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# Railways in Renaissance — Review of Achievements and Reflection on Prospects

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Additional information is available at the end of the chapter

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## Abstract

The authors introduce railway renaissance by considering the rail mode's inherent strengths, energy frugality, and developmental role. They address the research question: *Does a new post-renaissance normal now prevail?* The research progresses a multi-variate design that they developed to a case study approach as proliferation of private railway operators as a consequence of renaissance has constrained access to formerly public information. The study examined four countries, Brazil, Russia, India, and China, and one region, the Gulf Cooperation Council States, whose railways have advanced substantially in recent years through implementation of high speed, heavy haul, heavy intermodal, and urban rail. It also examined the migration of countries from the previously identified Fortuitous and Insecure railways clusters to the Enlightened, Progressive, and Assertive clusters. It found advances in institutional learning with respect to design of interventions to achieve renaissance, ownership and funding, market structure, as well as networking and expanding strategic horizons. It concluded that countries that have embraced the railway renaissance have been able to reposition their railways to play a substantial role in their economies and societies, and that a new normal has emerged, with the rail mode now a formidable contender in high-speed, high-volume, heavy-traffic corridors.

**Keywords:** Energy, intervention design, new normal, strategic horizon, railway renaissance

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## 1. Introduction

### 1.1. Manifestation of railway renaissance

From their origin in the Industrial Revolution, first-generation railways grew to dominate land transport, ultimately peaking in the late 1940s. Thereafter, they declined in the face of disrup-

tive competition from other transport modes that had flourished on the momentum of the World War II technology boom. Why did rail not get onto the same bandwagon? By then most countries had either nationalised or regulated their railways, to restrain their monopolistic power, and they had become too unresponsive to technology and market opportunities to get in on the action.

Nevertheless, railways have experienced renaissance in an increasing number of countries in recent decades. The authors have researched the associated phenomena, and published their findings in [1–7]. This chapter continues that research stream, and addresses two additional considerations that have arisen since it started, namely, the transition from finite to renewable energy sources, and the revival of the rail mode's developmental role in economic geography. While the image of global railway renaissance originally appeared pixelated, every incremental investment in one of the four market spaces where railways can compete vigorously has increased the resolution and clarity to a level where it is appropriate to once again review achievements and reflect on prospects for the future.

Railways manifest renaissance by having exploited their three genetic technologies, supporting (the ability to carry heavy loads), guiding (the ability to travel at high speed), and coupling (the ability to connect many vehicles together), that set them apart from other transport modes. The three genetic technologies and the four market spaces that they support, namely high speed (passenger), heavy haul, heavy intermodal and urban rail, have been described in detail in [1–4, 6], so this chapter will only recapitulate as necessary to introduce its content. Together, they have turned railways around from grave decline and set them on new growth curves in each of the four market spaces mentioned. They have realised new opportunities by taking markets away from air over medium distances, from road and maritime transcontinental and intercontinental container movements, and created new markets in rampant urban rail.

## 1.2. Rail's inherent strengths

Rail's inherent strengths have been explained before in the references mentioned in subsection 1.1. What follows is, therefore, a brief recapitulation with emphasis on subsequent learning.

By comparison with other transport modes, such as air that offers three degrees of freedom of movement (longitudinal, lateral, and vertical) at relatively high cost, and road that offers two degrees of freedom of movement (longitudinal and lateral) at moderate cost, the rail mode is constrained to a single degree of freedom of movement (longitudinal) by its guideway, back and forth on a predetermined, inflexible route. To compete effectively against transport modes that take advantage of more degrees of freedom of movement to get closer to the ideal of ubiquitous access, railways must offer compensating advantages. Fortunately, a guideway endows railways with three genetic technologies that at once distinguish it from, and offer advantages over, all other transport modes. The rail mode's inherent competitiveness resides in its genetic technologies, and it must draw on them for competitiveness and sustainability in the aggressive global logistics and mobility markets.

A pair of flanged wheels on an axle running on a pair of rails fixed to the ground precisely defines the spatial relation between rail and wheel. The three genetic technologies that stem

from this relation are first, the supporting genetic technology, or the ability to carry heavy loads. The application path of the wheel load to the rail is precisely known and it is therefore possible to design the wheel-rail system to carry much heavier axle loads than can road vehicles. The highest heavy haul railway axle load in current operation is 40 tonnes in the Australian Pilbara, with aspirations to 42 tonnes. By contrast, vehicles on the rail mode's major land transport competitor, road, are driven autonomously; one cannot define the application path of the wheel load to the road precisely, but must design the entire road surface to accept the applied load. Consideration of economic relations among the amount of traffic and capital and maintenance expenditure has converged permissible road vehicle axle loads in the 8–9 tonne range around the world. Interestingly, where one can define the vehicle path more precisely and design the road structure accordingly, higher axle loads are possible: Thus, bus rapid transit axle loads can go as high as 12½ tonnes on specially designed runways. What about maritime transport, also a form of surface transport that can carry heavy loads? Vessels displace their own mass of water, hence their draught increases in proportion to their mass until buoyancy and deadweight forces are in equilibrium. Thus, while their cargo deadweight might be several times higher than the payload of a heavy haul train, they are nevertheless also subject to physical constraints such as limited draught, while hull drag in a medium more viscous than air incurs higher energy consumption than railways except at very low speeds, but more on that in the next section.

Second, the guiding genetic technology endows ability to travel at high speed. Once again, by contrast to its major land transport competitor, railway vehicles are precisely guided by wheel-rail forces, and can therefore safely attain much higher speeds than road vehicles that are still generally guided by humans exercising control through road-to-tyre friction forces. Freight and passenger vehicles are generally limited to no more than 120 km/h on public roads, whereas entry level on standard gauge track is 160 km/h with the ultimate maximum commercial service currently at 380 km/h. Railways can therefore generally service destinations faster and further than road, and at medium distances can also offer credible competition to aviation.

Third, the coupling genetic technology endows the ability to connect multiple individual vehicles to deliver high freight and/or passenger throughput capacity. The rail mode is therefore able to scale capacity to match demand within wide limits. For comparison, the number of trailers in Australia's commercial road trains is expressed by only a single digit; the number of barges in a single tow on the Mississippi river may be expressed by two digits; but no transport mode other than rail expresses its vehicle combinations by three digits, as for example South Africa's Sishen-Saldanha iron ore trains at 342 wagons, currently the longest in the world, and many other three-digit heavy haul train lengths around the world. For passenger traffic, coupling railway vehicles together essentially reduces the headway between them to zero. Thus, for example, single railway cars carrying say 200 passengers at two-minute headway would carry 6,000 passengers per hour per direction. Coupling ten of them together in a multiple unit train increases throughput to nearly<sup>1</sup> 60,000 passengers per hour per direction on the same infrastructure. Other modes do not support this magnitude of capacity scalability, while some modes do not scale at all, for example, aviation.

After a post World War II pessimistic interlude, during which sceptics questioned the rail mode's future and many stakeholders lost faith in it, optimism returned when appreciation of its genetic technologies stimulated vigorous new growth curves, in high-speed intercity starting in 1964 in Japan; heavy haul when mineral railways around the world recognised North American heavy freight standards in 1972; heavy intermodal or container double stacking when railroad deregulation in the United States released pent-up competitive forces in 1980; and contemporary urban rail spontaneously around the world from the start of economic globalisation in 1989. These events are widely acknowledged as having launched a global railway renaissance that would position the mode as inherently competitive against other modes in high-volume corridors.

### 1.3. Energy's vital role

Although rail is known to be an energy-efficient transport mode, it is nevertheless valuable to contextualise this attribute to develop an appreciation of what role railways should fulfil in an energy-scarce future.

Rail's energy efficiency essentially spins off from its genetic technologies. The supporting genetic technology requires a strong wheel-to-guideway interface to sustain heavy axle loads, and rail's steel-on-steel system provides just that. The wheel and rail deflect minimally to develop a small contact patch between them, and steel-wheel-on-steel-rail rolling resistance and associated energy consumption, is therefore very low. By contrast, a rubber pneumatic tyre on a road deflects much more to develop a contact patch sufficiently large to sustain the load, which increases rolling resistance by comparison with rail and hence also the associated energy consumption.

The guiding genetic technology supports high speed, which in turn allows more potential energy to be converted to kinetic energy and vice versa by widening a train's actual speed range over undulating grades, thereby reducing both energy consumed during traction and energy dissipated during braking. High speed also reduces journey times, and hence reduces the period during which auxiliary services such as heating, ventilation, air conditioning, lighting, and catering must operate. Consequently, high speed passenger trains actually consume less energy per passenger for a given journey than conventional passenger trains [8].

The coupling genetic technology averages grades under a long train, thereby reducing traction energy input and braking energy dissipation by comparison with a short train, particularly for heavy freight trains that are limited to comparatively low speed, which in turn limits the acceptable speed variation range over crests and sags and hence also the quantum of kinetic energy that can be converted to potential energy and vice versa. Coupling also reduces aerodynamic resistance because the frontal area of a train in relation to its length is small compared to any other transport mode; for example, the ratio of the frontal area to vehicle length for a TGV Duplex train is one-tenth that of an Airbus 380 aircraft, both double deckers.

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<sup>1</sup> Increasing the number of cars on a train increases its length, and hence the time it takes to clear signals for a following train. Capacity therefore scales at slightly less than in direct proportion to the number of cars.

The rail mode, therefore, occupies an energy consumption sweet spot that other transport modes cannot match. All other things being equal, propulsion energy consumption is a function of total resistance to motion, whether due to aerodynamic, hydrodynamic or mechanical phenomena, and speed. Railways essentially undercut the resistance to motion, expressed in Newtons per tonne, of all other transport modes. Relative to pipeline, railways have lower resistance from speeds higher than  $\approx 3$  km/h. Relative to maritime in displacement mode where resistance rises exponentially with speed, railways have lower resistance from speeds higher than  $\approx 20$  knots ( $\approx 40$  km/h). In addition to being faster, railway routes can also be materially shorter, for example Beijing to Athens Piraeus is 8,500 km overland, but 16,000 km by sea. In the same way that high speed trains consume less energy because the journey time is shorter, freight trains consume less energy when the journey distance is shorter. Relative to road trucks, railways always have lower resistance,  $\approx 50\%$  at low speed, increasing to  $\approx 80\%$  at 100 km/h [9]. Relative to aviation, railways always have lower resistance, although it cannot match aviation's top speed. Nevertheless, railways can be attractive even on relatively long centre-city to centre-city journey times, e.g., the fastest current Beijing to Wuhan schedule averages 285 km/h over 1,229 km, a performance that aviation would be hard put to beat when accounting for time to commute to the airport, check in, check security, reclaim baggage, and commute to destination in addition to the scheduled flying time.

Relatively low braking and traction adhesion inhere in the rail mode's steel-wheel-on-steel-rail technology. Whereas contemporary high-performance passenger trains use a high proportion of motored axles and therefore accept comparatively steep grades despite low adhesion, exploiting the coupling genetic technology with locomotive-hauled trains, freight or passenger, results in heavy trailing loads that generally require comparatively flatter grades than rubber-on-road technology to balance braking or tractive effort against total resistance and gravity component. The flatter a ruling grade, the more long-wave topography influences it and the longer the distance between grade sign changes. Thus, in a given terrain, railway grades tend to be longer and flatter than road grades. Where the downgrade gravity component exceeds mechanical plus aerodynamic resistance, any vehicle generates instantaneously surplus energy, which needs to be dissipated or stored on board, or exported to where it can be consumed or stored. Road vehicles, singly or even in combination, have higher aerodynamic resistance than long trains, so on their comparatively short down grades they generate less instantaneously surplus energy to be stored, and hybrid road vehicles with on-board energy storage have become workable. However, current on-board storage technologies are totally inadequate for line-haul railways, particularly for heavy haul but also for heavy intermodal with its progressively higher rolling resistance: Therefore such trains need to dissipate instantaneously surplus energy on board, or conduct it off-board for consumption or storage elsewhere [5, 7].

Because railway rolling resistance is very low, its instantaneous traction and braking power requirements are largely determined by grade undulations. The resultant wide swings between demand and regeneration make it desirable to exchange energy in both directions with its environment. Railways and renewable energy are thus natural symbionts, particularly when railways are linked to a sizeable grid that can also store instantaneously surplus energy

when necessary. Railways can then both consume and regenerate energy without restraint. For scale, locomotives and wind-turbines are of similar size, in the range of 2½–6 MW. While electrification infrastructure is an expensive way for railways to exchange energy with their environments, guided transport in general has the advantage that electrification need be confined only to routes defined by the guideway. Hence the emergence of inductive recharging of catenary-free light rail vehicle batteries or capacitors during dwell time halts.

It is common cause that railways are more energy efficient than other land transport modes, and at the higher speeds of which it is capable, it is also more energy efficient than waterborne transport. Nevertheless, since the first major oil crisis four decades ago, despite technological progress, potential for cost-effective energy efficiency improvements and policy efforts, the transport system has not fundamentally changed [10]. Nevertheless, recently published research has found that despite technological advances, there are still situations where freight railways do not achieve the best energy efficiency that they can [7]. Thus, while heavy freight baseline diesel traction uses comparatively expensive, but nevertheless available fuel, holds no systemic interaction surprises, and readily scales throughput, electric traction can decouple railways from on board power generation and facilitate access to other electricity generators and consumers. However, to realise its full potential, electric traction would require matching vertical alignment to locomotive performance characteristics: providing graduated release train braking; providing catenary, transformers, and feeder lines; providing high-capacity, low-latency, long-lived energy storage; and implementing net metering to render transactions transparent. Where a smart grid is within reach, the storage should come with that, and renewable energy would likely be available. There is still some way to go.

#### **1.4. Rail's developmental role**

When railways dominated land transport during their initial growth phase, they shaped the development of countries and continents, peaking in that role around mid-20th century. Thereafter, road and air transport together came to own the market until high speed railways commenced new growth in the 1960s, heavy haul in the 1970s, heavy intermodal or double stacking in the 1980s, and finally contemporary urban rail in the 1990s, thus establishing the four sub-modes of the railway renaissance. Railways in renaissance offer high capacity with high efficiency and low cost in well-defined high traffic volume corridors. After changing the economic geographies of Japan and France by means of high speed trains, developing remote regions throughout the world by means of pit-to-port heavy haul operations, shifting substantial traffic from road to rail in double-stack container trains, and supporting rapid urban rail growth in developed and developing countries, it is evident that the rail mode is once more stimulating widely dispersed economic and social development through each of its four new growth curves.

While the rail mode's initial growth phase spawned monolithic railways that introduced the first motorised transport ever with minimally differentiated offerings, renaissance has encouraged railways to do what they do best in particular market spaces in the face of strong competition from other modes. Renaissance rail is therefore always a high-capacity, high-performance transport mode in well defined corridors. Its initial investment is relatively

expensive, and particularly, infrastructure needs therefore to be long lived. While it is possible to implement rail solutions in already highly developed settings, for example, deploying monorail in the air space above existing roadways as the only remaining option to introduce urban-guided transit, the rail's combination of high performance and low energy consumption are best exploited by positioning it as the foundation on which other transport modes should build to support integrated intermodal solutions. Thus, particular building-block solutions have emerged that spatial and transport planners can customise and assemble as required. Consider domestic and international airports connected to their catchment areas by urban, regional, and high speed rail; mixed-use, transit-oriented development that maximises both access to public transport and interchange with non-motorised transport; dedicated high-speed corridors that bring agglomeration benefits to otherwise disconnected communities and conurbations; logistics parks that add value to line-haul rail service through integration with intermodal facilities and distribution centres; dedicated heavy haul railways that link ore bodies with ports; and dedicated freight corridors that convey double-stacked containers from ports to their hinterland; all competitive, effective, and efficient solutions.

Renaissance rail's contemporary developmental role is nowhere more evident than in the BRIC (Brazil, Russia, India, China) countries, which are playing an increasingly influential role in the global economy [11], and who are positioning railways as the backbone of their transport systems in fulfilment of projections that they will, in due course, join the world's major economies. This chapter will examine them and the Gulf Cooperation Council States in more detail in Section 3.

## 2. The research approach

### 2.1. New research questions

One could hypothesise that, half a century after its launch, the railway renaissance might have completed its mission, and that for railways a new normal prevails. The hypothesis is important, because not all railways have experienced renaissance. What then is to become of the stragglers? The research stream underlying this chapter initially identified a suite of technologies that encouraged the rail mode to enter vigorous new growth curves in the high speed, heavy haul, heavy intermodal, and urban rail market spaces. The logical research question at this time must then be: *What outcome has the railway renaissance facilitated in countries that have purposefully embraced it?*

The research question then is: Does a new post-renaissance normal now prevail, and as a corollary, does there seem to be any viable alternative?

### 2.2. Recap of variables used

The following groups of variables, used to examine positioning of railways in relation to their setting, have been carried over from previous research [2, 4], with comment here on their

continued relevance, and the need to introduce new ones to address the changed global setting in which railways now find themselves.

Business Group represents the way in which line haul railways deal with their task (variables: *Infrastructure Operator Diversity*, *Train Operator Diversity*, *Information Technology Leverage*, and *Total Road Network, Motorways and Paved Roads Percentage*).

Competitiveness Group represents the way in which railways position themselves to compete in their chosen or allotted market spaces (variables: *R&D Level*, *Relative Maximum Axle Load*, *Relative Maximum Speed*, *Distributed Power Presence*, *Heavy Haul Presence*, *High-speed Intercity Presence*, *Heavy Intermodal Presence*, *Motive Power Type*, and *Attitude to Competition*). Nowadays pre-competitive research is undertaken at the country or industry level, while competitive research is undertaken within industries, hence latest technologies are freely available in a global market and the R&D level has been deleted.

Contribution Group describes the railways' contribution to their host society (variables: *Network Coverage*, *Transport Task—Freight and Passenger Traffic Volume*, *Employment Created*, and *Initiative Source*, except that the latter has been redefined as *Initiative Direction*, with scale poles *Authority Initiative* and *Market Initiative*).

Networkability Group describes the extent and gauge of track, and the contiguous network beyond a country's borders (variables: *Narrow, Standard, and Broad Gauge*; *Networkability*; and *Strategic Horizon*).

Ownership Group describes the industry structure (variables: *Infrastructure-operations Separation*, *Infrastructure and Rolling Stock Ownership Locus*, and *Infrastructure and Rolling Stock Commitment Horizon*).

Society Group describes the railway setting (variables: *Country (Name)*, *Economic Freedom Index*, *Population*, *Gross National Income*, *Physical Size*, *Determinism*, and *Climate-change Position*, except that *Determinism* has been deleted in favour of the redefined *Initiative Direction*, and *Climate-change Position* has been superseded by the more comprehensive *Presence of Renewable Energy Sources*, *Ability to Regenerate Energy*, and *Availability of Smart Grids*).

Sustainability Group describes adaptation and fit (variables: *Infrastructure and Rolling Stock Investment Capacity*, *Stakeholder Satisfaction Level*, *Service Reputation*, *Safety Reputation*, and *Subsidy Influence*). Note, however, that subsidies and social obligations may be obscured to the public domain. It is therefore proposed that *Subsidy Influence* is no longer relevant, and that *Infrastructure and Rolling Stock Investment Capacity* are adequate proxy measures for sustainability. Likewise, *Presence of Independent Railway Safety Regulator* and *Presence of Automatic Train Protection* should supersede *Safety Reputation*.

Guided Urban Transit Group also describes adaptation and fit (variables *Metro Population*, *Population Growth*, *World Cities Score*, *Green Cities Index*, *Smart Card Application*; and in respect of each of the sub-modes *Light Rail and Tram*, *Light Metro*, *Heavy Metro*, *Monorail*, *Automated Guided Transit*, and *Bus Rapid Transit*: *Inaugural Year*, *Operators*, *Status of Project*, *Network Coverage*, *Rolling Stock Fleet*, *Passenger Journeys*, *Routes*, and *Stations or Stops*. In addition, driverless or automatic train operation, which maximises throughput capacity and

minimises human shortcomings is gaining market share and should be recognised by the variable *Presence of Automatic Train Operation*).

Time Group represents passage of time, a prerequisite for longitudinal research (variable: *Calendar Year*).

### 2.3. Further research design

The country as basis for defining cases is still valid in most instances, but one needs to be sensitive to larger groupings. One example is Europe, where the tortuous passage of the Fourth Railway Package through the European Parliament illustrates that, despite significant shared interests, member states also have significant own interests. Another is the Community of Independent States (CIS), whose commercial behaviour reflects the broad gauge track that they share among themselves but not with their neighbours.

The authors originally followed a multivariate statistical approach. Not unexpectedly, renaissance has changed much of the global railway industry structure. Despite uncontested broad socio-economic benefits, increasing private sector participation has constrained the amount of commercially sensitive financial and operational performance data available to researchers in the public domain. Unsurprisingly, the railway operators' corpus in several countries now resembles that of other diversified and fragmented transport modes, with information dissemination restricted to legal minimum requirements. Thus, despite its limitations, a case study approach now appears to be more workable and has therefore been adopted in this chapter. The cases were selected by virtue of their extraordinary commitments to progress towards positioning railways as the backbone of their national or regional transport systems, in Brazil, Russia, India, China, and the Gulf Cooperation Council States, or of their urban transport systems in the world's cities-with-railways as a group.

As before, the authors used content analysis of trade periodicals and associated marker events to identify countries and market spaces in which positive shifts relative to their previous positioning have taken place. Notwithstanding adopting the case study approach, the authors' ultimate objective, the scientific method, rests on measurement and hypothesis testing. Hence this chapter will serve as a spinoff to identify additional variables intended to be used in a later round of statistical research.

## 3. The cases

### 3.1. Brazil

To revitalise its freight railways, Brazil initially implemented reform-led intervention through long-term concessions (30 years renewable for another 30 years) on its freight railways in the mid-1990s. This resulted in vertically integrated concessions over a total of twelve regional freight railways, which have since grown traffic by 117% [12]. Heavy haul operations on both broad and narrow gauge, as well as general freight on broad gauge networks have flourished, attaining creditable densities of 81 million tonne-km/route-km for Vale's dedicated heavy haul

operations, and 37 million tonne-km/route-km in heavy general freight. However, Brazil's narrow gauge general freight railways achieve less than 2 million tonne-km/route-km [13]. It is therefore evident that the inherent competitiveness of Brazil's narrow gauge general freight railways is low and that their performance falls short by comparison with its BRIC peers reviewed in the next three sections.

Lease income from concessions and taxes on concessionaires have become a source of revenue for the Brazilian government. However, investment in rail services other than heavy haul has been meagre, and notwithstanding its economic upswing, high logistics costs characterise Brazil. They are estimated at  $\approx 20\%$  of the gross domestic product (GDP) and thus double the average in OECD countries. The high costs are attributed to regional differences in the state of infrastructure, even though the organisation of the Brazilian transport sector has improved substantially since the 1990s. The national rail network lacks investments and modernisation, while high harbour fees further contribute to high logistics costs. The logistics sector is highly dependent on the highway network, transporting 60% of total freight volume.

However, the network remains restricted, hindering economic growth. Although rail freight increased its logistics market share from 17% to 25% in 2013, the government would prefer a share above 50%. To achieve this, it envisages expanding the network from the present 30,000 km to 50,000–60,000 km [12]. Brazil, therefore, recently changed to an investment-led intervention, the Logistics Investment Program, a strategic project of the Brazilian State [14]. The primary intervention was to invest in railways, to raise their inherent competitiveness so that they can support economic development, and while elements of reform are still present, that is no longer the prime objective. It has connected its formerly isolated northern and southern broad gauge networks, albeit with breaks of gauge, by means of the new North-South Railway, which runs the length of the country. It is following up with two more priority freight rail projects of more than 1,000 km—the East-West line and the Trans-Northeastern Line—to open the interior of the country to development. Funding will partly be by public-private partnership (PPP), involving USD 121 billion over 30 years.

Importantly, Brazil is changing the way the new railways will operate to break monopolies in provision of rail services. Instead of awarding a single concession to operate and maintain a railway, a concessionaire will construct and maintain a line, as well as control train movements on it for a period of 35 years. State agency VALEC will manage the demand risk through the government guaranteeing to purchase the full capacity and then on-selling access to the whole new rail network to private rail freight operators, with an individual operator able to purchase up to 30% of the capacity of a particular line. This unique development in the railway world is something to follow closely. Thus far, observers feel that the significant sunk costs of building or improving a railway seem to have deterred more private investment. The federal government has filled the gap and observers expect that continued government investment in railroads is needed in the long term. Nevertheless, the World Bank considers that several steps could improve private investment in railways, among them enhancing interconnectivity between railways—Brazil operates on different track gauges, and the sheer lack of physical interconnectivity between the lines slows return on investment [15].

Brazil is working on a high speed railway in the Rio de Janeiro-São Paulo-Campinas corridor, to be implemented by PPP, although after two false starts, tendering has been postponed to give prospective bidders sufficient time to prepare. Rio de Janeiro-São Paulo is eighth on the list of the world's top 50 busiest passenger air routes. The envisaged concession period is 40 years, with commercial operation projected to start in 2020.

Brazil's cities have benefited from renaissance in urban rail: Since it started in 1989, heavy metro, light rail and monorail projects have been under construction or completed in Brasília, Fortaleza, Porto Alegre, Recife, Rio de Janeiro, Salvador, Santos, and São Paulo [13].

Brazil has thus contemplated or implemented three of the four railway renaissance sub-modes, the outstanding one being heavy intermodal or double stacking. Loading gauge on some routes is restricted, and this state possibly reflects the concentration of heavy industry in the south and southeast of the country. Brazil is oil self-sufficient and insignificant routes are electrified outside urban areas.

### 3.2. Russia

The Russian Federation is the sole shareholder in Russian Railways (RZD). It exploits its strategic location to take full advantage of its key geographical position by fully integrating the Russian railway system into the Eurasian transport network [16]. RZD's strategy for developing rail transport up to 2030 envisages significant expansion of the rail network in two stages.

The first stage involves modernisation from 2008 to 2015 to ensure necessary capacity on key routes, fundamental renewal and upgrading of existing infrastructure, and the beginning of planning and surveying work for expansion, as well as starting construction of some high-priority lines. Among the company's top priorities were reconstruction and technical enhancement of existing main lines along with construction of new lines to remove infrastructural limitations to Russia's economic growth. RZD already operates high speed passenger trains in the upgraded St Petersburg-Moscow-Nizhny Novgorod corridor. The next focus was on the Baikal-Amur Main Line as an investment in Russia's future that will substantially increase transportation of oil products and exports to the East, a more intensive development and exploitation of raw materials in its Far Eastern region, and an increase in the line's share of East-West transit traffic. The latter's catchment area stretches from China, South Korea, and Vietnam in the East, and to Estonia, Finland, Germany, Hungary, Latvia, Lithuania, Poland, Romania, and Slovakia in the West. A further priority was the construction of dedicated freight lines to tap natural resources and develop new industrial zones in Western Siberia. Around 13,800 route-km were upgraded for heavy axle loads to reduce the cost of bulk freight shipments.

The second stage from 2016 to 2030 will involve large-scale expansion, creating infrastructure to develop new economic growth areas across Russia's vast territory, deploying world-class technology and improving the competitiveness of the country's rail system on the global market [17]. This includes the North-South International Transport Corridor in strategic partnership with countries to the south, initially India and Iran, while Belarus, Kazakhstan,

Oman and Tajikistan have subsequently opted in, and requests to join from Syria, Azerbaijan and Armenia are under consideration [18]. It also includes ambitions to build a 104-km tunnel under the Bering Strait to connect the Asian and North American continents. The recent Ukraine imbroglio has, however, dampened Russia's ability and aspirations to network railways on continental and intercontinental scale. Hot off the press, in March 2015, RZD called for tenders to undertake surveys, project development, and route planning for the proposed 770-km Moscow–Kazan dedicated high speed line. One of the benefits Russia attributes to this high speed line is simply an increase in the country's prestige, since in the modern world no economically developed country will remain without a system of high-speed railways in the coming years.

Because of limits on State funding, RZD is financing its investment programme through PPPs, in the ratio 46% generated by RZD, 30% met by the private sector, 19.5% provided by the Russian Federation, and 4.5% from regional governments. Raising outside capital is done in accordance with the company's Loan Programme, which provides for various instruments to finance its operations, including syndicated and bilateral loans, rouble bonds and Euro bonds, as well as leasing and others. Key focus objectives for RZD are the interests of shareholders and partners, as well as increasing efficiency and speed of management decision-making and improving transparency of the group's activities [19].

RZD was separated from ministry control in 2003 to become a public company responsible for operational and commercial functions. Separate daughter operating companies are being or have been set up for freight and passenger activities as a possible prelude to a sale of shares. It has commenced unbundling the former monolithic entity into, among others at time of writing, Eurosib, which runs container services linking Russia's ports with central Russia and Siberia; Federal Passenger Company, a subsidiary that manages long-distance passenger operations; Freight One, a subsidiary that offers cargo and intermodal shipment using its own fleet of hired wagons, and offers rolling stock leasing; Freight Two, a second freight subsidiary that will lease or acquire new and modernised wagons; Globaltrans, a rail freight operator and freight forwarder; JSC High Speed Rail Lines, a subsidiary to promote development of high speed lines including HSR1 from Moscow to St. Petersburg, and HSR2 from Moscow to Kazan and Yekaterinburg; RailTransAuto JSC that handles a range of commodities including finished motor vehicles [13].

RZD achieves line densities of 23.6 million tonne-km/route-km plus 1.6 million passenger-km/route-km in operations where block-load freight rather than dedicated heavy haul trains share the same infrastructure with passenger trains.

Russia has lagged its BRIC peers since urban rail renaissance started in 1989. Projects completed or under construction include only three metro lines in Chelyabinsk, Kazan, and Moscow, as well as metro extensions and a new monorail line in Moscow [13]. RZD owns and maintains infrastructure and rolling stock, which it leases to suburban companies, and receives a subsidy from the state for providing infrastructure services at a reduced rate. The primary institutional weakness is unprofitability due to ticket revenue failing to cover expenditure and insufficient compensation from state authorities. Thus, ageing and under-maintained rolling

stock is gradually being withdrawn from service and not being replaced [20], to the extent that systems in two cities have ceased service.

Russia has, therefore, contemplated or implemented two of the four railway renaissance sub-modes, the outstanding two being heavy intermodal or double stacking, and urban rail. Russia's main east-west and north-south and railway routes, which among others, convey substantial amounts of container traffic are extensively but not completely electrified using 80% non-coal sources. The overhead contact wire would need to be raised to accommodate double-stacked container trains.

### 3.3. India

A railway budget presented to Parliament by the Railway Minister has traditionally funded Indian Railways (IR). The Ministry of Railways has a dedicated financing entity, Indian Railway Finance Corporation Ltd (IRFC), whose objective is to raise funds from the market to part finance the planned outlay of IR. Money so provided is used to acquire rolling stock and to meet other IR developmental needs. Rolling stock funded by IRFC is leased to the Ministry of Railways, which pays lease rentals to the corporation. IR also operates a Wagon Leasing Scheme to encourage shippers and private operators to invest in rolling stock, but it has continued to flounder. It appears that politicised relations between IR and the government, and the consequent apparent lack of strategic direction, deterred private participation. To overcome these obstacles in moving its railways into renaissance, IR has adopted the special purpose vehicles, described in the next two paragraphs.

First was the Dedicated Freight Corridor Corporation of India Ltd (DFCCIL) in 2006 under the Ministry of Railways administrative control, to plan, develop, fund, resource, construct, maintain, and operate Dedicated Freight Corridors (DFCs). Building DFCs across the country, to operate double stack container trains and/or heavy haul trains, marked a strategic inflexion point in IR's history, which has traditionally run mixed freight and passenger traffic across its network. DFCs will enable IR to improve customer orientation and meet market needs more effectively. Creation of rail infrastructure on such a scale—unprecedented in independent India—is expected to drive the establishment of industrial corridors and logistic parks along its alignment. Currently under construction, the Eastern DFC is being funded in three different ways: the Ludhiana-Mughalsarai section by the World Bank through an International Bank for Reconstruction and Development loan; the Mughalsarai-Sonnagar section by the Ministry of Railways directly; and the Sonnagar-Dankuni section by PPP. Also currently under construction, the Western DFC is funded through foreign direct investment by the Government of Japan who provided a Special Terms of Economic Partnership Loan to finance construction and procure locomotives. The Ministry of Railways will bear a remaining portion of the project construction cost as equity funding to the DFCCIL. Thereafter, construction of four more DFCs is slated to complete India's Golden Quadrilateral that connects Delhi, Kolkata, Chennai, and Mumbai, as well as its two diagonals.

Second was High Speed Rail Corporation of India Ltd in 2013, on directions of the Ministry of Railways to develop technical standards, undertake project-related studies, as well as prepare financial and implementation models. It appears that a 540-km dedicated high speed line

between Mumbai and Ahmedabad could be first, followed by five other projects during the next ten years to connect major metropolitan centres Delhi-Amritsar, Delhi-Chennai, and Chennai-Mysore. Two of the projects are set to serve portions of the Delhi-Mumbai corridor, currently tenth on the list of the world's top 50 busiest passenger air routes. The recently elected government has implemented a fast track, investment-friendly and predictable PPP mechanism to modernise and revamp the railways and implement expensive projects such as high speed rails [21].

India's networking aspirations have, thus far, not pursued a strategic horizon much beyond the 1,676 mm broad gauge that it shares with neighbours Bangladesh and Pakistan, as well as Sri Lanka's island network. It is incompatible with the two other major track gauges in Asia, China's and Eurasia's standard gauge, and the CIS' 1,520 mm broad gauge, so it is beholden to transloading containers, bogie changing or gauge-changing, which would dampen networking enthusiasm unless there were major traffic flows at stake.

India's cities have also benefited from renaissance in urban rail. Since urban rail renaissance started in 1989, projects completed or under construction include 17 metro lines in Bangalore, Chennai, Delhi, Gurgaon, Hyderabad, Kolkata, Mumbai, and Navi Mumbai, as well as a monorail line in Mumbai [13]. Interestingly, Delhi's three Phase 1 lines are the same 1,676 mm broad gauge as its national network, while its four Phase 2 lines are standard gauge, to benefit from lower prices in the larger standard gauge market. This practice subsequently spread to metros in Bangalore, Chennai, Gurgaon, Hyderabad, Mumbai, and the planned metro in Pune.

India has in quick succession rolled out metro systems in major cities, started construction of dedicated freight corridors, and recently announced a cooperation agreement with China to develop a high speed network. It is a member of the International Heavy Haul Association, and already operates double-stacked container trains. IR achieves creditable overall line densities of 10.9 million tonne-km/route-km plus 16.6 million passenger-km/route-km in operations that at present include freight and passenger trains sharing the same infrastructure. Approximately 67% of freight and 50% of passenger traffic is hauled by electric traction [22]. It has positioned itself strongly in all four of the railway renaissance market spaces.

### 3.4. China

China's railway financing system is based on the government taking the leading role, diversified investment, and market orientation. Joint ventures are the major vehicles for new railway projects. By the end of 2008, RMB 300 billion had been committed from outside the Ministry of Transport. Major financing channels include the Railway Construction Fund, contributions from local governments and cooperative agreements between Ministry of Railways and 31 provincial governments, treasury bonds and budget from the central government, strategic investors such as power plants, coal mines, ports, insurance groups (either public or private), the Dedicated Construction Fund from operation revenue, restructuring railway assets to initial public offering, issue of Railway Construction Bonds, and domestic and foreign bank lending. Implementation rests on a clear vision, a good plan, an efficient implementation mechanism, and a creative financing system.

China recently opened its third heavy haul line, the 1,216-km public private partnership Shanxi South Central Railway from Watang in Xingxian County to the port of Rizhao in Shandong Province. It follows construction of the original 653-km Datong–Qinhuangdao coal railway completed in 1992 and the 1,040-km Shenmu–Huanghua Railway, all with nameplate capacity 200 million tonnes per year.

China Railways commenced high speed service as recently as 2007, and today operates the largest and most heavily used high-speed railway network in the world.

China's cities have benefited since urban rail renaissance started in 1989. Projects completed or currently under construction include 107 metro lines in Beijing, Changchun, Changsha, Chengdu, Chongqing, Dalian, Dongguan, Foshan, Fuzhou, Guangzhou, Guiyang, Hangzhou, Harbin, Hefei, Kunming, Lanzhou, Nanchang, Nanjing, Nanning, Ningbo, Qingdao, Shanghai, Shenyang, Shenzhen, Shijiazhuang, Suzhou, Taiyuan, Tianjin, Ürümqi, Wenzhou, Wuhan, Wuxi, Xi'an, Xiamen, Xuzhou, and Zhengzhou; nine light rail lines in Changchun, Nanjing, and Suzhou; six rubber- or steel-tyred automated light metro lines in Macau and Wuhan; two monorail lines in Chongqing; and two suburban lines in Wenzhou [13]. China also operates bus rapid transit systems. Its urban-guided transit catalogue thus includes the full range of three steel-tyred solutions, namely, heavy metro, automated light metro, and light rail; and three rubber-tyred solutions, namely, automated light metro, monorail, and bus rapid transit. It is therefore able to nuance solutions for particular city requirements.

China currently sets the world pace for railway expansion and performance. It achieves a creditable 26.9 million tonne-km/route-km plus 8.89 million passenger-km/route-km on a network that at present includes dedicated freight lines (heavy haul) and dedicated passenger lines (high speed), as well as extensive mixed traffic heritage infrastructure that has been progressively upgraded. It participates in all four of the railway renaissance market spaces, although the height of double-stacked containers is limited by overhead electrification, and has developed means to finance huge railway expansion in support of its rapid economic growth. It is a strong role model for driving railway renaissance through investment in inherently competitive railway technologies.

One aspect of China's railway development elevates it above its BRIC peers, and indeed all other railway countries of note, namely, its global railway network ambitions and the progress that it is making in this regard. Its Silk Road Economic Belt and Maritime Silk Road initiatives embrace countries situated on the original Silk Road through Central-, South-, Southeast- and West Asia, the Middle East, and Europe, as well as Oceania, and North and East Africa. They call for integration of the region into a cohesive economic area through building infrastructure, increasing cultural exchanges, and broadening trade [23]. China's railway strategic horizon thus reaches out from its 107,000-km standard gauge home network to surrounding and remote regions, e.g., the entire Asia, North America, Western Europe, and Africa. The following examples start from the north and proceed clockwise to show the magnitude of China's ambitions to open up transcontinental and intercontinental standard gauge trade routes.

- Connecting into broad-gauge Mongolia to support the latter's mineral exports.

- Strengthening linkages with Russia through additional border crossings, including lines from China's northern provinces to Russian ports Pos'et and Slavyanka on the Sea of Japan.
- Cooperating with Russia to build a 7,000 km high speed line from Beijing to Moscow.
- Reaching out to North America, together with Russia. Counter-intuitively, the great circle, i.e., shortest, route from, say, Chinese manufacturing city Chongqing to the western United States is not across the Pacific Ocean, but overland via the Bering Strait between the Asian- and North American continents.
- Routing rail traffic from standard-gauge North and South Korea through China to Europe, at present routed through Russia and Belarus.
- Connecting China's southern cities Nanning and Kunming to Vietnam, Laos, Thailand, and Myanmar, by re-gauging from narrow gauge to standard gauge in the countries mentioned, with ultimate vision to connect to Singapore through Malaysia.
- Connecting Xigaze railhead in Tibet over some 1,700 km along China's south-western border to Kashi railhead in Xinjiang Autonomous Region. This will springboard links among other to Bhutan, India, and Nepal under Mount Everest by 2020; through Pakistan to the Arabian Sea; and through Kyrgyzstan and Tajikistan to Herat in Afghanistan, soon to be the easternmost outpost of the Eurasian standard gauge network.
- Leveraging its existing connection with Kazakhstan's broad-gauge network via two border crossings west of Ürümqi, one to the northwest, and one to the southwest.
- Upgrading lines from the port of Piraeus in Greece through the Balkan states to Hungary, to access Western Europe.
- Promoting new standard gauge railways in several equatorial African countries: China has encouraged standard gauge ambitions and initiatives in Cameroon, Chad, Mali, Nigeria, Senegal, and others. This topic is addressed in more detail in sub-subsection 4.1.3 in respect of schemes that have already borne fruit.

To be fair, China is not having it all its own way. While its propositions may appear attractive, smaller countries, nevertheless, seem wary of a longer term agenda. Some would like to leverage China's overtures to their own benefit. Negotiations can take a long time. Several disputed territories mark its south-western border, so political challenges are likely to equal technical challenges. But ultimately, high performance rail has become the backbone of choice for integrated, multimodal freight and passenger transport in an energy-scarce world. Countries that cannot achieve that by their own means will likely eventually accept what is on offer.

### 3.5. The Gulf Cooperation Council States

The countries of the Cooperation Council for the Arab States of the Gulf, commonly called the GCC States, are arguably the world's current railway investment hotspot. The GCC comprises United Arab Emirates, the Kingdom of Bahrain, the Kingdom of Saudi Arabia, the Sultanate of Oman, Qatar, and Kuwait.

Saudi Arabia is a relative newcomer to railways, the first line having been built in 1951 to indirectly connect the port of Dammam on the Gulf of Persia with the capital Riyadh. A direct line followed in 1985. Saudi Railways Organization operates double-stack container and passenger trains on these lines. As the spectre of peak oil approached, Saudi Arabia established the Supreme Economic Council in 1999 to formulate and better coordinate economic development policies in order to accelerate institutional and industrial reform and diversify its economy beyond petroleum. Several key railway projects followed. First is the Saudi Land-bridge, a 950-km, mixed traffic link from Riyadh to the port of Jeddah on the Red Sea to convey double-stack container trains at 120 km/h and passenger trains at 220 km/h. Scheduled for completion in 2021, the Public Investment Fund will finance it with operations contracted out. Second is the North-South Railway, a 1,400-km heavy haul route from mineral deposits in the north-western region to the Gulf port of Ras Az Zawr, completed in 2013. Saudi Railway Company, whose shares may put to subscription, administered construction, while Saudi Arabian Mining Company has a concession to operate the line. A 500-km link to Riyadh is under construction, to enable passenger and freight services to run between the capital and the Jordanian border. Third is the 320-km/h Haramain High Speed Rail linking Makkah, Jeddah, and Madinah, currently under construction. Fourth is the GCC railway, a new 2,177-km, 200-km/h double track international freight and passenger railway currently under construction to link the six abovementioned countries and integrate them with the railways of Saudi Arabia. It will follow the Gulf coast from Kuwait's border with Iraq to Salalah in southern Oman, with branches to Bahrain and Qatar, linking all six states and sharing the cost in proportion to the length of the main line in each country. The first phase was delivered in 2014 with completion expected in 2017. Fifth is Jeddah, with a joint venture of the Jeddah Municipality and the Jeddah Urban Development Company set to open three light metro lines in 2020. Sixth is Makkah, with an elevated metro to carry Hajj pilgrims opened in 2010 and four further regular metro lines approved in 2013. Seventh is Riyadh, with a university campus automated light metro opened in 2012, and an automated six-line metro, for which Arriyadh Development Authority has placed turnkey contracts for completion in 2018, and a monorail under construction to serve the financial district. Eighth is Dubai, which opened its first line in 2009, It currently operates two metro lines plus a tram line.

Saudi Arabia and its GCC fellow members have in around one decade moved from few or no railways to one of the world's most comprehensive systems. It includes all four of the railway renaissance sub-modes, high speed, heavy haul, heavy intermodal, and urban rail. The GCC example illustrates how quickly a committed authority can establish renaissance rail by selecting industry-leading practices in each of the previously mentioned sub-modes.

### 3.6. Urban rail

The following paragraphs are built on previously reported research [3, 4], including all urban-guided transit with the exception of bus rapid transit. Urban rail applications are too many to detail, therefore this section takes a necessarily highly aggregated view of the global urban rail and urban guided transit situation. The observations include all operations that qualify for inclusion in the Railway Directory's City Railways section, using the ten years spanned by the

2006 and 2015 issues [13]. Table 1 below presents their pertinent statistics in a way that brings out their significance.

During the nine years to 2015, the number of cities that have implemented urban rail or have it under construction has increased from 120 to 487 (32.7%). Of cities with existing urban rail, 47.7% increased their network size accounting for 23.3% of growth, which together with 13.4% growth in cities that previously had no urban rail of any description, resulted in 36.7% total network growth in nine years. This is exceptional growth by railway standards, and it is evident that urban railway renaissance has responded rapidly to the global megatrend migration of people to cities. Note that while the increased network size is mainly attributable to greenfield sites, there are a few brownfield sites where operations have been extended on existing, upgraded, or disused infrastructure of others, for example some tram-train projects.

Observations			Analysis							
Year	Cities, number	Global Network, km	Urban Rail Activity, number of cities				Global Network, km			
			Decrease	No change	Increase	New	Decrease	No change	Increase	New
2006	367	29457	36	156	175		-1589	27868	6859	
2015	487	38675				119				3948
Change, %	32.7	31.3	9.8	42.5	47.7	32.7	-5.4	94.6	23.3	13.4

**Table 1.** Analysis of global urban rail growth over time.

Two concurrent trends underlie the net change in global urban rail network size. The first is obviously the dominant expansive and new growth mentioned above. Notwithstanding that, 36 cities recorded an aggregate network decrease of 1,589 km. There are many reasons for this change including the ups and downs of economic growth; shifting relative economic and political power from country to country; population migrations; failure or inability to renew assets; the rise of alternative transport modes; changing social preferences; inappropriate institutional arrangements; redefined jurisdictions, usually by combining and sometimes by separating them; rationalising pre-existing networks as agglomerations develop; extending routes to tram-train applications on conventional networks; increasing intermodal integration among modes; and many others. This chapter reports on global shifts that generally favour rail, hence the foregoing phenomena are outside the present research scope and no grounded position is offered. They could justify substantial research in their own right.

Previous research has found that although Heavy Metro remains unchallenged in the highest capacity rail applications, rubber-tyred guided transit modes have challenged rail’s former unquestioned status in the light-axle-load, low-speed market space [3]. One would therefore expect Light Rail and Light Metro to be more vulnerable to competition from rubber-tyred systems. Notwithstanding that potential weakness, their good green credentials attract smaller cities that value inherent environmental friendliness over the expediency of simply moving people under the weight of popular demand. Automated Guided Transit and Monorail nevertheless seem well-positioned to drive a wedge between the heavy and light poles of urban rail. Note, therefore, that Automated Light Metro, Automated Guided Transit, and Monorail are already present in 26 of the world’s 487 cities with urban guided transit solutions.

## 4. Key results

### 4.1. Settling in of the renaissance

#### 4.1.1. Selected country outcomes

The following comments on outcomes are confined to those countries that achieved significant positive repositioning relative to their baselines in the Insecure, Fortuitous, Enlightened, Progressive, and Assertive clusters published in 2008 [2], the countries being mentioned in the same order as in that publication. This chapter, therefore, records a parting of ways between countries that have embraced railway renaissance and those that have not yet. The strong entry of new countries that have recently built their first railways, such as most of the Gulf Cooperation Council states, has demonstrated the major impact that renaissance rail can make on the transport dispensation in a country or region. It also does not necessarily mean the end of the track for countries in the Insecure cluster. As mentioned under China in section 3.5, its expanding influence is also set to change the fortunes of several countries in that cluster.

#### 4.1.2. The fortuitous cluster

Recall that that this cluster subsumed standard or broad gauge state railways, whose redeeming quality was an axle load sufficiently high to support a modicum of competitiveness [2]. In this cluster, Israel has undertaken substantial urban rail expansion and rolling stock procurement, including opening its new Jerusalem Light Rail Transit in 2011. Lithuania and Latvia, together with Estonia that is a member of the Enlightened and Progressive super cluster, are participating in Rail Baltica, a European Union (EU) sponsored project to integrate them into the European Union [24]. Landlocked Mongolia has recently started exploiting its mineral resources, connecting with consumer markets through China and Russia by means of heavy haul railways. Turkmenistan, together with Iran and Kazakhstan, has inaugurated a line linking all three countries. Azerbaijan and Georgia have joined forces with Turkey to complete missing links in a railway from Kars in Turkey to Baku on the Caspian Sea in Azerbaijan, to facilitate networkability [25]. Azerbaijan is also pursuing a north-south railway to leverage its position between Russia and Iran. Saudi Arabia is investing heavily in the full range of renaissance sub-modes, namely heavy haul, high speed, double stacking, and several variants of urban rail. Panama re-gauged its broad gauge Pacific Ocean–Gulf of Mexico line to standard gauge and now operates double-stack container trains under a 30-year concession. It also opened Panama City Metro in 2014. These countries are leveraging variables such as *Relative Maximum Axle Load*, *Relative Maximum Speed*, *Heavy Haul Presence*, *High-speed Intercity Presence*, *Heavy Intermodal Presence*, *Networkability*, *Climate-change Position*, *Market Initiative*, *Infrastructure* and *Rolling Stock Investment Capacity* to rise from the Fortuitous cluster.

#### 4.1.3. The insecure cluster

This cluster subsumes predominantly narrow gauge railways that generally rated low on all variables [2]. The World Bank considers that Africa's many concessions perform poorly [26],

not surprisingly because they are inherently uncompetitive. Insecure railways that aspire to elevate themselves therefore initiate interventions predictable from the factors *Positioning Passenger Rail, Exploiting Opportunities, Positioning Freight Rail, Exploring Horizons, Pursuing Competition, Aligning Assets, Greening the Image* and *Constraining Downside* identified in [2].

For example, Morocco is implementing a high speed line from Casablanca to Rabat, currently suspended due to expropriation issues. Iran has expanded its network to exploit its valuable geographic location to provide through routes to neighbouring countries, north-south between its Persian Gulf ports and Turkmenistan and Kazakhstan, as well as a planned route to Russia through Azerbaijan, and in the east between Herat in Afghanistan, and the rest of the Eurasian standard gauge network in the west. Jordan is set to replace its isolated narrow gauge railway with a standard gauge one that can network with the standard gauge railways of the Middle East. Ethiopia-Djibouti's and Kenya's new standard gauge railways are under construction, the latter as an element of a larger agreement that includes the other East African Community states Burundi, Rwanda, Tanzania, and Uganda with the prospect of South Sudan also linking up. Colombia has entered the bulk mineral business and is now the fifth largest coal exporter in the world [27]. Guinea is constructing a high-capacity standard gauge heavy haul railway to export iron ore from its Simandou deposit. Indonesia is seeking private investors to build standard gauge heavy haul coal export railways in Kalimantan and Sumatra. Southeast Asia has standard gauge initiatives in Laos, Malaysia, Myanmar, and Thailand's Legislative Assembly recently decided to proceed with a standard gauge railway from the Laotian border to the port of Rayong on the Gulf of Thailand, with a branch to Bangkok. A matching link through Laos to China is under negotiation. Peru has commenced operation on the entire Lima Metro Line 1, and has commenced construction on Line 2. Mozambique is opening up its minerals exporting potential, and has taken the first steps to upgrade some of its lines to convey export coal. Longest of these is the 910-km Nacala Logistics Corridor from mines at Moatize, a joint venture between Brazilian mining and logistics entity Vale and national rail and port operator CFM [28]. The Malaysian government has approved establishment of a state-backed project delivery company to manage Malaysia's share in the Kuala Lumpur-Singapore high speed project.

These railways are leveraging variables such as *Relative Maximum Axle Load, Relative Maximum Speed, Heavy Haul Presence, High-speed Intercity Presence, Attitude to Competition, Network Coverage, Market Initiative, Networkability, Infrastructure-operations Separation, Infrastructure- and Rolling Stock Ownership Locus*, and *Climate-change Position* to lift themselves out of their inherent uncompetitiveness and hence to enjoy railway renaissance. The outlook for railways that remain in the Insecure cluster is bleak. Their significance is dwindling, e.g., narrow gauge freight tonne-km are down to less than 3% of the global total, while long-distance passenger services are generally moribund and, due to small market size, rolling stock has become more expensive than for standard gauge while its performance is inherently inferior.

#### 4.1.4. The enlightened and progressive super cluster

All but five members of the Enlightened and Progressive clusters were either longstanding member states of the EU, joined during the 2002–2007 duration of data acquisition, or acceded

after 2007, the last year included in the database. Norway, as member of the European Free Trade Association, is aligned in all pertinent respects with EU railways. Two more, Serbia and Turkey, are candidate countries. These clusters were neighbours in the icicle plot from which they were derived, and under the European Union's Regional Policy as well as its-railway specific directives, they can for the purpose of the present analysis be considered to have melded into one. The cluster includes only two non-European countries, Japan and the Republic of Korea, but despite geographic separation, their railways happen to be statistically aligned with those of the EU.

Developments in this super cluster have leveraged rail's inherent competitiveness in the high speed and urban rail market spaces. Its major challenge is that freight rail development has not followed economic development. The comparatively small size of Japan's linked islands opposes the heavy and/or long hauls that railways do well, and rail freight has therefore consistently declined over the last nine years [13]. Rail freight has similarly stagnated since railway reform in 2005 in South Korea [29], also a small country whose railways are currently politically constrained from networking with neighbours. However, while such constraints are absent in the EU, its rail freight performance is nevertheless cause for concern [30]. While railways in the EU rated highly on most variables, there is no evidence of them leveraging variables such as *Relative Maximum Axle Load*, *Heavy Haul Presence* and *Heavy Intermodal Presence*, which are fundamental to competitive and sustainable freight rail positioning. Note, however, that the recently completed EU-sponsored 1,500-m freight train Marathon project [31] has explored the value of *Distributed Power Presence* to support operation of long freight trains. This effort parallels that of other railways that are constrained by low axle load while high speed is not critical for business success. The only remaining genetic technology that can come to the rescue is coupling, which has led to commercial operation of trains conveying more than 300 wagons on Brazilian and South African narrow gauge heavy haul lines.

#### 4.1.5. The assertive cluster

In line with expectations, members of this cluster have increased their commanding lead in several respects. Mexico follows North American practices and standards, so it is already strongly positioned in freight rail. In pursuing another of the railway renaissance growth curves, it awarded a contract for a 210-km high speed line from Mexico City to Querétaro in 2014, but subsequently cancelled the deal to maintain probity. It reopened bidding in January 2015, expecting to announce the preferred bidder in July 2015 [32]. Switzerland is exploiting its strategic location, having opened the 35-km Lötschberg Base Tunnel in 2007, and expecting to open the 57-km Gotthard Base Tunnel in 2016. Their objective is to increase total transport capacity across the Alps especially for transit freight between Germany and Italy, to shift freight from road to rail to reduce fatal accidents and environmental damage by ever-increasing numbers of trucks passing through Switzerland, and to cut passenger train journey times [33, 34]. Australia has taken the lead in heavy haul by increasing axle load on an iron ore export line in its Pilbara region to 40 tonnes, currently the world's highest. Canadian National, which despite its name is a private company, has from its traditional east–west Canadian transcontinental network extended its strategic horizon to the Gulf of Mexico through acquisition of

US north–south railroads. The United States has extended its across-the-board lead by commencing construction of the California High Speed Rail project that is set to link San Francisco with Los Angeles, with later extensions to Sacramento and San Diego.

Brazil, India, China, and Russia are making extraordinary progress in all or most of the four sub-modes of the railway renaissance, and have therefore been given special treatment in sections 3.1, 3.2, 3.3, and 3.4 respectively. No more will be said here. South Africa's Passenger Rail Agency in 2014 awarded the world's largest current order for electric multiple units, namely 3,600 cars. Its Transnet Freight Rail State-owned company also awarded orders for more than 1,000 locomotives in that year. However, noting that high speed and heavy intermodal (double-stacked containers) are not possible on narrow gauge, and that heavy haul needs standard gauge to maximise its performance, it will be interesting to follow its long-term sustainability.

These countries are generally leveraging variables such as *Relative Maximum Speed*, *High-speed Intercity Presence*, *Attitude to Competition*, *Network Coverage*, *Passenger Traffic Volume*, *Employment Created*, *Broad Gauge*, *Networkability*, *Strategic Horizon*, *Rolling Stock Ownership Locus*, and *Infrastructure and Rolling Stock Investment Capacity* to round out their already strong Assertive positioning.

## 4.2. Institutional learning

### 4.2.1. Interventions to achieve renaissance

Two railway revitalisation intervention mainstreams are evident in section 4.1, competition-led and investment-led. Although introducing competition to revitalise railways seems to enjoy top-of-mind awareness among many stakeholders, it is not appropriate in all settings. In developed countries, where standard or broad gauge track and adequate axle load, speed and train length parameters may already have made existing railways inherently competitive, introducing competition among service delivery functions may be desirable, and may indeed be the only available revitalisation lever. Thus, countries in the Enlightened and Progressive Railways super cluster have generally embraced competition to leverage maximum good from their investments in expensive long-lived railway assets.

However, competition alone is not the only remedy. For example, railways that operate, or contemplate operating, freight and passenger trains on the same network cannot concurrently optimise the train–infrastructure interface for both types. Thus, light-axle-load high-speed passenger trains require wide curves but tolerate steep gradients, while heavy-axle-load long freight trains require easy gradients, but tolerate tight curves. Optimising the interface for one train type unavoidably sub-optimises it for the other. Freight rail in the Enlightened and Progressive super-cluster (European Union plus Japan and the Republic of Korea) is a case in point. Its train–infrastructure interface is optimised for the dominant passenger traffic, thereby precluding concurrent optimisation for freight trains. Consequently, the latter are inherently uncompetitive and have, unsurprisingly, not responded positively to competition-led intervention, and currently face a bleak future.

Similarly, where inherent competitiveness is inadequate and new investment is required to make it good, it is futile to introduce competition and/or private sector participation only. Typically by way of operating concessions, such interventions risk reluctance to invest and even asset stripping as concessionaires find they need to subsist on stagnant or declining income. To illustrate, in Sub-Saharan Africa the World Bank found that few passenger train services cover above-rail operating costs, that few concessions generate significant profits for their operators and certainly not enough to fund long-term track renewals; and that government oversight of railway concessionaires is inconsistent with good business practices, which all result in expectations not being met [35]. Competition should, therefore, be introduced only in settings where inherent railway competitiveness is sufficient to sustain all operations that are present—freight and passenger.

#### *4.2.2. Ownership and funding*

Countries and railways that have participated in railway renaissance have of necessity invested in one or more of the Heavy Haul, High-speed Intercity, Double Stacking, and contemporary Urban Rail market spaces, to transition from the terminal decline phase of their first growth curve to new renaissance growth curves. Except for the privately-owned railways in the United States and Canada, as well as heavy haul railways around the world that mining houses have funded integrally with their mining investments, governments in many countries have traditionally led requisite railway investments. However, as contending claims on their funds have constrained the quantum available for railways, public and private sectors have increasingly come to share responsibility for railway investment, in such a way that each sector bears the risk for investments to achieve its objectives, developmental for the public sector, and productive for the private sector.

Opportunities for private sector participation in railways have stimulated a plethora of solutions. Outsourcing of routine maintenance work has been a mutually acceptable starting point that allows the two sectors to size one another up without deep commitment. However, the latter is required to establish the mutual respect and deeper trust that is the foundation of longer-term relationships.

It has been customary for private participation to fund moveable assets, which may be redeployed elsewhere if the project runs into difficulties. Rolling stock has traditionally filled that role. There are many opportunities, but they tend to start with special-purpose freight wagons that have limited redeployment opportunities. They are nevertheless a valuable way to cement a relationship, because they limit a customer's transport options, and signify strong commitment to rail with a high exit barrier. In recent years, it has become common to purchase multiple unit passenger stock with long term 30–35-year life cycle maintenance contracts that require a much deeper level of mutual understanding and commitment. Private participation in infrastructure has taken a long time because the exit barriers can be very high. That part of funding has, therefore, traditionally been left with the authority initiating the project. A tunnel in the ground has limited alternative deployment opportunities if a project runs into difficulties. Nevertheless, infrastructure is also slowly entering the private sector arena. Typically the authority needs to accept the demand risk for the asset, which can be done through it agreeing

to purchase all the capacity over the life of the agreement, and then selling it to users. This has become a model for funding infrastructure, where a long route may be divided into portions funded by different agreements, as in the case of India's dedicated freight corridors. Initially, there was resistance to foreign participation, but there again India has broken ground on foreign direct investment, also on a dedicated freight corridor. In reality, long-term relationships bring stability by binding participants. Concessioning is frequently used for such schemes, where a concessioning authority owns an opportunity and needs market initiative to develop it.

Such interventions have stimulated a range of regulation models that reflect the developmental and socio-economic objectives of particular countries, as well as the quantum and diversity of funding sources that they can assemble. In the first instance, a railway economic regulatory function is required, either implicitly by way of coherent political will during the early stages of reform, or later explicitly by way of a statutory regulator, to ensure that railways are enabled and encouraged to contribute appropriately and fairly to the broad economic and social objectives of a country in a competitive setting. Thereafter, safety regulation also needs to be introduced in settings where multiple entities come to operate trains to ensure the establishment and maintenance of a safe operating environment.

#### *4.2.3. Market structure*

Railway systems may offer single or multiple routes between origin and destination. Multiple routes originated in the early days of railways, for example the railways of Britain prior to railway nationalisation and establishment of British Rail in 1948, the railways of the North American Free Trade Agreement that preserve alternative routings, and parallel railways from an ore body to the coast, as in the Australian Pilbara. Railway offerings can be competitive or monopolistic. This yields four quadrants. Notwithstanding the structure of an industry, many governments consider it desirable to preserve competition in all industries, even those that are essentially vertically integrated. Thus they tend to require regulated access by third parties, to ensure the presence of competitive operators.

Throughout the world, railway renaissance has been achieved only by investment in assets that have increased rail's inherent competitiveness against other transport modes. This is true for railways competing against other transport modes in domestic markets, or supporting competition against other countries in export markets, as well as for railways cooperating in intermodal alliances, particularly with road carriers. Appreciate that for freight, heavy intermodal goes beyond simply transferring a load unit (container or swap body) from one mode to another, such as between road and rail and vice-versa. When rail is involved, the axle load of container wagons needs to be increased to the heavy haul domain, by double stacking containers, to exploit the competitive strength of rail's heavy-axle-load genetic technology, supporting.

Regarding competition between rail and road, appreciate that logistics service providers and passengers incline naturally toward the more aggressive competitor, and will choose road until rail comes up with a superior offer, either alone or in cooperation with road carriers. Inherent competitiveness is thus an important element of railway positioning because as long as

logistics service providers and passengers have a choice, rail is competing with road, either over the entire distance where it can offer such a service, or for the long-haul portion where customers want a door to door service and rail needs to complement its offer with feeder and/or distribution service by another mode.

#### *4.2.4. Networking and expanding strategic horizons*

Consolidation of rail's strengths in the four renaissance market spaces foretells even greater rail significance in future national, international, continental, and intercontinental transport. The authors' earlier research identified networkability as a factor in positioning railways for competitiveness and sustainability [1], and several large-scale international initiatives have confirmed that finding. In transposing Metcalfe's Law, that network value increases as the square of the number of nodes [36], to the railway industry, the UN-led Trans-Asian Railway, mooted pre-renaissance in 1960, and the EU-led multilateral development of the Transport Corridor Europe-Caucasus-Asia in 1998 are examples. On the smaller-scale are Russian Railways' extensions eastward to North Korea (implemented) and westward to Vienna (planned), and the Bosphorus rail tunnel completed in 2009, Asia-Europe's first standard gauge connection. However, they progressed slowly until recently, primarily due to track gauge incompatibilities. Now Chinese rail ambitions have morphed earlier plans by others into wider strategic horizons, including freight services into Europe, a 7,000-km Beijing-Moscow high-speed line, and connection to North America under the Bering Strait. China's bold railway diplomacy is turning challenge into opportunity, with Premier Li promoting Chinese railway technologies around the world as advanced, secure, reliable, and cost-competitive [37]. The Jamestown Foundation [38] recommended the world should pay attention to a telling sign of things to come on global scale.

Great circle overland rail routes can be shorter and faster than maritime passages. For context, by weighting their latitude and longitude coordinates by their GDP, and calculating the weighted average, the author found the economic centre of Earth's top 100 cities by GDP to be in western Iran. All Europe, most of Asia, and much of Africa, lie within some 7,000–8,000 km radius thereof, less than the Trans-Siberian railway's 9,288 km benchmark. Note that this exercise excluded Australia, because it is more than 1,200 km from the nearest land (the island Java) that could conceivably link into a global railway network.

It seems axiomatic that political differences should be separated from traffic flows. Even the European Union has experienced push-back since publishing its first Council Directive on development of the Community's railways in 1991. Similar challenges have been experienced in consigning containers by rail from China through Kazakhstan, Russia, and Belarus into the European Union. Although they seem eventually all to be resolved, the time it takes allows other modes to entrench themselves at the expense of the rail mode.

### **4.3. Emergence of the new normal**

Renaissance has passed. The first Japanese Series 0 Shinkansen train that started it all more than fifty years ago is already a display piece in the National Railway Museum in York,

England. Railways have settled into a new dispensation. From a position of strength, their abilities stretch from heavy-duty urban transport across continents to distant strategic horizons.

The 14<sup>th</sup>–17<sup>th</sup> century Renaissance, or rebirth, provides a fitting archetype of the 1964–1989 quarter-century railway renaissance. Looking back to 1989, it is evident that the following quarter century to 2014 has been a period of settling railways into their four inherently competitive sub-modes high-speed intercity, heavy haul, heavy intermodal, and contemporary urban rail. The Enlightenment, the period that followed the Renaissance and exploited the intellectual freedom that it had let loose, has inspired this section.

The know-how of the railway renaissance has been captured in a myriad of publications and widely dispersed railway industry institutional knowledge. Now freely available, it is being applied to position railways for an energy-scarce future. Global consensus seems to be building around the year 2050 as the date by which the shift from a fossil-fuelled economy to a renewables-powered economy should be largely in place. The timing recognises the need to wear out the present fleet of transport vehicles—planes, ships, and trains—and to adapt, construct, or renew infrastructure and rolling stock. The exact year is not important. What is important is the form that transport systems will take at that time. The European Commission's [10] Transport White Paper, for example, provides valuable perspectives on that time by envisioning:

- An efficient core network for multimodal intercity travel and transport with greater use of buses and coaches, rail and air transport for passengers and, for freight, multimodal solutions relying on waterborne and rail modes for long-hauls.
- New transport patterns emerging, according to which larger volumes of freight and greater numbers of travellers are carried jointly to their destination by the most efficient (combination of) modes.
- A global level playing field for long-distance travel and intercontinental freight in which (high speed) rail should absorb much medium distance traffic.
- Clean urban transport and commuting where a higher share of travel is by collective transport, and the interface between long distance and last-mile freight transport is organised more efficiently.

The realisation of integrated, optimised, multi-nodal networks featuring urban rail within densely populated, commercialised, and industrialised areas, and regional rail within larger agglomerations and corridors, is already visible in several countries. Consider the example of Verkehrsverbund Rhein-Ruhr in Germany, serving a conurbation of eight million inhabitants in a 7,300 km<sup>2</sup> area. Formerly isolated light rail networks of individual local authorities have been connected to one another, going so far as to regauge some from metre gauge to standard gauge to promote networkability. This has in turn made acquisition of new 160 km/h regional trains sensible, to reduce journey times over longer distances. At national and international scale, long distance, high-speed passenger and heavy freight trains are common in Europe and North America, respectively. Dedicated freight and passenger corridors, where traffic volume

is sufficient to separate freight and passenger trains, have been realised in China and India. China's One Belt, One Road framework takes rail-based corridor development to an unprecedented level. So the building blocks of the Railway Enlightenment or New Normal exist: What should now follow is expansion of application to countries that are earnest about road-to-rail shift to reduce congestion and the dependence on fossil fuels and the accompanying pollutant emissions.

#### 4.4. Further research

Despite the difficulty of obtaining requisite data, the authors, nevertheless, continue seeking substitute sources that could support multivariate statistical analysis of post renaissance railway positioning. Substantial movement within the clusters is evident, so it is expected that changes in the composition of the variables used, and of course a different time period, could possibly identify new, more refined factors and clusters. Having established the benefits of achieving renaissance, it would now be useful to understand how to further optimise the role of railways in societies that are progressing well in their transition to an energy-scarce future.

### 5. Conclusions

For convenience, the research question repeated from section 2.1 is: *Does a new post-renaissance normal now prevail, and as a corollary, does there seem to be any viable alternative?*

Rail is to be observed doing the transport heavy lifting in countries that have embraced railway renaissance, as it should do by virtue of strong positioning in its inherently competitive market spaces and its comparative energy efficiency. Transcontinental and intercontinental hauls at higher speed and lower energy consumption than waterborne transport are emerging. Regional rail is expanding around the world, frequently with double-deck trains. High speed finds favour as an effective economic and social development intervention. Urban rail is standardising on standard gauge, even in non-standard gauge countries such as Brazil and India, to economically deliver high capacity in burgeoning cities. Urban guided transit scales capacity offerings from rubber-tired light solutions for small cities to heavyweight metro solutions for densely populated cities. No solution other than heavy haul comes to mind to move large tonnages of bulk minerals over long distances. Double-stack container trains are able to wrest high-value, low-density goods from road hauliers. Overall, railway renaissance has aligned customers and suppliers around what works and what does not work in a global market, enabling suppliers to produce widely acceptable products and solutions at competitive prices.

It is now evident that the answer to the research question is that countries that have embraced railway renaissance have been able to reposition their railways to play a substantial role in their economies and societies. In the sense that the Enlightenment exploited the intellectual freedom that it had let loose, yes, that is happening today in the post railway renaissance period. In present colloquial language, the Enlightenment would more likely be called the New Normal. And that is just what has happened over the five decades since 1964. It is once again

business as usual, the material difference being that the rail mode is now a formidable contender in the High Speed, Heavy Haul, Heavy Intermodal and Urban Rail market spaces. The authors therefore argue that the hypothesis has not been disproved.

Regarding the corollary to the research question, there is no evidence of railways emerging from the Fortuitous and Insecure clusters other than by following one or more of the renaissance growth curves through appropriate investment.

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