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Policy Considerations for Positioning Rail as Logistics and Mobility Leader in 2050

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Abstract

Fifty years after the start of railway renaissance, the authors fashioned a Year 2050 scenario that related climate change imperatives to the desired rail logistics and mobility outcomes, described it by approximately eighty railway-and-setting variables and measured them in a ten-year longitudinal database of all countries with long-haul railways and/or urban guided transit. They applied factor analysis to reveal latent policy issues, and cluster analysis to reveal industry state and structure. From the premise that rail's genetic technologies constitute a stable base for the industry's development trajectory to 2050, the analysis found factors that should inform policy considerations to guide the industry to the 2050 outcome. The analysis also revealed that many countries have transitioned, or are transitioning, from former national railways, to vital new market-related entities.

1. Introduction

Starting with Japan's high-speed railways fifty years ago, renaissance has stimulated a vibrant global railway industry. Yet countries and regions still position their railways differently, e.g. Europe excels at passenger rail, while freight rail is less significant: North America the opposite. Developed countries appear more set in their (rail)ways than developing countries that are implementing comprehensive railway renaissance. Railways emerge in countries that previously had none, while others die. Urban guided transit (UGT) solutions grow rapidly as global populations migrate to cities or conurbations.

The following three genetic technologies distinguish rail from all other transport modes: *Supporting* promotes heavy axle load, *Guiding* promotes high speed, and *Coupling* promotes long trains. Hence rail is inherently competitive in Heavy Haul (heavy axle load but low speed), High Speed (high speed but light axle load) and Heavy Intermodal (double-stacked containers, heavy axle load and high speed). By the same token it is potentially weak in relatively light axle load and low speed passenger service, but Coupling compensates by achieving shorter average headways between vehicles than competing modes, thereby delivering higher throughput capacity than competitors can match. Inherent competitiveness thus extends also to high-density urban rail, where single-deck vehicles cannot achieve heavy axle load and maximum speed is only 80km/h, and to regional- or suburban services with longer distances between stops allowing 160km/h, often deploying double deck vehicles to maximise passenger count and axle load and hence to minimise capacity appropriated from others. Despite these precepts being widely understood, the aforementioned differences among countries, regions and railways indicate that settings are significant determinants of outcomes.

2. Application and context

This paper develops the authors' previous research into fit of the global population of long-haul railways [7] and UGT [8] in their respective task environments, and in relation to renewable energy [10]. They developed multivariate understanding to predict rail competitiveness and sustainability, and among other applied it to develop a global frame of reference within which to draft a Green Paper on National Rail Policy [1]. The latter proposed revitalising railways by investment-led strategies to exploit rail's inherent competitive strengths [9]. They have subsequently been engaged to draft a White Paper on National Rail Policy and a National Rail Bill: This study's maiden application will provide the holistic frame of reference within which to consider policy options to position railways on a robust development trajectory despite a host of future uncertainties.

As railway renaissance progressed, sensible investment has gravitated to opportunities that leverage rail's inherent competitiveness against other transport modes. Concurrently, significant global initiatives to mitigate global warming, e.g. the European Commission's White Paper *Towards a competitive and resource efficient transport system* [2], envision Year 2050 as the deadline for establishing a sustainable dispensation.

Scenarios for that time envisage most traffic on rail. Regarding long-haul passengers, people are economically able or physically willing to spend only limited time on journeys: Thus present high-speed train services generally peter out beyond three hours or 1000km. Nevertheless, China has already stretched limits with ten-hour domestic high-speed services, some of them overnight, and the mooted 7000km Beijing-Moscow high-speed line (say 24h at 300km/h average) reveals the mind of thought leaders. Regarding freight, pit-to-port heavy haulage has been a rail staple since the sub-mode was recognised in 1972, while containers are being railed over ever longer distances, e.g. between China and Western Europe, even more competitively where double stacking elevates the axle load of low-density high-value freight into the heavy haul domain. The juxtaposition of Northern-hemisphere land masses encourages extremely long continental- and intercontinental overland rail hauls, some of them challenging maritime transport by offering higher speed over (shorter) great circle routes, thereby reducing both harmful emissions and logistics costs [3]. Regarding cities and conurbations, UGT and regional or suburban rail will provide short- and medium distance mobility, as well as service high-speed rail catchment areas. Regarding airports, high-speed rail will connect nationally, while urban- and/or regional rail will connect locally.

Multimodal freight transport chains are no stronger than their weakest links. In free economies, they originate spontaneously rather than being coerced by arbitrary provision of intermodal terminals. Rail must thus maximise its inherent competitiveness to position itself as the preferred long-haul transporter. Where it has been insufficiently competitive to do so, the default option, road, has woven itself so intimately into urban fabric that distribution centres are frequently located without regard to rail. This prevents rail from clawing back traffic lost to road, and impedes road-to-rail shift. Thus even in an energy-scarce future, scenarios envisage road as primary urban logistics transporter.

This Year 2050 scenario informed selection of variables for the statistical analysis introduced later.

3. Research question and methodology

The research objective was to understand, from present railway techno-positioning in relation to economic-political-social drivers, what policy considerations might realistically guide railways towards the Year 2050 scenario. As departure point, the authors hypothesized that current economic, political and social drivers have already established a rudiment of that scenario. The research question *What generic policy guidelines would position rail as global logistics and mobility leader in 2050?* therefore examined relations between these drivers and rail positioning. The essential methodology was to garner variables that could credibly describe railways both during a 2015-and-earlier longitudinal data observation period and thereafter through multivariate statistical analysis infer valid relations regarding their positioning 35 years hence. As touchstone, rolling stock with a typical design life of 35 years delivered in the medium term will still be in service at that time.

Considering the long tenor of the research design, it is prudent to examine the probability of technical developments in rail or other modes derailing it. A critical methodological tenet is that rail's three genetic technologies distinguish it from all other transport modes, particularly road for the present. Note therefore that public roads worldwide limit axle load to around 9 tonnes to offer affordable, ubiquitous access over their vast surfaces, while rail carries significantly higher axle loads because its supporting structure is placed immediately under the load application path. Tyre-to-road friction guidance generally limits vehicles to no more than 120km/h on public roads, while wheel-rail forces precisely guide trains at 350km/h or more. Road vehicles support limited load unit scalability, while rail scales capacity or train length to match demand by two orders of magnitude or more. Rail therefore occupies a clear, unique, and advantageous position in specific market spaces.

Road does emulate rail to a limited extent. Its lane-departure warning systems may emulate rail's Guiding genetic technology, and adaptive speed control may emulate its Coupling genetic technology. However, notwithstanding such smarts, automated vehicles cannot break out of public roads' low axle load domain to threaten rail's high axle load domain. While both road's and rail's genetic technologies are comparatively mature and advances are incremental rather than disruptive, information and communication technology does disrupt, but by cutting across modes. Thus the influence of logistics on transport modes has profoundly influenced how they relate to their task environment, but has not changed what they do, because the latter inheres in their genetic technologies. The authors therefore argue that the probability of the methodology not providing a robust foundation for examining rail's 2050 positioning is low.

4. Research design: Variables

The following variables describe and measure rail's positioning with respect to its present setting in relation to the Year 2050 scenario. Operational definitions and measurement scales exceed the word limit, so they appear in the database column headers at www.railcorpstrat.com/databases.html. Where appropriate, absence of data defaults to zero on the scales, to pre-empt empty cells. Note that each variable's longitudinal time series implies a growth rate. Several of the variables control for the presence of an attribute: Presence means at least one appearance. Generally-accepted high performance maps to the highest scale scores.

First, the economic-political-social setting into which railways have been positioned: Intuitively the following variables apply; *Country Name; Area of Country, Total Population* and *Growth Rate* and *Total Population of Cities with Urban Rail. Economic Freedom Index, Global Competitiveness Index and Global Peace Index* represent state-of-the-nation. *Information and Communication Technology (ICT) Leverage*, *Renewable Energy* C*ontribution* and *Smart Grid Initiative Presence* describe contemporary nurturing technologies, the first applicable to all transport modes, the second applicable to railways that can wring lower- and greener energy consumption from electrification infrastructure, and the last a proxy for regeneration receptivity and real-time grid storage [10]. As renaissance advanced, privatisation and/or deregulation changed the economic status of long-haul railways in many countries: While aiming to improve innovation and service quality, they also wished to preserve rail's generally good safety performance [4]. Thus *Presence of Railway Economic- and Safety Regulation* were added. *Motor Vehicle/Person Ratio*, *Total Road Network Distance*, and *Motorway Network Distance* represent rail's major freight- and passenger land transport competitor, the road mode. For longitudinal purposes, *Calendar Year* measured passing of time.

Second, variables that describe and measure long-haul railway positioning in a country: *Freight-* & *Passenger Task* and *Employment Created* measured rail's economic and societal contribution. *Dominant Investment Funding Sources* measured orientation to private- or public funding. *Narrow-, Standard-,* and *Broad Gauge Network Coverage* measured the length of track for each gauge, *Networkability* measured the extent of same-gauge contiguous network open to interoperation among country neighbours or regions, ignoring current political differences. *Network Percentage on Gauge ≥1435mm* controlled for countries having a small network gauged sufficiently widely to support inherent competitiveness, but whose railways are primarily narrow gauge. *Connections with*

Neighbouring Countries measured connectivity with neighbouring countries, including breaks of gauge where present. The following variables controlled for the extent to which rail exploited its genetic technologies: *Relative Maximum Axle Load,* -*Speed,* and -*Train Length* and, beyond coupler strength limits*, Distributed Power Presence. Strategic Horizon* measured vision, from National through Continental to Intercontinental. *Highest Automation Level* measured its contribution to productivity and safety [6]. Pure vertical integration is waning as competition authorities and commercial pressures mandate access to others without going as far as open access: *Operator Diversity* therefore measured market structure as number of train operators less number of infrastructure operators on which scale zero denotes pure vertical integration. *Heavy Haul-*, *Heavy Intermodal- High speed-,* and *Regional Rail Presence* measured the number of inherently competitive market spaces in which rail is present.

Third, variables that describe and measure UGT positioning in a country: *Highest Planning Level* measured urban rail planning centralisation. *Aggregate Network Coverage* measured the total network coverage of all UGT sub-modes in all cities. *Highest Automation Level* measured safety and service level enhancement by mitigating human factors. From previous research [8] the following sub-modes are competitors or substitutes positioned between Heavy Metro and Light Rail, and related to them through economic-, political- and social attributes: Automated Light Metro- (light rail with fully-segregated right-of-way and automatic train operation, e.g. Copenhagen and Brescia), Automated Guided Transit- (similar to Light Metro but with rubber tyres that address the question *If high axle load is beyond reach, are steel tyres necessary?* e.g. Lille and Taipei Metro Line 1), Transit-grade Monorail- (similar to Automated Guided Transit but with close-coupled wheels, e.g. São Paulo Metro Line 15 and Tokyo Tama) and Bus Rapid Transit (included in UGT because its heavier-than-normal axle load requires strengthened runways that provide loose guidance). They were therefore included, measured by the variables *Number of Operators*, *Network Coverage*, *Rolling Stock Fleet Size*, *Passenger Journeys*, *Number of Routes* and *Employee Count* for each sub-mode.

5. Research design: Cases, observations and statistical analysis

As before [7, 8], the authors defined cases as countries, because national legislation still dominated economic-political-social railway positioning: The world's countries with long-haul railways and cities with UGT are not overly numerous, allowing to select the entire population rather than a sample. Years 2005 through 2015 supported a ten-year longitudinal study. Previous studies deleted marginally sustainable cases for lack of sufficient data, so their outcomes may have been biased toward sustainable cases. This study intentionally acquired missing information from the Internet's cornucopia rather than deleting cases, thereby adding nine marginally sustainable railway-country cases.

The database was populated from Railway Directory's *Regulatory Authorities*, *Railway/Train Operators* and *City Railways* sections [5], the World Bank database and Internet sources. It contains observations from 132 countries, which subsume 475 cities with UGT, over 11 years (except the few that have existed for less). Thus 1415 long-haul cases times 38 variables, plus 5188 city cases times 39 variables, yielded 256 102 observations. Notwithstanding many railways developing metamorphic interventions, the authors recognised only those completed by December 2015.

Multivariate analysis simultaneously examines relations among many variables and many cases in a large database. The authors selected factor analysis to analyse relations among the large number of variables and then explain them in terms of a smaller number of common underlying factors, and cluster analysis to group the large number of cases into a smaller number of clusters such that cases in a cluster exhibit within-cluster homogeneity and between-cluster heterogeneity.

6. Findings

Please see the Factor Loading Matrix at www.railcorpstrat.com/databases.html. Originating in time-series data, the factors represent outcomes of activities, named at authors' discretion as informed by their knowledge of the global railway industry. Appreciate that some variables turn out to be complex, representing more than their name indicates, e.g. HM Employee Count loaded 0.66 onto Factor 1, but also 0.61 onto F2, which complicates interpretation of such factors.

Factor 1 (F1), CIS Rail Positioning: Light Rail and Heavy Metro elements associated with Long-Haul Broad Gauge Network Coverage and Country Area, their low association with Investment Funding Sources indicating public funding. Community of Independent States data appears to have dominated this factor, several of which countries have sizable broad gauge railways plus extensive urban light rail, predominantly supported by public funding.

F2 Long-haul Freight Rail Positioning: Long-haul Standard Gauge Network Coverage and Rail Freight tonne-km associate with Motorways and Total Roads, reinforcing a positive road–rail association previously found [7], i.e. high-performance road transport seems to provoke high-performance rail freight (but may overwhelm inherently uncompetitive rail); strong positive loading by Heavy Metro and Monorail elements indicated synergy between long-haul rail freight and large cities that supported substantial UGT.

F3 Regional and Long-haul- Passenger Rail Positioning: 160km/h Regional or Suburban and High-speed Long-haul- Railways, with several competing train operators sharing infrastructure with high Automation Level, associate with Safety- and Economic Regulation. As for long-haul freight, high Motor Vehicles/People ratio suggests the beneficial presence of road competition.

F4 Monorail Positioning: Most Monorail variables are present, the single association with Rubber-tyred Automated Guided Transit (AGT) probably attributable to Japanese data, representing more Monorail and AGT than any other country. Transit-grade Monorails are still comparatively rare and not widely appreciated; although their ability to serve cramped corridors is achieving recognition as urban migration concentrates ever-increasing populations into cities.

F5 Bus Rapid Transit Positioning: This UGT sub-mode associated with high population growth, which typically associates with large, populous countries [8]. However, it was also found less climate-friendly than its natural competitor Light Rail.

F6 Rubber-tyred Automated Guided Transit Positioning: This factor did not associate with any variables in its setting. It typically aligns with developed, service economies, together with Monorail and Light Metro [8].

F7 Light Metro Positioning: From previous research [8], Light Metro fits into developed, service economies in smaller cities, although not yet assertively due to its comparatively recent emergence, as indicated by absence of association with other variables.

F8 Long-haul Passenger Stimulation: Long-haul Passenger-km associated with Country Population, and high Employee Count. The association occurs spontaneously where high passenger volume justifies dedicated lines. However, given substantial freight traffic presence, faster passenger trains claim a disproportionate line capacity share. Selectively upgrading the Chicago-St. Louis corridor for higher-speed passenger trains on freight-dominated infrastructure is thus an interesting application.

F9 Maximising Networkability: Standard and Broad Gauge railways associated with high Networkability in a peaceful setting. Note the negative sign: As a rule exception beyond the authors' control, higher state-of-peace scores numerically lower on the Global Peace Index scale.

F10 Freight Rail Technology Positioning: Note that F2 addresses where to position freight rail, F10 addresses the modalities. Led by Heavy Intermodal, countries that are earnest about freight rail understand Train Length, Axle Load, Distributed Power and Heavy Haul, witness practitioners in

Australia, Brazil, Canada, China, Colombia, India, Mauritania, Mexico, Norway, Panama, Russia, Saudi Arabia, South Africa, Sweden and the US.

F11 Strategic Positioning: Economic Freedom, ICT Leverage, Competition Regulation and Global Competitiveness associated to offer opportunities to pursue the benefits of competition, higher quality and lower price. However, Strategic Horizon's negative sign suggested that railways in high-scoring countries preferred their national comfort zone, whereas the Strategic Horizon scale extends through Sub-continental and Continental to Intercontinental.

F12 Urban Guided Transit Positioning: Escalating UGT planning level runs counter to precedent in many cities and conurbations, but noting its association with Total Population of Cities and high Automation Level, this finding signalled a trend to coordinate high-quality UGT at higher government levels as populations migrate to conurbations.

The foregoing twelve factors explained 80% of the database variance, the remainder comprising only two variables each. Thus, briefly: F13 revealed an interesting relation between Light Rail Journeys and Connections with Neighbouring Countries, suggesting that well-connected countries attract door-to-door passengers using a light rail–cross border mainline–light rail itinerary; F14 revealed Smart Grid Initiatives rolling out over Time without attracting any railway-specific variable, suggesting that rail was largely still outside the renewable energy mainstream; F15 revealed low Narrow Gauge Network Coverage to associate with low Renewable Energy Contribution, suggesting that narrow-gauge railways associated with non-renewable energy sources.

Now please see the Icicle Plot at www.railcorpstrat.com/databases.html: To ensure clear interpretability, the cluster analysis used only a single year's data for each country, the latest available, 2015 for most cases. It might have been interesting to undertake separate cluster analyses for each of the 11 years, and then to trace their development over time, but that would have been a paper by itself.

The shared icicle length represents the amount of similarity between icicle neighbours. The actual icicle lengths indicate neither more nor less of any attribute. To illustrate by example, while China and the US have very low similarity, and Norway and Sweden, the Nordic Cluster, have much higher similarity, both pairs are more similar to each other than to any other country. The authors placed the red line in Column F by inspection to cut icicles, thereby to demarcate clusters, which they named as informed by their knowledge of the global railway industry. Only four true clusters emerged: The Insecure Cluster, 51 countries, and the Enlightened Cluster, 8 countries, generally retained from previous research [7]; the Transit Cluster, 4 countries, and the Nordic Cluster, 2 countries, also generally retained from previous research but under different names [7]. That left four quasi-clusters, whose statistical similarity between neighbours was insufficient to reach a cut line and form clusters, which the authors named First-, Second-, Third- and Fourth Wave. Their progressively drooping similarity between adjacent countries revealed a material shift from the previous outcome [7], when only 10% of cases formed quasi-clusters, against 50% in this study. By inspection, they show cases that have migrated from the Insecure Cluster to waves of countries actualising railway renaissance by one or more of: Investing in rail's four inherently competitive market spaces; market liberalisation, private sector participation, economic regulation, and increasing competition; leveraging their location on major continental- and intercontinental trade routes; running heavier, faster, longer trains; supportive, sympathetic government; cessation of hostilities; planting UGT in new cities and expanding it in old, and more. Argentina, Azerbaijan, Bangladesh, Belarus, Bolivia, Chile, Colombia, Cuba, Ecuador, Egypt, Ethiopia, Indonesia, Iran, Iraq, Ireland, Israel, Kazakhstan, Korea DPR, Kosovo, Latvia, Liberia, Lithuania, Malaysia, Mauritania, Myanmar, New Zealand, Pakistan, Peru, Philippines, Portugal, Saudi Arabia, Syria, Thailand, Tunisia, Turkmenistan, Ukraine, United Arab Emirates, Uzbekistan and Venezuela have all been drawn into these transitionary waves since the 2008 study [7].

7. Conclusions

Having integrated long-haul-, urban rail- and energy-related variables in a common longitudinal database, the present research found factors and clusters that offer valuable insights into the railway world as it advances from the present to Year 2050. To extract policy guidelines for 2050 rail positioning, the authors grouped the factors by railway signalling convention.

At green or proceed are F1, F2, F3, F4, F9, F10 and F12. They align broadly with the 2050 scenario by associating long-haul network coverage with the freight task, and heavy metro, light rail and monorail with cities. Long-haul and regional passenger rail positioning associate with competitive open access under economic and safety regulation. In both instances road competition is beneficial. Rail freight faces fewer competition issues: Its natural competitors keep it sharp (or rout it if not inherently competitive), and the heaviest freight railways lean toward vertical integration, often with regulated access by others. Note a slight difference in emphasis between CIS countries and the rest, greater economic freedom associating with a greater variety of sub-modes. Note also a trend to raise the level at which governments coordinate UGT, likely attributable to the increasing significance of urban populations relative to national populations. Maximum contiguous networking opportunities associate with standard and broad gauge railways in peaceful settings: The 3% global freight tonne-km remnant on narrow gauge needs policy attention. Europe's struggling rail freight, an exception that does not conform to F10 Freight Rail Technology Positioning, also needs policy intervention when compared to China and India, developing countries that dedicate separate corridors to heavy freight- and high-speed passenger services.

At flashing green, proceed at reduced speed, are F6 rubber-tyred Automated Guided Transit Positioning and F7 steel-tyred Light Metro Positioning. Their light axle load and low speed offer lighter-duty UGT solutions for smaller cities and lower density corridors in large cities. Together with monorail, expect them to form a natural adjunct to traditional rail solutions in the cities of 2050.

At yellow or caution are F5 Bus Rapid Transit Positioning, more economically attractive but less climate-friendly than light rail, and finding favour in developing countries. F8 Long-haul Passenger Stimulation illustrates the challenge of higher-speed passenger trains in low density corridors: Without them, traffic defects to air or road, with them freight line capacity is compromised. Strategic Horizon's negative association in F11 Strategic Positioning is of concern because the value of commercial opportunities in networked systems such as railways increases exponentially with the number of nodes. China's One Belt One Road policy well understands this, but many other countries could do with policy emphasis on expanding their railway strategic horizons.

At red or stop, F14 revealed that renewable energy and smart grids have not achieved significant factor loading. Diesel traction still hauls much of the world's heavy rail freight: An energy policy that promotes access to real-time energy storage in 10-15MWh quanta could facilitate shifting some of that to renewable energy [10]. F15 associated narrow-gauge railways with non-renewable energy sources: Such railways will need strong intervention to fit them to the Year 2050 scenario.

The presence of half the world's railway countries in four statistically-similar waves attested to fundamental transformation currently underway within them. A vital new generation of liberated railway entities, able to position themselves as logistics and mobility leaders, has already displaced many former monolithic national railways and reinvigorated sluggards. Thus one may accept the hypothesis that favourable economic, political and social drivers have already established a rudiment of the Year 2050 scenario. Noting further that nine of the fifteen factors that point to 2050 positioning are at green or flashing green, one can conclude that gentle policy rather that strong intervention will generally suffice to achieve the 2050 scenario. The transformation is at present insufficiently advanced to discern in cluster analysis, but as countries and railways accomplish their interventions expect a set of new clusters to emerge, the railway archetypes of Year 2050.

Lastly, appreciate that the limited number of variables used necessarily circumscribes the space for findings and conclusions: Thus if this research were an artwork portraying rail's logistics and mobility leadership in 2050, it should be considered impressionist.

8. Glossary

Fit: The counterpart of Positioning. Interested and affected parties determine its goodness or otherwise.

Inherent competitiveness: An attribute determined by the extent to which railways exploit the strengths of their genetic technologies. In combination, trains with light axle load, low speed and few vehicles tend to be inherently uncompetitive.

Position, verb: Put in place a suitable type of railway to undertake a given logistics or mobility task in a particular setting. It is a top management or government agency function, as applicable.

Positioning, noun: The outcome of Position, verb. It characterises a (rail) service in relation to similar or competing market offerings. The objective is to occupy a clear, unique, and advantageous market position.

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