Differences and Similarities: Learning from Heavy Haul in Cold and Heat

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Summary:
The study compared selected heavy haul systems in Russia, representing extreme cold, and South Africa, representing extreme heat. It unpacked essential differences to answer the research question, whether contrasting perspectives on challenges shared in extreme cold and -heat could enhance scientific understanding to respond to them. Descriptions of key characteristics and parameters of both railroad systems are developed. A case study methodology explored their differences, and unsurprisingly also found several similarities. The latter concerned locomotive availability and -reliability, allowable axle load, electric traction, and systemic growth. Differences were found in respect of terrain, optimizing operations, transcontinental versus sub-continental trips, system throughput, train length, and brake systems. In conclusion, and to answer the research question, different perspectives on shared problems in extreme cold and -heat can indeed enhance understanding of them. In particular, both cases shared a need for highly reliable locomotives, to ensure high mission reliability in their respective extreme conditions. The authors also agreed that there was substantial mutual learning in the simple interchange of experiences and ideas during the study.

Index Terms: Extreme cold heat; availability, reliability, capacity, electric locomotive, car, traction

1 INTRODUCTION

Accumulated scientific understanding rests on description, measurement, and analysis of differences among a set of variables in dissimilar settings. The authors' respective railway backgrounds reflect operations in sites located in the coldest and hottest places on Earth. The conference theme *Railroading in Extreme Conditions* thus prompted a naturally comparative paper. As research question, can contrasting perspectives on challenges shared in extreme cold and -heat enhance scientific understanding to respond to them? The authors examined and compared the history, current state, and prospects of heavy haul railroads in eastern Russia and in South Africa. Despite the geographical- and technological distance, they identified several comparable aspects in their respective heavy haul operations. Both countries have several railroads that could be compared: To narrow the research to a manageable scope, the authors selected the following two cases, to accentuate differences between two disparate operations.

2 SYSTEM DESCRIPTIONS

2.1 Russia

Russian Railways, Rossiyskie zheleznye dorogi (RZD) has a huge railroad network that starts about 6000 trains every day. Topology of the western part is classic, with multiple routes between any two points, that convey mixed passenger- and freight traffic. By contrast, topology of the eastern part is simple, but with very long hauls. Its current freight mix is export oriented – oil, coal, metal, and grain. In 2010, it experienced container traffic growth in the east-west direction. Both eastern and western parts of Russia's railroads feature heavy haul operations.

This paper will focus on the eastern part, which comprises two major routes, the Trans-Siberian Railway and the Baikal-Amur Magistral (BAM). Coal, oil and ores, mined in Siberia, move to domestic- and overseas consumers in 6300-tonne trains in the easterly direction, and 9000-tonne trains in the westerly direction. The growing Asia-Pacific market needs ever more of these commodities, so much so that both major routes work at 90-100% load factor and now face a capacity challenge. Eastern railroad capacity is a major constraint on developing regional industry and increasing export volumes. Not surprisingly, growing coal exports from other countries fill the shortage left by Russia in the Pacific region.

The Trans-Siberian Railway was built from Moscow to Vladivostok between 1891 and 1916. It is now double tracked and electrified throughout its 9288km length. The highest point is Yablonevy Pass, 1019 meters above sea level. The entire Trans-Siberian is electrified: 3kV DC in the west and the Ural region, and 25kV AC in the east. Main locomotive classes in the east are VL-80 and, since 2007, 2ES5K – see Table 1 for key locomotive parameters. Maximum capacity is about 100 million tonnes per annum (Mtpa). The Minister of Transport recently stated that capacity of the Trans-Siberian was already exhausted, that traffic on the BAM was limited; and that the Trans-Siberian Railway should be destined for container and passenger transportation, and the BAM should be enlarged and used for freight traffic [1].

The BAM connects eastern Siberia and the Russian Pacific ports. It was constructed intermittently between 1938 and 1984, with long pauses; the last tunnel was completed only in 2003. The highest point is Mururinsky Pass, 1323 meters above sea level. The western part, from Taishet, where it connects to the original Trans-Siberian Railway, to Tacksimo, is electrified at 25kV AC: Main locomotive classes are VL-80, VL-85 and the new 2ES5K. The route is not electrified east of Tacksimo. It uses diesels 2TE10 in various modifications. Typical train mass there is 5600 tonnes. The BAM is double tracked from Taishet to Ust'-Kut, the remainder is single tracked.

The route traverses harsh terrain. Some 50% is located higher than latitude 56°N, and operates in extreme Arctic conditions. Most parts of the BAM have strong continental climate with extreme temperatures; 35°C and higher in summer and -55°C and lower in winter. The maximum annual temperature range at a single site can approach 100°C. Around 200 days per year average below 0°C.Tynda, capital of the Baikal-Amur route, is considered comfortable, with ≈50°C average annual temperature range and daily temperature changes of ≈20°C. Taishet and Sovetskaya Gavan have average annual temperatures of 0°C, while New Chara has only -11°C. Permafrost depth in the Tacksimo area is 10-15m. Summer rains can precipitate more than 100mm at a time. Additionally, the north part of the Transbaikal region has seismic activity – earthquakes up to XII on the MSK scale, i.e. all surface and underground structures completely destroyed, are possible.

Standard axle load was formerly 24-25 tonnes: Since the early 2000s new- or reconstructed track supports 30 tonnes, although no such cars are yet in service. Mainlines use continuously welded R65 rail of 65 kg/m, laid at 1520mm track gauge. Temperature for de-stressing is 25-35°C, and cold season stabilization is by means of expansion joints only. The westerly direction has only light gradients, except two passes over the Ural Mountains (Chelyabinsk-Ufa and Perm'-Ekaterinburg), while the easterly direction has some sections with 2.8% upgrade. Moscow to Irkutsk has no tunnels, whereas Irkutsk to Vladivostok has 21 tunnels, plus one to Nakhodka.

Trains typically convey 71 loaded cars or 100 empty cars. However, many short stations cannot accommodate 100-car trains. A graduated release air brake system is used. Couplers are SA-3, also used by Nordic heavy haul: The nominal maximum force is 2500kN, but operational limits of 950kN for starting and 1300kN when moving above 10km/h apply. Distributed power (DP) is not currently in use. A domestic radio distributed power (RDP) system, ISAVP-RT, exists for old-type DC electric locomotives hauling 18000-tonne, 780-axle trains. However, in 2007, a brake application command did not reach the remote locomotive, resulting in derailment of 19 cars and a locomotive. Hence RZD has questioned ISAVP-RT, and currently supports development of a new system SUL-R-RT for AC and DC microprocessor controlled locomotives. Interestingly, RZD can link two 9000- or 6300-tonne trains and move the coupled train with crew coordinated by voice radio. This technique is widely used in summer, when one track is closed for maintenance.

Typical 25kV AC substations are placed 50km apart and feed 25km to left and right. They have 25- or 40MVA transformers that support 60MVA peak. For heavy upgrades, 40MVA substations with two transformers in parallel are provided: In this case the overhead conductor can feed 880A nominal, while during test trips more than 1200A has been observed.

Table 1: Key Parameters of Russian and South African Locomotives

Loco-motive Class	Year in Service	Wheel Arrangement	Mass, tonnes	Power at Rail, kW	Traction Motor Type	Continuous Tractive Effort, kN	Wheelslip Control	Electric Braking	Track gauge, mm	Power Supply
VL-80t	1970	Bo'Bo'+Bo'Bo'	184	6160	DC	400	Per bogie	Rheostatic	1520	25kV AC
VL-80s	1979	Bo'Bo'+Bo'Bo'	192	5920	DC	400	Per bogie	Rheostatic	1520	25kV AC
VL-80r	1974	Bo'Bo'+Bo'Bo'	192	6160	DC	400	Per bogie	Regenerative	1520	25kV AC
VL-85	1986	Bo'Bo'Bo' +Bo'Bo'Bo'	288	9360	DC	657	Per bogie	Regenerative	1520	25kV AC
2ES5K	2007	Bo'Bo'+Bo'Bo'	192	6120	DC	423	Per bogie	Regenerative	1520	25kV AC
2TE10m	1981	Co'Co'+Co'Co'	276	3660	DC	245	Per bogie	None	1520	Diesel
9E	1978	Co'Co'	168	3900	DC	390	Per bogie	Rheostatic	1067	50kV AC
15E	2010	Co'Co'	180	4500	AC	450	Per axle	Regenerative + rheostatic	1067	50kV AC
34	1976	Co'Co'	111	1760	DC	181	Per bogie	Rheostatic	1067	Diesel

2.2 South Africa

South Africa has a railroad network of ≈23000 route km, most built to narrow track gauge, 1067mm, in colonial times. It forms part of the contiguous Southern African Development Community network that stretches from Cape Town to within 400km of the Equator. However, narrow gauge railroads are not inherently competitive, so much of the latter network has gradually lost traffic to other transport modes, and Africa has not developed a continental railroad network. Nevertheless, narrow gauge can support entry-level heavy haul. South Africa's national railroad, Transnet Freight Rail (TFR), has two heavy haul operations, the Sishen-Saldanha iron ore export line, and the Ermelo-Richards Bay coal export line.

The authors selected the Sishen-Saldanha line as example of heavy haul in extreme heat. Traversing generally arid, hot, terrain between latitudes 28ºS and 33ºS, it presents an ideal counterpoint for extremely cold, wet Russian conditions. Built between 1972 and 1976 to export 18Mtpa of iron ore, this 861km single-track railroad was archetypical heavy haul in many respects. Mines are located near Sishen, 1295m above sea level, and the port is in Saldanha Bay on the Atlantic coast. Except for the last 150km close by the coast, inland temperatures range from a minimum of -5°C in winter to a maximum of 45°C in summer, giving a range of only 50°C. Precipitation is ≤160mm per year, and ≤5mm in dry months. Snow is unknown. Topography is generally fairly easy, but crossing three river valleys (Kenhardt, Orange, and Berg), plus one escarpment, challenge train handling at those sites. Ruling gradients are asymmetrical, 0.4% against loaded trains, and 1% against empty trains. Initial axle load was 26 tonnes for cars and 28 tonnes for locomotives. Rails are 60kg UIC laid on concrete ties at 650mm spacing.

Initial trains conveyed 202 cars hauled by six Class 34 diesel locomotives. Please see Table 1 for key locomotive parameters. The cars are fitted with AAR direct release air brakes, and equipped with AAR F-type rotary couplers to allow dumping them without uncoupling unit trains.

The line was electrified at 50kV 50Hz AC in 1977 as a hedge against oil sanctions. At that time, 50kV AC was heralded as the future of electric traction, but contrary to expectations, only three railroads ever electrified at that voltage. Now, after de-electrification in 2000 of BC Rail's Tumbler Ridge Subdivision in Canada, Black Mesa & Lake Powell in the United States, and Sishen-Saldanha, are the remaining two railroads using 50kV AC. Six substations, each with two transformers of 40MVA each, i.e. 480MVA total, supply electricity to trains. The substations are on average 170km apart, one of the advantages of 50kV in sparsely developed territory. The locomotive technology of the time did not support regenerative braking, so the Class 9E electric locomotives that came with electrification were equipped with dynamic or rheostatic brakes only. Regeneration has however now been implemented for Class 15E locomotives.

Sishen-Saldanha has followed a growth trajectory since the early 2000s, in response to increasing iron ore export demand. In 2001, car and locomotive axle loads were increased to 30 tonnes. Next, starting in 2002, the original Class 9E electric locomotives were overhauled and a new control system fitted, to increase mission reliability. Currently, new Class 15E electric locomotives are being built in South Africa. Thirty of them are already in service, with the remainder of a first order for 44 still under construction. A follow-on order for a further 32 locomotives has been placed, for a total fleet of 76 locomotives. The original nine even-numbered crossing loops plus one odd-numbered loop, have been supplemented by building nine intermediate uneven-numbered loops for a total of nineteen loops between Sishen and Saldanha. The car fleet has been expanded to match. Trains now convey 342 cars with locomotives in four consists under radio distributed power control. They are 3.6km long, with a gross trailing mass of 41040 tonnes and a payload of 34200 tonnes. Five Class 15E locomotives are required to haul a 342-car train, which constrains the number of such trains per substation. TFR therefore deploys trains with both diesel- and electric consists, typically three electric locomotives plus seven diesels. This is a suboptimum solution, which sacrifices load on the diesel locomotives so that they balance at the same speed as the electric locomotives, to avoid forcing traction motors on the latter into short time rating.

Frequency is up to 35 trains/week [2]. This relatively small number of trains supports a service design that is robust against perturbations. When complete in 2014, the expansion scheme will support throughput of 61Mtpa [3], with an ultimate vision of 90Mtpa [4].

3 METHODOLOGY

Railroad development in each country was significantly affected by cultural, economic, geographical, political, and many other differences, including the conference theme, extreme conditions. The authors set out to learn what they could from the resultant variations in fundamental railroad technologies and -practices. In the absence of an established paradigm, this paper necessarily follows a case study research design to explore topics for mutual learning. The following mix of aspects is therefore unapologetically eclectic.

4 RESULTS: SIMILARITIES

4.1 Locomotive availability and reliability

Both counties feature a high proportion of relatively old locomotives. The former USSR built electric- and diesel locomotives essentially for its domestic market. The main types, VL-80 and TE10, date from the late 1970s until 1994. However, for political and economic reasons, locomotive R&D practically ceased in the 1990s, some locomotive builders now find themselves in foreign states, e.g. Ukraine and Georgia, and overhauls were halted for a decade. For similar reasons, South Africa’s locomotive industries were decimated. New locomotive acquisition was interrupted from 1993 to 2009, and average locomotive age escalated to 30 years. These issues have contributed to current questionable reliability, while heavy haul service needs high reliability.

RZD approached this challenge sensibly, by progressively optimizing trips to decrease operating expenditure. Short trips of ≈250km for crew and ≈800km for locomotives, a legacy from steam- and diesel traction, have been optimized to respectively 400-500km and ≈3000km. Optimized crew trips are comparable to South Africa’s ore line, which has rest facilities at the halfway crossing loop. Table 2 presents pertinent availability and reliability data for the locomotives under consideration (faults per million km for two-section locomotives refer to the entire locomotive). Noting that locomotives with 95% availability and ≈20 mission critical faults per million km, on long trips of about 3000km (i.e. 72 hours between operational services), will cause an average locomotive failure delay of ≈3.75 hours on every 7th train, it is evident that target reliability must be significantly higher than at present. Russia’s superior availability and reliability achievements, based on modern condition monitoring systems, operation analysis, and failure prediction, suggest that South Africa can learn from it

New Russian locomotives may initially be less reliable than old locomotives, because they have new equipment and functions, and testing of experimental series may be incomplete. Their failure rate therefore exhibits a bathtub curve. Old but simply constructed locomotives often have superior inherent reliability. But dramatically changing working conditions for old locomotives, for example running them on super-long trips, or extending their maintenance period, or hauling heavy loads, can destroy them.

Table 2: Locomotive Availability and Reliability

Locomotive Class	Availability %		Reliability Faults per million km	
	Actual	Target	Actual	Target
Russia, VL-80 and 2TE10	95.0	95.0	14.0	14.0
Russia, 2ES5K	99.0	97.0	26-48	11.1
South Africa, ore line, all [5]	88.4	88.5	31.2	35.0

4.2 Axle load

Notional maximum axle load, at 30 tonnes, is the same for both railroads, but with qualifications. South Africa uses 30 tonnes only on Sishen-Saldanha: The rest of the country uses 26 tonnes for dedicated heavy haul routes, and ≤21 tonnes for other lines. Russia applies 30-tonne standards only to new or heavy-repaired lines – at present not yet the entire length of the Trans-Siberian or the BAM. Operation at 30 tonnes/axle is only likely in the next decade, but for selected lines, e.g. the BAM, it is possible earlier. At this time, RZD infrastructure is now fully ready for 25-27 tonnes/axle [6]. In 2010, the Tikhvin Plant started producing 25 tonne-per-axle cars. Bogies for 27 tonnes are now in certification, and production will commence in 2012.

In extremely low temperatures, construction metal properties and track substructure behavior change dramatically. Rails and metal details in deep cold are brittle and suffer accelerated fatigue and therefore need more frequent inspection. Frozen track substructure has lower elasticity that induces higher forces in interaction with rolling stock. Rolling stock maintenance is also more critical, to avoid impact forces from flat- or skidded car wheels, and rail burns caused by malfunctioning locomotive wheelslip prevention equipment.

While climatic conditions play a role, 30 tonnes seems to be the ceiling for narrow gauge track, but only the threshold for standard- and broad gauge track. Something for South Africa to learn.

4.3 Electric traction

Both routes use electric traction, which is gaining ground in global heavy haul—a desk study revealed the present tonne-kilometer ratio to be roughly ⅔ diesel to ⅓ electric. South Africa's experience in applying electric traction to heavy haul is important to Russian railroads. Sishen-Saldanha has shown that 40000-tonne trains are workable, provided that power supply is adequate. Ermelo-Richards Bay has shown that 200-car trains with head end power and electronically controlled pneumatic (ECP) brakes can tame rugged terrain (note an intention to ultimately implement wire distributed power on the ECP cable on Ermelo-Richards Bay). Both operations hold valuable lessons in absorbing regenerated energy, weak external power supply, and low line voltage.

4.4 Systemic growth

Heavy haul in both countries is growing. However, the railway capacity shortage in eastern Russia has already resulted in lost export income and hampered development of mining and domestic beneficiation. Similarly, Sishen-Saldanha throughput has lost ground to competing countries because it could not ramp up capacity sufficiently quickly. Markets abhor a vacuum: If one exporter cannot fulfill the growing needs of China, India, Japan, and South Korea, another exporter will bag the opportunity. It is therefore important for both railroads that full development precedes implementation. New development on a time critical operation spells trouble.

5 RESULTS: DIFFERENCES

5.1 Terrain

The Sishen-Saldanha route falls gently from mines to port. Ruling gradients are asymmetrical, because loaded trains travel in one direction only, and it is therefore possible to fully utilize the same motive power in both directions. However, even though the route can potentially be self-sufficient by regenerating its total traction energy requirements, use of car friction brakes on steep downgrades dissipates so much energy that this ideal is out of reach on the existing alignment. Maximum altitudes on the Trans-Siberian and BAM are lower than Sishen, and the distances are immense, so the average gradient is approximately zero. Conditions are therefore good for regenerative braking, which is widely used by VL-80r, VL-85, and 2ES5K locomotives. Depending on local conditions, regeneration has been shown to recover 15-20% of energy consumed.

5.2 Optimizing operations

The main objective is to maximize the working time of locomotives. When a train travels without stopping in one direction through all stations, it banks time for major locomotive maintenance, and increases productivity. This is of interest to South Africa. Similarly, it is necessary to increase crew productivity: Five years ago Russian crews lost substantial work time at the beginning and end of their shift. Now, after optimization, special preparation crews accept the locomotives after maintenance or repair in a depot, and move them from depot to yard and back. It saves time for the mainline crew's work. Similarly, implementation of distributed power in Russian railroads would dramatically increase crew productivity.

5.3 Transcontinental versus sub-continental trips

Rolling stock for long hauls must have high reliability. If not, frequent use of diagnostic equipment to detect failure in critical components – wheels, bearings, bogies, brakes, and car bodies, is required. However, for locomotives such control is insufficient, and it is therefore necessary to monitor a wide spectrum of internal equipment that is not accessible by track-mounted sensors. Therefore an onboard diagnostic system is needed. This was one of the drivers of Sishen-Saldanha's Class 9E upgrade. Locomotive repair depots are placed far apart, and defective or failed locomotives may travel 700-800km to nearest depot. It will be more effective if the onboard diagnostic system sent failure reports to the depot to prepare the facility. Compared to Sishen-Saldanha, the Trans-Siberian is ten such operations strung end-to-end: What for Trans-Siberian is a locomotive trip, is several round trips for Sishen-Saldanha – there is much to learn regarding mission reliability.

5.4 System throughput

If Russia were to operate Sishen-Saldanha-sized trains on its double Trans-Siberian plus at least one BAM track, it would have potentially huge throughput capacity. However, concrete and steel alone do not make railway capacity. Sishen-Saldanha runs under a corridor strategy that improves customer service through better operational interface management, improved monitoring of corridor performance, managing operational risk, identifying improvement opportunities, and managing strategic projects across all stakeholders – mine, railroad and port. Although a vastly more complex operation, a similar corridor strategy could help railways in eastern Russia increase and balance productivity in the overall mines, railroad and port logistics system. Furthermore, Russian unloading facilities cannot use rotary dumpers without uncoupling cars: Therefore rotary coupler technology is very important for decreasing unloading time.

5.5 Train length

It appears that eastern Russian railways could convey substantially more traffic than at present by deploying longer trains. Distributed power, by radio as on Sishen Saldanha, or wireline as envisaged for Ermelo-Richards Bay, is worth considering. When increasing train length by radio distributed power, the train air brake system remains unchanged, and inherits whatever issues it had before RDP. When increasing train length by wire distributed power (on the same train communication network as ECP braking), the train pipe becomes a feed pipe, and electronic control enables features not possible with radio distributed power. Importantly, on cars they include control of empty/load settings, and remote application and release of handbrakes. This eliminates two major defect categories, hot wheels and skidded wheels: In turn this increases mission reliability, and essentially eliminates associated track damage by cars, in extremes of both cold and heat.

The latter variant is appropriate for unit trains with rotary couplers so that cars need not be uncoupled for unloading. At this time Russia does not operate unit trains, and connectors for ECP braking or wired DP is a major concern because they are perceived to have low reliability in extremely cold conditions. Perhaps unit trains will emerge when the freight operators' market has matured. It should then be workable to start using ECP braking for selected freight trains (coal, oil or container) that operate on stable routes. It is also important to recognize that many infrastructure issues must be resolved for successful distributed power implementation.

5.6 Brake system

Against South Africa's direct release background, it is interesting to note that RZD uses graduated release braking – its trains of maximum 71 cars loaded, and 100 cars empty, must be the longest graduated release trains in the world. Long empty trains are possible because braking plays a smaller role for them. However, pneumatic graduated release braking may induce high coupler forces near the front of long empty trains, and perhaps derail them. It is also interesting to note the practice of combining trains in summer to support closing one line for track maintenance. ECP braking, which supports simultaneous graduated release on all cars on very long trains, would make a natural contribution to the efficiency and safety of very long trains.

6 DISCUSSION

Although shared extreme-condition locomotive challenges initially attracted the authors, they found even more valuable synergy by examining car-, energy supply-, locomotive-, and track subsystems. With appropriate architecture, such subsystems have the potential to be integrated and to show online, the collective health of a complex railroad system, to provide information for data mining, and even to provide more information about locomotives than their own onboard systems. Such topics will therefore assist in determining the scope of future research interaction, which will no doubt follow on this exploratory study. Railroads require substantial investments in assets that take long to implement and that have a long design life. The opportunities for mutual learning should therefore evolve over time into sustainable relationships.

Comparison of their current states shows that both railroads are at a stage when demand exceeds capacity. While some may see this circumstance as serendipitous, it should come with a warning that source competition for bulk commodities from other exporting countries can not only step into the gap, but reduce the perceived severity of the problem. In contrast to South Africa, Russian Railways do not now have dedicated lines for heavy haul operations. However, this type of specialization is on the horizon in Russian Railways' strategy for developing rail transport [7]. There will be opportunities to use make use of advanced heavy haul insights and technologies from heavy haul operations in South Africa. To reciprocate, Russian Railways' insights into sweating its assets could leverage substantial capacity from South Africa's heavy haul systems.

It was heartening to reflect on how extreme climatic conditions breed innovative railroad people. Both Russia and South Africa have explored and pushed heavy haul boundaries far beyond normal practice. In 1986, the heaviest Soviet train, with gross mass 43407 tonnes and length 6.5 km, was conducted on 300km of the Celinnaya Railroad. In 1989, South African Transport Services set a world record with a train of gross mass 71765 tonnes and length 7.3km, on the full 861km length of the Sishen-Saldanha railroad. Such achievements give confidence to keep challenging everyday limits and to act boldly when strategically significant opportunities arise.

7 CONCLUSIONS

In conclusion, and to answer the research question, different perspectives on shared problems in extreme cold and -heat can indeed enhance understanding of them. Nevertheless, the authors also concluded that railroads in extreme conditions must in the first instance simply be built to resist those extreme conditions. Both railroads traverse long distances through vast, sparsely populated, inhospitable, open spaces, so infrastructure in particular must respond directly by means of custom solutions that reflect the external impacts of local conditions. However, the differences between extreme cold and extreme hot conditions are so diverse that the amount of sharable insight and knowledge is arguably limited.

By contrast, while rolling stock must also be designed for relevant extreme conditions, it became evident that both cases share a need for highly reliable rolling stock, locomotives in particular, to ensure high mission reliability in the abovementioned extreme conditions. The authors had envisaged examining synchronized data acquisition from onboard-, energy supply-, and track monitoring systems which, when processed, would support optimal train movement and maintenance planning. Furthermore, service reliability offers scope to enhance performance of hardware subsystems that already asymptotically approach their present known limits. This is particularly valuable for narrow gauge rolling stock, because failure rates tend to be similar for any track gauge. E.g. if narrow gauge locomotives haul less because their axle load is lighter, then they will generate more perturbation per unit throughput. However, the sheer volume of other topics waylaid them, so reliability becomes a recommendation for further research.

What was also interesting is that many problems are shared among all railroads, without regard to extreme conditions. Having completed the course, the authors agreed that there is substantial mutual learning in the simple interchange of experiences and ideas, which is unlocked by exploring differences. As example of mutual learning, Russia can consider much longer trains, managed as unit trains, using electronically controlled pneumatic braking and distributed power: South Africa can consider heavier axle loads and heavier rail – if Russia can entertain 30 tonne axle load in Arctic conditions. It should be possible to increase axle load even further in hot conditions. Of course, this conclusion is perfectly aligned with the IHHA mission.

Now that South Africa has joined the Brazil Russia India China (BRIC) group, both countries will no doubt find more comprehensive and structured opportunities for experience and technology exchange, and for mutual learning.

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