industry. In the railway field, it was awarded, among other, as follows:

1957 The diesel-electric locomotive.
1966 The New Tokaido Line.
1977 Tapered roller bearings for railroad use.
1987 Curved plate railroad wheel designs.
1994 A slack free connector for articulated railroad freight cars.
2000 The *Train á Grand Vitesse*.

Mapping these awards to appropriate quadrants in Figure 1, to produce Figure 2, indicates that they indeed have marked significant contributions in the cross-break. The Sperry Award thus lends credence to the quadrants described above, and the variables that define them.

5.3. Competition type

5.3.1. Source competition

The time-honoured heavy haul railway conveys bulk commodities in one direction, and empty wagons in the other. Such railways typically support a global logistics solution, which subsumes items such as mining, land transportation, stockpiling before export, maritime transportation, stockpiling at destination, and ultimately consumption. Because several global sources may compete for business, the total logistics cost, including that of the rail sector, comes under pressure. Such source competition therefore tends to favour relatively short railway hauls from mine to port. South African experience in this market segment has been positive.

5.3.2. Modal competition

Modal competition is possible where more than one mode connects an origin-destination pair in parallel. Here the rail mode may compete with other transportation modes, usually road or water, in respect of high-value freight. Railways ought to be able to make the most of their fundamental advantages, namely heavy axle load and high speed, to maximize their competitive advantage in this market segment. Such modal competition therefore tends to favour relatively long, continental-scale or even intercontinental-scale, railway hauls.

One sees evidence of this driver at work in North America, where emphasis on interchangeability (uniform track gauge and interoperable rolling stock) has resulted in a railway network of continental scale. One sees further evidence of continental-scale objectives in Europe, where initiatives such as Trans Europe Rail Freight Freeway set out to establish a continental-scale railway network. Last, one also sees emerging evidence in initiatives such as Transport Corridor Europe Caucasus Asia (TRACECA), and the Trans Asian Railway Network, that set out to establish intercontinental railway networks.

Thus, where modal competition is involved, competitive networks will offer large-scale connectivity. In this respect railway networks that convey freight, differ little from telecommunications networks that convey information. South African experience in this market segment is minimal.

5.4. Realizing high axle loading

5.4.1. Influence of traffic type

How does one raise axle load in practice? Railways in South Africa have not been able to increase axle load to the 25 tonne heavy haul threshold, other than on bulk traffic routes that convey coal or iron ore. For example, the average axle load on the Johannesburg-Durban Corridor is of the order of 10 tonnes/axle, while 22 tonnes/axle is permissible. Traffic in this corridor comprises a broad mix, but includes the highest proportion of container traffic in South Africa. The immediate challenge therefore is to lift actual axle load out of road vehicle domain, rather than to aspire to unattainably high axle loading. Two reasons underlie this situation.

First, vertical clearance, constrained by overhead traction equipment, is insufficient to allow double stacking of containers, and hence achieve high axle load. It is difficult for a railway to compete with road hauliers for high-value freight when it cannot fully realize its inherent competitive advantages, while the competition offers superior door-to-door service. European railways have applied small-wheel bogies to maximize utilization of available vertical clearance. However, as in South Africa, double stacking, and hence high axle loads, seems beyond reach. Small wheels may in any case be inconsistent with the heavy axle load practice of relying on wagon wheels to contribute a substantial portion of braking energy dissipation during long descents.

Second, the modalities of increasing axle load on a general freight network, or a mixed freight and passenger network, are daunting. It is impractical to economically increase the payload of existing wagons by more than marginal amounts, but it is eminently feasible to increase the payload of new wagons. It is also uneconomic to upgrade track in a general freight setting before there is traffic to use it. The North American approach has been to first increase permissible axle load, and apply the resulting revenue increase to upgrade the track. This requires judicious trade offs among degradation rates, increased maintenance costs, increased revenue, and capital investment. A project is currently under way at Saaiwater in South Africa to assess the implications of operating 26 tonne axle load over track originally designed for 18½- or 20 tonnes (Tournay 2001), with this approach in mind.

5.4.2. Coupler strength

It is axiomatic that, for given permissible train length, train mass will increase as axle load increases, if the permissible vehicle profile can also support a higher mass per unit train length (if it cannot, higher axle load may be pointless). Trains that fully exploit the competitive advantages of heavy axle load thus tend to be heavy and to require high tractive effort. While distributed power is always an option to contain coupler forces within existing limits, it is not the simplest solution. Sufficiently strong couplers thus help to leverage the advantages of heavy axle loads.

6. Critical insights

6.1. Supporting factors

Several railway operations in South Africa meet all three criteria in the IHHA definition of a heavy haul railway. However, the Ermelo-Richards Bay operation, at 26 tonnes, is barely over the 25 tonne/axle threshold, while the Sishen-Saldanha operation is currently undergoing an upgrade from 26- to 30 tonnes/axle in a program that commenced in 2000. Both operations have nevertheless consistently contributed substantial profits. One should thus reflect on what other, supporting, factors apply. Some follow.

6.2. Value of discipline

Heavy haul constrains planners and operators to recognize one or more of the following considerations. First, movement between limited origin-destination pairs encourages formation of unit trains. Second, in a mixed traffic railway, one cannot accommodate long, heavy trains at will—it is simply uneconomic to grade and lengthen all facilities to suit. On single line routes, this becomes even more important. Consequently, fixed crossing- or yard facilities are assigned, which means that scheduling and execution need to be precise. Third, driving heavy trains frequently demands a high level of skill, which means that train driver training must be at a suitably high level. Although one may perceive these considerations as burdensome, the outcome is disciplined functioning and efficient deployment of assets, which ultimately reflect positively on financial results.

6.3. Fault tolerance

Track maintenance under heavy axle loads must be impeccable, to prevent minor defects from leading to rapid degradation. Nevertheless, severe defects do sometimes occur, and although they are mitigated by temporary speed restrictions, they demand compliant rolling stock. Three-piece bogies have become the preferred choice for heavy axle load (International Heavy Haul Association, 2001: 4–65) because they are more tolerant of the sort of geometric deviations that may occur under heavy axle loads. One needs to assess to what extent this is consistent with higher speed passenger operation.

6.4. Dedicated facilities

Heavy haul generally implies provision of purpose-built loading facilities, yards, crossing loops, and terminals. Where traffic volume justifies it, even dedicated routes are appropriate. While many may perceive these as impediments, once implemented they serve to emphasize the distinction between heavy haul and general freight businesses. Over time, they engender a sense of pride, and lift heavy haul personnel to a new can-do attitude.

6.5. A caution on intermodal

Intermodal traffic, which in railway context usually means moving containers between terminals, has not been a commercial success within South Africa, and is only marginally better over border to neighbouring countries. It is simply not competitive with road over the relatively short hauls (700-1600km) offered in the market. Although container business is unlikely to be culled, because it is part of the government's mild growth strategy, it serves as a caution to other railways contemplating whether and how to implement heavy haul.

6.6. Mixing traffic types

The author examined the issue of mixing heavy haul- and passenger traffic in a previous presentation (Van der Meulen, 1999). He found, among other, that focus is important. While there are many railways in the world, successful ones focus tightly on not more than two of the quadrants mentioned in Paragraph 5.2, and as yet there are no examples of railways attaining notable success in both passenger and freight markets. This could well prove to be a major challenge in implementing heavy haul in Europe.

7. Conclusions

7.1. Context sensitivity

At present, European railways and heavy haul railways occupy different clusters. The author has shown that heavy haul blends technology and context. In turn, both blend art and science. Within heavy haul railways, the science is understood; and the context is plain, hence the art content is small. However, outside dedicated heavy haul railways, the context is complex: Although science plays a role, art appears to dominate at this time. While transferring heavy haul benefits to other settings would doubtless be advantageous, the author concludes that the context into which they are transferred, the modalities by which they are transferred, and the final system architecture, will need careful thought.

7.2. Bold versus conservative attitude

Heavy haul has flourished in intensely competitive environments. The absence of constraints from other operations has promoted a bold approach. Sometimes, commitments are made, without assurance that there will be no problems, but with confidence in competent people who can solve them on the fly. This contrasts with the more conservative approach that is sensible in an environment that involves passenger traffic, possibly with regulation that is more rigorous. The author concludes that in addition to a sound technological foundation, and integrating system architecture, a bold attitude is an essential element of making a success of heavy haul

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Table 1: Heavy haul route lengths

Country	Route	Distance, km	Reference
Australia	BHP/Mount Newman	636	Railway Directory
Australia	Central Queensland	190	IHHA 1986, p. 496
Australia	Hamersley	638	Railway Directory
Australia	Robe River	203	Railway Directory
Brazil	Carajás	1089	Railway Directory
Brazil	Vitória a Minas	951	Railway Directory
Canada	BC Rail	950	IHHA 1986, p. 320
Canada	Canadian Pacific	1100	IHHA 2001, p. 107
Canada	Québec Cartier	260	ABA 1998, p. 233
South Africa	Ermelo-Richards Bay	580	Spoornet
South Africa	Sishen-Saldanha	861	Spoornet
Sweden	MTAB	479	Railway Directory

Table 2: Fields and cases

Fields
NG Route km, MG Route km, SG Route km, BG Route km, Main Line Diesel Locomotives, Main Line Electric Locomotives, MU Passenger Fleet, Passenger Coaches, Freight Wagons, Passengers, Passenger-kilometers, Freight Tons, Freight Ton-km, Staff, Diesel Locomotive Availability, Operating Ratio without Normalization, Average Lead, Freight, Average Lead, Passenger, Employee Productivity, Employee per km of Line, Total Wages per Total Revenues, Traffic Density, Locomotive Productivity, Wagon Productivity.
Cases
Antofagasta & Bolivia, Argentina, Bolivia-Andina Network, Bolivia-Oriental Network, Brazil – FEPASA, Brazil – RFFSA, Chile, Colombia, Cuba, Mexico, Peru, Uruguay, Venezuela, Cameroon, Congo—CFCO, Cote D'Ivoire, Ethiopia, Gabon, Ghana, Kenya, Malawi, Mali, Namibia, Nigeria, Senegal, South Africa, Sudan, Tanzania, TAZARA, Uganda, Zaire, Zambia, Zimbabwe, Algeria, Egypt, Iran, Jordan, Morocco, Saudi Arabia, Syria, Tunisia, Albania, Bulgaria, Czech Republic, Slovakia, Hungary, Poland, Romania, Turkey, Slovenia, Russia, Ukraine, Kazakhstan, Belarus, Estonia, Lithuania, Armenia, Myanmar, China, Indonesia, Republic of Korea, Malaysia, Mongolia, Philippines, Thailand, Viet Nam, Bangladesh, India, Pakistan, Sri Lanka, Austria, Belgium, Denmark, Finland, France, Greece, Ireland, Israel, Italy, Japan, Netherlands, Portugal, Spain, Sweden, United Kingdom, Germany, Australia: ANR, New Zealand, Canada: Via Rail, Canada: Canadian National, Canada: Canadian Pacific, USA: Amtrak, USA: Commuter Railways, USA: Burlington Northern, USA: Conrail, USA: Denver & Rio Grande, USA: Florida East Coast, USA: All Class I Railways.

Figure 1: Four railway quadrants

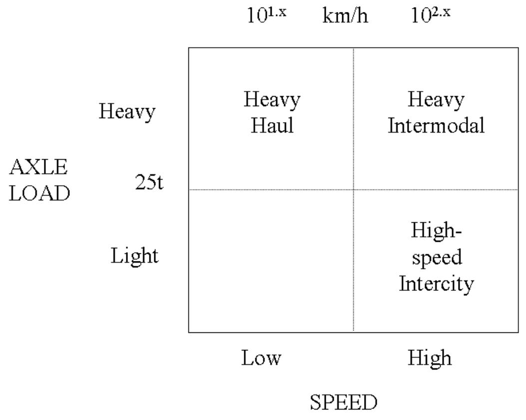

Figure 2: Relevant Sperry Awards