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A VISION FOR RAILWAYS IN 2050

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TABLE OF CONTENTS

SUMMARY

Yogi Berra, the legendary American baseball player, is often quoted as saying that predictions are hard, especially when they involve the future. Forecasting railway innovation far into the future certainly falls within that rubric. Revolutionary change, which usually has the most impact, is by definition unpredictable. About all we can identify is the likely course of evolutionary change into the near future.

The term “railways” is deceptively simple. In fact, railways range from tiny to immense, and can be found in six different gauges. Unlike highways and airlines, which can in principle connect all countries, railways are often unable to cross borders without expensive transfers.

Fortunately, for the purposes of an overview, the problem of complexity can be simplified because railway traffic is highly concentrated on only a few networks. In fact, approximately 90% of all railway traffic (freight and passenger) can be found on only six networks, North America (freight oriented), China, India, Russia, Japan (passengers) and the EU 25. Thus, at the risk of offending railway aficionados, this paper focuses on the top six (and there will be no pictures of steam locomotives).

In broad terms, these six systems have experienced traffic growth over the past four decades (China and India much faster than the others, whereas Russia’s growth was severely affected by the collapse of the Former Soviet Union) because the economies they serve have been growing. At the same time, they have uniformly experienced a loss in market share, the only exception being the private freight railroads in the US after deregulation in 1981.

There has been significant innovation over the past 40 years, both in technology (which is what we usually think of as innovation) and in the softer areas of policy, system structure and regulation. Innovations in freight technology, such as heavy haul techniques, diesel technology, signaling improvements and intermodal systems, have reduced the cost of rail freight service by as much as half. Passenger rail innovations, especially High Speed Rail (HSR) have acted to extend the competitive range of rail services, while innovations such as three-phase AC traction have improved energy efficiency. Both freight and passenger services have benefited enormously from implementation of GPS and IT systems that have enabled much closer integration and control of system operations, reduction of costs and improvement of service quality and safety.

“Soft” innovations in policy, structure and regulation have probably been even more important. The breakdown of the old railway monolith into owner-tenant approaches (Amtrak and VIA) or the European Commission’s full infrastructure separation (which might better be called revolutionary than evolutionary) have greatly changed the way in which railways are understood and operated. In parallel with this has been the expansion of the private sector through franchising, concessioning or even full privatization in place of the almost total public ownership and control that prevailed four decades ago. Changes in regulation that freed the railways from stifling government oversight further strengthened the process of “soft” innovation.

With this as prologue, we can (with appropriate *caveats*) reasonably predict broad traffic patterns into the future based on likely economic growth and recent trends. Predictions for freight show that China and India, and possibly parts of the Russian and North American rail networks, will require considerable investment for expansion of capacity as there are no

foreseeable trends in technology that would permit the levels of traffic density that could arise. On the passenger side, current visions for High Speed Rail (HSR), if implemented, could lead to significant investment that might have a positive, if minor, impact on congestion reduction and greenhouse gas (GHG) emission limitation programs.

Many countries have relatively weak or uncoordinated transport policies, and a few large countries have yet to establish a single focus for transport within the government. It is thus somewhat difficult to assess whether the projections support or contradict a clear transport policy. Even so, the freight and passenger traffic levels foreseen pose no major conflicts beyond that of capacity expansion, with one significant exception – the role of freight railways in the transport of carbon-based fuels. More than one-third of all the world's CO_2 emissions from energy production and consumption come from carbon-based fuels (principally coal) hauled by railways. By comparison, if all of the world's railway freight traffic were shifted to trucks, the world emission of CO_2 would increase by slightly more than two percent. There is thus a dilemma posed by the fact that railways' energy efficiency facilitates the transport of fuels that add to the GHG challenge.

With this in mind, if there are controls on GHG emissions in future, the primary "game changer" in innovation for railways appears to be **carbon capture and sequestration**: without sequestration, a major rail freight market will be threatened; with effective sequestration, rail efficiency in hauling fuels will be a continuing strength. Other than sequestration, there are clear opportunities for continuing evolution in application of IT/GPS techniques that will both reduce costs and vastly improve service to customers. "Soft" innovations, including the full implementation of the European Commission's structural Directives and privatization and/or franchising of services can continue to enhance the rail role.

Innovation (however hard to predict) flourishes when the economic and policy environment welcomes and facilitates change. Though it can be difficult for governments to foster or steer innovation, painful experience (such as the mis-regulation of US freight railways before deregulation) has clearly demonstrated that innovation can easily be strangled. The innovatory policy emphasis should always be on allowing the transport system maximum flexibility and resilience to respond to changes, evolutionary or revolutionary, because, while most changes cannot be predicted, they often do require an immediate response.

INTRODUCTION

Transport is usually described as a “derived demand” in the sense that demand for transport is almost always determined by broader aspects of economic or personal activity. Freight must be moved from production point to markets, and passengers travel to work or to shop or for leisure: rarely is the trip itself the object of the transport. Transport thus has been understood to arise from other determining economic drivers rather than being a principal actor.

In some ways, though, this has become a limited and outdated paradigm. There is a feedback loop between the relatively passive idea of a derived transport demand and the impact that the uses and construction of the transport assets have on present and future economic and social possibilities. Much of the development and operation of the transport sector in the 20th century was based on transport as response-driven, without recognizing the return part of the loop. To paraphrase the movie *Field of Dreams*, “we built it and they came – in droves.” Unfortunately.

The result was, most markedly in North America, an increasingly unsustainable spatial organization of population and economic activity and, everywhere, energy intensive activity accompanied by air pollution, noise, traffic congestion and accidents, and a significant acceleration of climate change. The first half of the 21st century looks quite different. Ever growing population density, personal wealth and climate change are creating a much more inclusive look at transport, not just what it does **for** us, but also what it does **to** us. Although economic forces will continue to determine how the transport modes compete, it is likely that external costs, especially carbon emissions but also congestion and safety, will play a larger role in the future of the transport system and of the role assigned to particular modes.

This conference will be looking at the roles and opportunities of the transport sector in the next half century. This paper will attempt to sketch the role for railways and the ways in which technical and policy innovations can affect that role. It goes without saying that anything that looks forward 40 years will be wrong, certainly in its details. Instead, this paper will attempt to identify the key influences that innovations could have, even if the magnitude is not quantifiable.

What are railways today?

The term “railway” is not easily defined. For the most part, the same aircraft fly in every country, though airports and air traffic systems may not be entirely the same. The same ships call at every port, and the same automobiles can be seen on the highways of every country in the world. It is true that some countries operate their highway traffic on the left side of the road, some allow heavier trucks, and some have more extensive systems of super highways, but most trucks and autos could operate at roughly the same speeds on most roads of the world. Railways are not so homogeneous, and this has important implications for the potential role of the railway.

Table One provides a broad picture of most the world’s railway systems in 2005.[1] In total, there were slightly over 900 000 km of rail lines, carrying over 28 billion passengers (2 495 billion passenger-km) and 11.4 billion tonnes (8 845 billion tonne-km) of freight.[2] There were about 7.1 million railway employees.

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[1] A number of caveats apply to Table 1. First, it shows **systems**, such as the US, that are actually made of a number of interconnected, but competing parts. Second, not all railways are included because of lack of data, though this is unlikely to affect the totals in any significant way. Third, as indicated, some data points are missing for some railways, and not all data are from the same year.

[2] Unless otherwise indicated, all measures in this paper are metric.

As Table One shows, however, there are actually **six** gauges (spacing between rails) in common operation around the world. In fact, there are a number of countries that have several gauges in the same network (Argentina, Brazil and Japan are particularly significant). Differing gauges are significant in two ways: first, it is difficult and costly to exchange traffic between different gauges and this limits the productivity and traffic potential of the overall rail network; and, second, the narrower the gauge, the less the bearing capacity of the railway tends to be, which also acts to limit the competitive position of the rail network.

Table Two stratifies the world's railways by gauge. The vast majority of railway freight tonne–km (89%) occurs on standard gauge and Russian broad gauge systems, with broad gauge, meter gauge, Cape gauge and narrow gauge much smaller (on the total world scale). Passenger–km traffic is distributed more widely, because of the large passenger traffic on Indian Railways (broad gauge) and the large amount of short haul passenger traffic (average trip 26 km) on the Japanese conventional rail system (Cape gauge). Traffic density on the Cape, meter and narrow gauge systems is also significantly lower (and would be lower still except for Japan), highlighting the restricted opportunity for higher traffic shares for rail freight and HSR[3] in countries with these systems.

Table Three provides the base data for a different picture – extreme concentration of rail traffic onto a very few of the 100 or so world railway systems. As Figure One shows, the top five passenger rail systems carry 87% of the world's rail passenger traffic.[4] In Figure Two, only four railway systems are needed to account for 82% of the world's railway tonne-km; adding the EU 15 and EU 10 systems adds another 4.4% of total world rail freight traffic.

The point to be emphasized is that, to the extent that rail transport is seen as a potential solution to world-scale energy or emissions problems, almost all of the impact is currently generated in a very few systems: North America, China, Russia, and India for freight, and India, China, EU 15, Japan and Russia for passenger traffic. When freight and passenger traffic are combined, just six railway systems (adding the EU 10 to the EU 15) account for around **90%** of world rail activity.

From a different perspective, the world's railways carry about 3.5 times as many net tonne-km as passenger-km. In very rough terms, energy consumption to produce a rail passenger-km is about twice that needed for freight, because passenger trains travel at higher speeds (energy increases exponentially with increasing speed) and because passenger trains tend to be less heavily loaded than freight trains. Passenger traffic represents roughly 28.5% of rail output (Traffic Units – the sum of tonne-km and passenger-km), but somewhat over 44% of rail energy use.[5]

Since energy use is closely correlated with carbon emissions, it seems clear that an analysis of the contribution that railways can make to world carbon emission restrictions by shifting traffic from less efficient modes (airlines, autos and trucks) can usefully be concentrated on only a few rail systems and should be somewhat more focused on freight than on passenger

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[3] There are currently no true HSR services (>250 km/hr) on Cape, meter or narrow gauge lines.

[4] Note that this ranking is by passenger-km. Using passenger **trips** would re-order the ranking within the top five, because of the enormous passenger numbers in Japan and the EU 15 and the fact that China has no suburban passenger systems, but would leave the percentage of world total essentially unchanged.

[5] I acknowledge that this is a very approximate calculation. UIC statistics taken together with North American data show (surprisingly) that the ratio of passenger gross tonne-km to passenger-km or freight gross tonne-km to net tonne-km is essentially the same for most railways. The same analysis shows that the ratio of energy used for passenger service (per pass-km) is between 2.2 and 2.7 times that of freight (per tonne-km). If anything, the share of passenger usage in total energy consumption by railways might be slightly higher than indicated.

systems. In one sense, this is good news: the challenge is reasonably definable and under the control (mostly) of governing authorities who are equipped to analyze the issues and take action: one could estimate that about 85% of the beneficial impact will be achieved (or not) in these countries. The bad news – the critical role of coal and petroleum in generating traffic **for** railways, and the fact that high-speed rail (HSR) is less energy efficient than conventional rail – will be discussed below.

Table Four provides an additional perspective of the traffic and roles of the major railway systems. Looking first at freight, the initial point from this table is the range in modal shares that rail enjoys. In 2007, the freight market shares for railways ranged from 6.2% (of tonne-km) to as high as 59.3% in Russia (if pipelines were excluded, the rail share would rise over 90%). Looking across the systems, the rail freight share is obviously strongly influenced by geography: large expanses (Russia, US and India) are friendly to rail, smaller systems, especially when broken into internal barriers or islands, are not. The other observation is the almost uniform loss of market share, whether measured from 1970, 1990 or 2000. The only exception is the US (and marginally, Russia if 1990 is the base), primarily owing to the impact of favorable transport deregulation (the Staggers Act) that occurred in 1981.

Rail passenger market shares also show a wide range, from less than one percent in the US to 77% in Russia.[6] The pattern of loss of market share by rail is the same as in freight: only Japan managed to stabilize its market share after 1990, and the loss in market share of the EU 10 and China is especially dramatic.

Taken together, Tables One through Four serve to delimit the impact that might be expected from innovation in railways or, from a different perspective, they serve partly to identify where analysis of innovation might be directed if the future rail role is to be enhanced. As of today, rail traffic is highly concentrated in only a few systems, most of which have been losing market share rapidly to autos, air and trucks. The exceptional performance of the US system in freight is an example of the potential impact of innovation, primarily in policy (regulation) but also supported by technology. The Japanese experience after privatization of rail passenger services may furnish another example, though Japan is unusual in its population density and fragmented geography.

Recent trends in railways

Traffic

Table Five shows the traffic trends in the major systems. Unsurprisingly, China and India show sustained and rapid growth for passengers and freight in both rail and total transport growth essentially without regard to the period considered. By contrast, the EU 15, US and Japan show low but stable growth in total freight transport and in rail freight transport; passenger growth rates are lower than in freight. Growth rates in Russia and the EU 10 were affected by the collapse of the Former Soviet Union: in both systems, rail passenger and freight traffic are actually below 1990 levels. Russia’s rail freight and passenger traffic began to grow again after 2000, whereas the EU 10 has seen slow rail freight growth since 2000, but rail passenger traffic has continued to shrink.

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[6] This number appears far too high, especially as auto ownership in Russia has risen in the last decade. It is based on official statistics though and, ostensibly, includes air travel.

The patterns above have mostly been in response to overall economic trends in the countries involved. At the same time, there has been significant technical and policy/managerial innovation over the 1970-2007 period that has acted to improve efficiency in rail (and elsewhere in the competitive transport sector) and enhance rail's service quality (speed and quality) vis-à-vis other modes.

Technical Innovation

It would be impossible to describe rail innovation since 1970 in complete detail. Instead, Table Six shows the broad details of the more significant changes, separating the innovations into technical and policy/managerial categories.

On the technical side, technical improvements have permitted roughly a 50% reduction in freight costs per tonne-km on the major freight systems, primarily through more intensive use of capacity and reduction in energy costs, coupled with far better use of information to control system quality and enhance pricing. The containerization revolution that started in the maritime area ended up as a major source of traffic for railways, especially in the US and Canada, though Russia, China and India have seen significant traffic increases in containers.

Passenger systems have been improved through better signaling and equipment design that fostered reduced energy use. This has been especially significant in HSR. Not only has HSR greatly expanded the competitive area for rail vis-à-vis air travel, but technical innovation has reduced energy intensity (at the same speed) by about half since introduction of the Shinkansen in Japan.[7] Passenger services have also benefited from information technology (IT) in far better ticketing and revenue maximization. Both freight and passenger have improved safety records as a result of improved signaling and traffic control techniques.

Policy and Managerial Innovation

Policy and managerial ("soft") innovation since 1970 have arguably been at least as important as technical change. Table Six shows three broad categories of innovation: structure, private sector role, and regulation.

At the onset of the 1970s, virtually all railways were monoliths – unitary organizations that controlled all of their activities and services. The result was large, slow moving, inefficient and bureaucratic organizations with little attention to, or knowledge of, customers. Beginning in 1970 with creation of Amtrak in the US (followed by creation of VIA in Canada and JR Freight in Japan) a few more market-focused operating companies were created. These companies were minor users of the system infrastructure and operated as tenants paying for their use of facilities provided by the dominant operator/owner of the system. In general, these innovations were successful at clarifying costs (for government support) and at improving market focus, but were less successful at improving financial performance.

The more revolutionary innovation by the European Commission beginning in 1991 was to require that infrastructure be separated from all operators and that operators be granted neutral access with non-discriminatory access charges. This has evolved into various versions of institutional separation of infrastructure from operators, operation of the infrastructure agency with separated accounts and access charge regimes that differ for each country, increasing

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[7] Obtaining actual energy data for HSR is quite difficult. These data are based on a presentation by Toyonori Noda, Japan Central Railway, "The Tokaido Shinkansen and Superconducting.

Maglev – Contributing to a Low-Carbon Society," November, 2009. See Figure Three.

separation of the various operators from each other (freight, intercity passenger, HSR, suburban passenger), and increasing access by competing railway operators. The Commission’s Directives met with considerable resistance from many rail agencies (and their governments) and the full impact of the changes has yet to be felt; but, albeit gradually, the process is moving forward.

Russia has recently adopted a form of organization that looks both to the EU and to the US, primarily because the freight operator is dominant, but also because the railway (RZhD) itself wanted to enhance its request for public support by clarifying the economic performance of the passenger services. As a result, there are: a tenant national intercity passenger carrier that started full operation in late 2009; a series of suburban operators that RZhD intends either to spin off to local agencies or at least to become a contract carrier on their behalf; a freight carrier subsidiary that will operate trains for all operators; a series of freight wagon owners (“operators”) that contract with the freight carrier for train movement; and, an infrastructure owner that charges access fees. As of now, the RZhD holding company controls infrastructure, the freight carrier, the largest freight wagon owner (operator), the passenger carrier and the various suburban carriers. The private wagon operators now control up to a third of the freight traffic and RZhD has tried to foster growth of private wagon ownership.

There has been limited structural change in Indian Railways (IR). Independent railways (the Konkan Railway for example) have been formed (though they are subsidiaries of IR), and there is a separated container operating company (Concor) with minority private ownership that pays for use of IR track. Future plans for separate, heavy haul freight railway lines from Mumbai to Delhi and Delhi to Kolkata may emerge as separated companies (majority owned by IR).

There are a number of “short lines” that are locally owned in China. Beyond this, there has been little or no innovation in railway organization as yet in China. China does have underway a massive investment program (US $200 billion through 2020) in added double-tracking, added electrification and separated high speed lines that may lead to separated and market-focused companies.

The role of the private sector has changed in a number of railways with a significant effect. Almost all freight and many suburban passenger railways in Latin America were concessioned during the 1990s. The old Japanese National Railway was broken up and the major pieces privatized in 1987, while the Canadian National railway was privatized in 1997. The break-up and privatization of the old British Railways (BR) has been amply chronicled, and there is growing experience in Germany, The Netherlands and Sweden with franchising of local passenger services.

As with any change, there have been failures as well as successes with privatization, concessioning and franchising. The achievements have generally been related to increased efficiency and market focus; certainly this has characterized most of the experience in Latin American concessioning as well as the Canadian and Japanese privatizations. Franchising has been generally successful in clarifying the economic performance of rail passenger systems: unfortunately, franchising sometimes experienced unrealistic bidding (often due to poorly formulated franchising strategies by inexperienced government agencies) and did not always lead to significantly improved efficiency (partly because of requirements that the prior labor conditions be continued).

Perhaps the most successful policy innovation was transport deregulation in the US, including air and trucking as well as rail freight deregulation (the Staggers Act). Although the US railways have long been privately owned and operated (as were trucking and airlines), a pervasive system of government regulation of tariffs and entry and exit had deeply distorted the competitive position of freight railways and prevented the freight railways from offering larger customers services directly tailored to market needs. The Staggers Act virtually eliminated regulation of tariffs and services, made abandonments easier, and explicitly legalized contract rates in which railway tariffs may be conditioned on minimum volumes and shipper/receiver investment. The result was a reduction by half in costs and tariffs accompanied by a two-thirds reduction in accident rates and a doubling of railway return on equity.

A nominal traffic projection

In an earlier study (Thompson 2007), I developed a series of rail freight and passenger projections through 2035. These were based on projections done by the World Energy Organization and were presented as projections (**not** forecasts) for the purposes of analyzing the key pressure points for the potential future of rail transport and estimating the amount of investment that might be needed for capacity growth. For the purposes of this study, Table Seven projects the earlier work another 15 years forward to 2050, again primarily for the purposes of investigating the magnitude of change and to provide a general reality check. I emphasize again that these are not meant to be forecasts of specific traffic segments in particular countries, but only order of magnitude projections to identify underlying issues (for which they are useful).

In one sense, these projections prove the obvious – that compound growth over a long time horizon produces mind boggling numbers and generates an immediate tendency to reject the projections. As will be discussed below, there are some reasons to question the projections as unrealistically high, especially in coal haulage: but, there are also reasons to argue that the totals might actually understate some types of traffic (containers and HSR).

In very broad terms, the growth ratios that occurred from 1970 to 2007 (37 years) as shown in Table Four do not differ wildly from the growth ratios projected from 2007 to 2050 (43 years) shown in Table Seven, particularly if growth in China and India continues and if the economic collapse of the former FSU has finally reached a continuing recovery and, of course, assuming that the current world-wide recession will end with a return to economic growth. Certainly there is no question that the enormous proposed rail investment programs in China (over US $200 billion added by 2020), India (separate heavy haul system), EU (TEN-T), Russia and the US are consistent with considerable rail system growth. Moreover, for example, emerging attention to HSR in the US could multiply the 2050 US rail passenger-km estimates by a factor of three or more.[8]

How do the nominal projections support or clash with established policy?

It is difficult to answer this question in the absence of a clear definition of transport policy. While it would be fair to say that the EU does have transport policies (at the EU level, if not always at the individual country levels), they are not always consistently applied (for example, the EU policy on rail access charges is not consistently applied by member states), and there remains a significant degree of national protectionism of traffic bases and labor practices. By partial contrast, the US, Canada, Russia, China and India have less consistent transport policies: in each country there are significant conflicts in modal approach (e.g. cost recovery by modes) and within each mode (e.g. cross subsidy of passengers at the expense of freight without explicit government compensation). As a result, the nominal projections conflict with some aspects of stated transport expectations, but this may be as much a result of incomplete or contradictory policies as it is of the outcome of established trends.

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[8] Author's estimates.

For the moment, if we take the approach that a generalized transport policy should aim at transport efficiency (proper competitive modal balance based on economic advantage), and then modify the sector goals and interventions appropriately to reflect social goals to which transport can contribute but which the market *per se* would not produce (CO_2 emission, air and water pollution, external congestion costs, and accident costs, among others), we can compare the trends against at least a reasonably desirable outcome.

The major outliers in this respect are probably China and India. China already has the highest rail traffic density of any country, 40 million TU/km, almost twice as high as the next highest (see Table One). The table projects about a five-fold increase in traffic on a system that will increase in length by 2020 by 60% for a net increase of about three times. This increase would probably challenge current technology even given continuing massive investment after 2020 in new lines and added tracks to existing lines. The planned Chinese investment in separation of passenger lines from freight will be helpful, but would still not deal with line density increases on the scale indicated. China, at least, would have a safety valve on its highways, but that could contradict other policy goals. Traffic densities in Russia and India might also be pushed beyond practical limits by the projected traffic levels, though the Indian program of separate, high capacity freight lines would be critical. Russia, with only limited ability to expand its highway system, might find the most difficulty in accommodating the freight traffic levels projected. The other systems, with appropriate investment, do not appear to be beyond the limits of feasibility. In broad terms, there is nothing about the projected traffic levels that obviously conflicts with transport policies if the traffic levels do materialize and, given appropriate support for social objectives and reasonable regulatory policies, the traffic levels can probably be met.

However, this conclusion would change significantly if broader goals such as climate change are brought into the picture. Yes, freight railways are generally more energy efficient than trucks, though this comparison is to some extent related to axle loads (rail and truck) and to efficient operation.[9] Passenger railways can be more energy efficient than autos or air, but this conclusion is highly dependent on load factor,[10] length of trip, types of equipment, and speed, among others. Rail also has the capability of being powered by electric traction, which can have two advantages: 1) electricity can be generated from sources other than carbon-based fuels, thus reducing CO_2 emissions; and, 2) in any case, electric power can replace petroleum fuels in autos, airplanes and trucks, thus reducing strategic petroleum dependency.

But, the higher passenger speed of HSR, though needed to compete with air on trip time, raises energy use significantly. Energy comparisons among passenger modes are highly contentious, but several conclusions appear to be clear: 1) as a matter of basic physics, for the same rolling stock and operating conditions, energy use will increase roughly as the square of speed[11]; 2) design improvements are steadily improving the energy use of high speed passenger trains at the same speeds. Figure Three displays the Japanese experience over time with improving design. Clearly the energy intensity must level off at some point, but the current trends are still downward.

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[9] The US average rail energy use is 457 revenue ton-miles per gallon of fuel (AAR 2009, pg 40). This is the equivalent of about 200 kJ/tonne-Km. Estimates of comparable truck energy consumption figures are virtually unobtainable; however, the World Bank's HDM model indicates a usage by a fully loaded heavy truck at around 850 kJ/tonne-Km. See Fraser, Swaminathan and Thompson (1995), Fig 2-1. The same study (Fig 2-8) shows that some lightly used railways actually have higher energy intensity than trucks.

[10] Empty trains can actually waste energy by comparison with fully loaded autos or airplanes. Full conventional short-haul trains are much less energy intensive than full HSR trains.

[11] See e.g., RSSB 2007, p. 35, which shows energy consumption as a function of speed for a number of typical train sets.

In addition, more recent energy studies are attempting to assess the total energy impact of competing modes, including the embedded energy needed to construct the facilities and operating equipment. Although results of these studies are not yet in general agreement because of methodology issues and the influence of particular conditions, indications are that rail has a measurably higher ratio of embedded carbon to operating carbon than air or highway modes.[12]

Related to this issue is the fact that while HSR may save energy with respect to air and auto, future HSR markets that are often based on a significant amount of new traffic generation (induced traffic) or on a significant shift from conventional rail to HSR that could actually increase overall carbon emissions. Moreover, in any event, the share of HSR in the total passenger market will never be large enough for energy savings due to HSR alone to carry much of the climate change control burden.

The CO_2 savings attributable to use of electric energy for rail traction are highly country-dependent. Table Eight shows the variation in CO_2 emissions for electric generation in a number of countries: while it is true that a kWhr of electric traction in France (nuclear) or Brazil (hydro) would not emit much carbon, the same kWhr in China or India would emit nearly **ten** times as much carbon (about eight times as much in the US) because of the high level of use of carbon-based fuels for electricity generation. It is, obviously, risky to generalize on the issue of the carbon advantage of electric traction in railways.

A potentially much more significant paradox for rail is the interaction between the energy saving aspect of rail freight, and the fact that one of the major commodities hauled by many railways is carbon-based fuels, primarily coal and petroleum. Table Nine shows the role of coal and petroleum in railway traffic in the world's railways. These carbon fuels generate between 40 and 50% of the tonnes and tonne-km of the traffic of the major freight railways, the US, China, Russia and India. The EU 10 countries generate slightly over 40% of their traffic from coal and petroleum as well. The EU 15 railways are less coal and petroleum-dependent than the larger railways, but still haul about 15% of their output as coal and petroleum.

Table Nine shows that carbon fuels hauled by railways were ultimately responsible for emitting about 10.6 billion tonnes of CO_2. According to the US Energy Information Administration, the total world emission of CO_2 from energy consumption in 2006 was 29.1 billion tonnes, which means that slightly over one-third of all world carbon emissions are generated from rail-hauled freight cargo. By contrast, if the alternative to rail haulage is trucks, then railways are saving roughly 700 million tonnes of carbon emissions from higher energy efficiency in transport.

This is not meant to suggest that coal and petroleum should not be burned to generate energy, nor does it mean that rail haulage of coal-based fuels is either bad or good. Rather, it does starkly indicate that the freight future (and significant profitability and capital generation) of the major railway systems is intimately bound up with climate change, but not in the way commonly perceived. Railways **can** save energy in transport, but programs to reduce carbon emissions may not necessarily save railways.

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12. See, e.e., Booz 2007, p. 3 and 4 (which shows life cycle energy for rail to be about 20% higher than operating energy while auto and air are shown to have negligible mark-ups) and Chester 2008, Abstract pg. 2 where the mark-ups for life cycle GHGs over operating are: 47-60% for autos, 43% for buses, 39-150% for rail and 24-31% for air. More research is apparently needed.

Potential game changing innovations (or, for the fun of it, what innovations could realistically help or harm railways significantly)

As suggested above, if climate change measures are implemented worldwide, the **most important innovation for freight railways will be carbon capture and sequestration**. If carbon sequestration is economically feasible, then what might well be a major weakness of railways will become a strength. If carbon sequestration is not possible, climate change measures and railway transport economics will be in conflict and railways will face a real threat of traffic erosion.

There is a danger in overly focusing on climate change as the driver of transport's future. In fact, transport is actually less carbon intensive than the power generation and industrial sectors and carbon trading programs or (more efficient) carbon taxing regimes would have less impact on rail, truck and auto (somewhat more on air) than on other sectors. In fact, if a carbonless, inexpensive wonder-fuel suddenly emerged, most of the problems of transport today would remain: in fact, most of transport was effectively developed on this basis since the effects of carbon have not been significant in the past.

Fuel efficiency innovations such as pure battery-driven vehicles and hybrids (truck and rail as well as auto) and better diesel engines (which will help rail, auto and trucks) are already in the works and will no doubt take an increasing role in transport: it is less clear which mode they will favor, and more likely they will help all modes to be more efficient. It is clear that there is considerable room for improvement in the efficiency of all modes, not just railways, and it is not entirely clear that the putative rail advantage will remain as large as it is today.

Airlines appear to be more vulnerable to energy cost and availability concerns. Improvements have been made in airline fuel efficiency, and they are likely to continue: however, the favorable impact may be felt more in long haul than in shorter haul markets competitive with rail or auto. Innovations such as cellulose-based biofuels and hydrogen, both of which might be less petroleum dependent for their production and which might generate less carbon in their use, could help air travel relatively more than rail highway modes. With this said, though, current generation biofuels (such as corn-based ethanol) remain very questionable on grounds of efficacy and scalability. Cellulose-based biofuels might well have a larger impact, but real innovation will be needed to make them fully scalable and economic in the absence of effective carbon control regimes. Hydrogen is so far certainly not a wonder fuel because of its inherently low energy density, the need for an entirely new distribution system, and the fact that most methods of hydrogen production result in the emission of CO_2.

Before turning to specifically rail technical innovations, it is worthwhile to identify innovations (other than energy efficiency) that can be foreseen that will improve other modes. Probably the most important innovation will be rapidly increasing use of GPS systems (perhaps combining the US GPS with Galileo for enhanced accuracy) in ways that could vastly change highway usage. There is every reason to believe that GPS-based data, along with enhanced instrumentation and communications, can lead to more efficient congestion pricing (see below for the related policy innovations) and to much better equipment utilization on highways, as it already has in railways. It is not much of a stretch to imagine a combination of GPS data with on-board performance data feeding through high capacity communications to system wide computers to yield much more efficient use of highway and airway capacity, with a related impact on the competitive position of railways in both freight and passenger markets. This could also lead to increasing automation ("intelligent vehicles") that would lead to improved safety and potentially more efficient use of labor. Railways clearly are shooting at a moving target.

In the same vein, it is not difficult to expect technical innovations in railways:

- Railway energy efficiency will continue to improve as a result of progression in diesel technology combined with operational improvements, though the curve may already be flattening out, because practical limits on train length and axle loading are being approached. Figure Four shows what has been achieved in US Class I railroads. Increased implementation of HSR may lead to somewhat more energy consumption if significant parts of future HSR markets come from induced travel or diversion from conventional rail.
- Improvements to rail efficiency through more electric traction are possible. China, India and Russia are expanding their electrified systems (though Table Eight shows that this might have a more favorable carbon impact in Russia than in China and India).
- Railways have a major opportunity to improve safety and productivity through continued innovations in signaling and automation combined with GPS, enhanced communications and computers. Electronically controlled braking (ECP) will also be significant on heavy haul railways. One part of this type of efficiency improvement will be standardization through programs like ERTMS in the EU or the US equivalent (PTC). These systems will become increasingly important if, as Table Seven suggests, traffic density on the rail networks continues to increase, and will be especially important for mixed passenger and freight lines and HSR lines where the safety margin of error is less and the potential damage from accidents is higher. It would have been unthinkable in 1970 to argue for single driver trains or elimination of cabooses (in the US) or passenger trains averaging 350 Km/hr (as the most recent Chinese HSR trains do): the year 2050 is only 40 years from now; but, if technological change continues or quickens (which is more likely), we can expect: trains without crews (done today in some Metros); real-time system management of all trains without wayside signals throughout the US and the EU; real time monitoring of all equipment condition and maintenance planning (already done by many airlines and some US freight railways); and even tighter integration of rail services into logistics chains.
- Given an appropriate regulatory environment, experience with the Staggers Act in the US shows that lower costs and higher quality will be shared with users in a way that will benefit all.

But, the parallel process of policy and managerial innovation may well be more important than, and will certainly be a complement to, technical innovation. There are a number of examples to consider:

- Policies in support of road and airport pricing are not fully in step with what current and emerging technology will permit. Highway congestion pricing is not yet accepted in the US and, probably more important, the concept of charging for external costs is bitterly opposed by a well-organized trucking lobby as well as anti-tax interests in general. By contrast, US railways have long had to pay the entire cost of their infrastructure, including system congestion. China, India and (to a lesser extent) Russia have in the past subordinated rail freight and passenger pricing to political goals and the railways lack the basic tools for efficient pricing: increasing competition from other modes will exaggerate this problem.
- There remains a lot to be done, much of it driven by policy innovation, to fully implement the EU ’s approach to infrastructure separation. To some degree, technical innovations (web based-information) have already been felt in the operations and pricing done by the Network authorities. Actual implementation of efficient access charges remains a work in progress, though, and innovations in economic analysis and national financial policies will be needed before the EU access charge systems permit maximally efficient use of the entire network.

- Experience is showing that passenger railway concessioning and franchising are more difficult than originally expected. In particular, the problem of appropriate alignment of incentives between public authorities and private operators has yet to be generally resolved because of inherent differences in objectives (private profit versus social objectives) and time horizons. The U.K. and Australian experiences with franchises has not always encouraged other countries to adopt the practice, but a slower process of experimentation in Sweden, Germany and the Netherlands is showing that franchises can lead to better and less expensive services. Innovation in franchising relationships should continue.

- Concessioning and privatization of freight railways has been generally more successful, but could also be improved, particularly in developing methods for supporting investment when the remaining life of the concession is less than the life of the assets needed.

- Although both Amtrak and VIA advanced the goal of clarifying and separation of passenger rail finances from those of freight, both countries left too much authority and financial responsibility for provision of local rail passenger services in the hands of a national authority. Policy innovation to decentralize these services to state or provincial authorities will be needed. Russia, China, India and possibly EU countries have the same problem. At least in the US, the emergence of HSR will require a better definition of public versus private benefits and a better balance among Federal, State, local and private investors.

- There is a spectrum in rail freight regulation, ranging from essentially no regulation in the EU (where it would be mostly irrelevant anyway due to intense trucking competition), through the US where freight tariffs are mostly unregulated (although there is pressure in the Congress to increase regulation once again), to Canada where government intervenes primarily to support agricultural interests and continuing through Russia, India and China where railway freight tariffs are more tightly controlled. Regulatory innovation in the latter three countries will be increasingly important if railways are to compete effectively with highways.

- Regulation of passenger services has been felt not only through direct intervention in fares, but also in calculation of support payment regimes. The European Commission’s pressure to separate freight operators from passenger operators and, within passengers, of commercial from social services, will depend on innovation in accounting and costing methods as well as contracting relations between increasingly independent entities (or private entities if franchises or concessions are involved).

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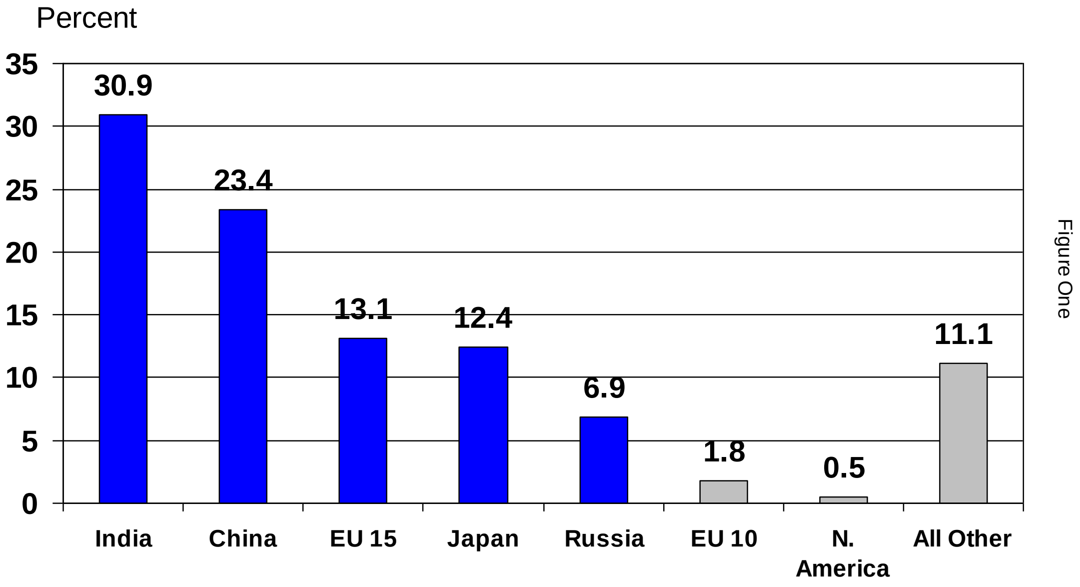
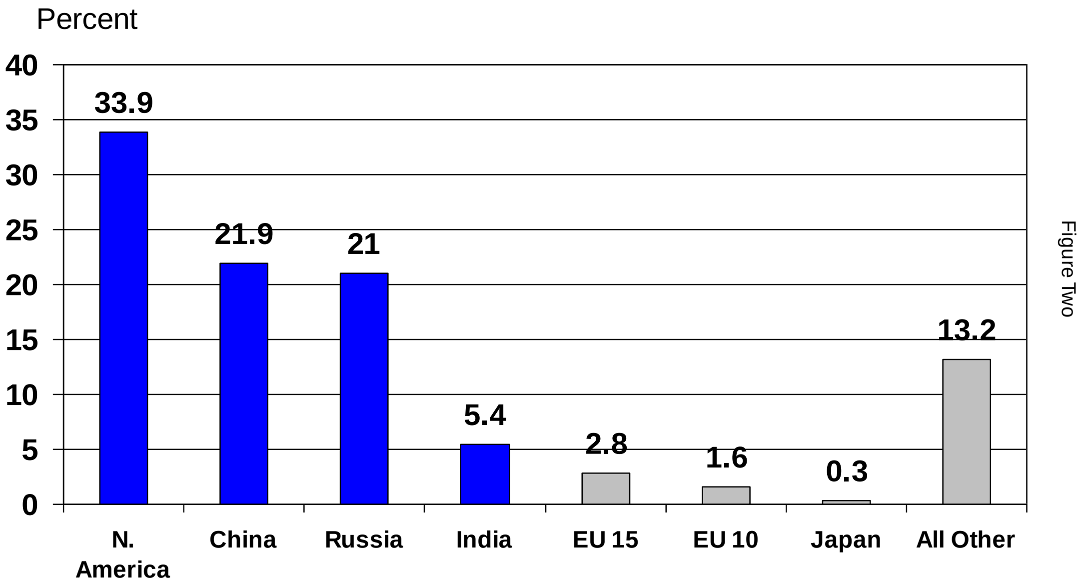
FIGURES

Figure 1. **Percentage of world passenger-km**



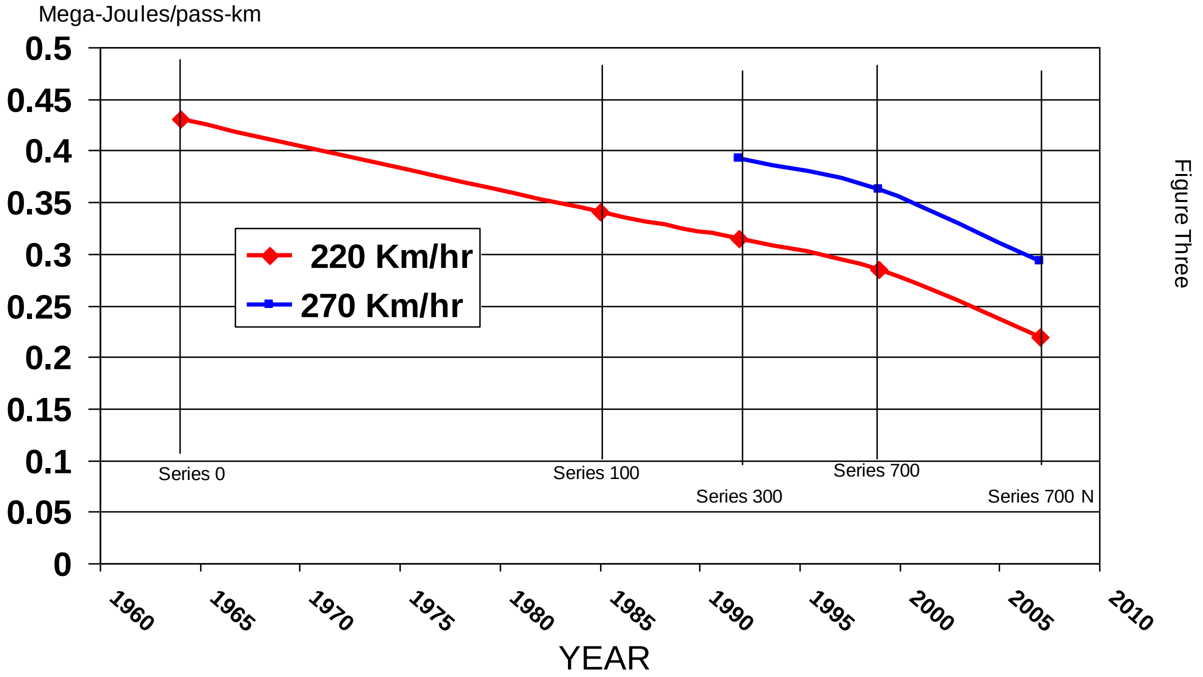
Top 5: 87%

Figure 2. **Percentage of world tonne-km**



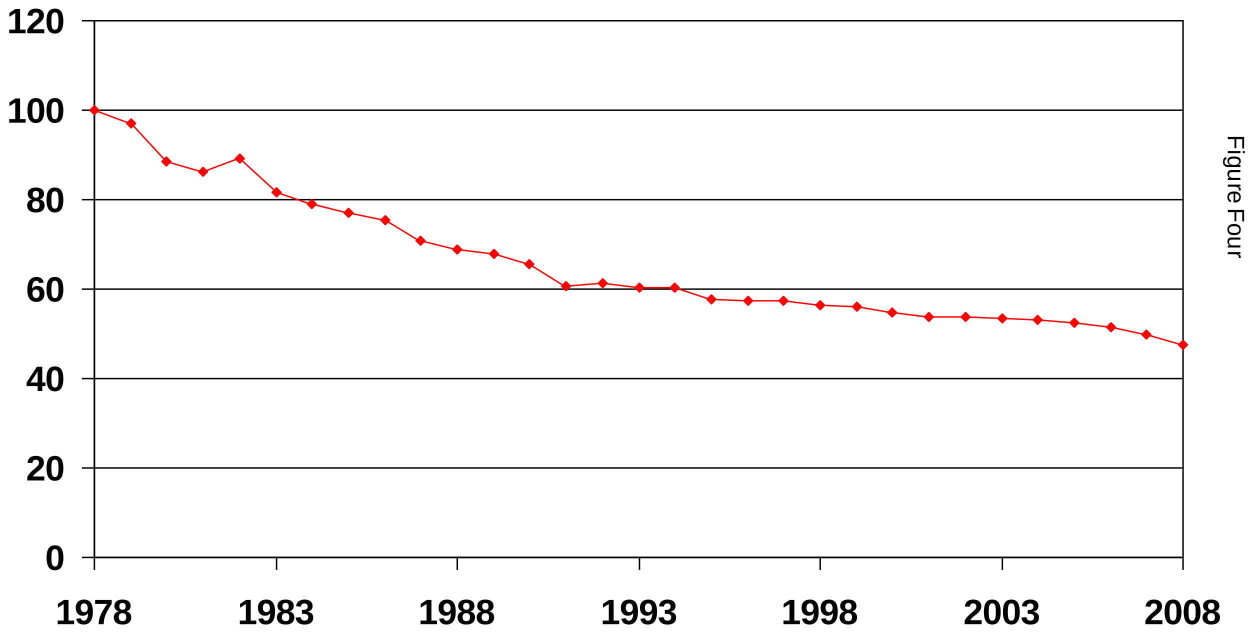
Top 4: 82%. Top 6: 87%

Figure 3. **Shinkansen energy use**



Data from Toyonori Noda, Japan Central Railway, presentation to Nagoya Conference entitled "The Tokaido Shinkansen and Superconducting Maglev – Contributing to a Low-Carbon Society," Charts entitled "The Energy Efficiency of Shinkansen Rolling Stock," and "The Environmental Superiority of the Tokaido Shinkansen." Assumes 60% load factor.

Figure 4. **US Class I railway fuel use per tonne-km**
(Index: 1978=100)



TABLES

Table 1. **The world's major railway groupings (2005 or latest available year)**

	Gauge*	Year	Total Route km	Passengers (000)	Passenger-Kilometers (000,000)	Freight Tonnes (000,000)	Freight Tonne-km (000,000)	Staff	Traffic Density** (000,000)	Avg Lgth of haul Frt (km)	Avg pax trip (km)
China	Std	2005	62,200	1,106,510	583,320	2,309.2	1,934,612	1,665,588	40.5	838	527
Russia	RB	2005	85,245	1,338,723	172,217	1,281.3	1,858,100	1,161,900	23.8	1,450	129
India Total		2007	63,273	6,524,377	769,956	727.7	480,993	1,394,520	19.8	661	118
Estonia	RB	2005	959	5,200	248	44.8	10,311	3,300	11.0	230	48
Latvia	RB	2005	2,375	25,900	894	54.9	17,921	14,600	7.9	326	35
Lithuania	RB	2005	1,772	6,700	428	49.3	12,457	11,300	7.3	253	64
Bulgaria	Std	2005	4,154	33,700	2,389	20.3	5,164	33,700	1.8	254	71
Czech Republic	Std	2005	9,513	178,200	6,631	75.8	14,385	65,200	2.2	190	37
Slovakia	Std	2005	3,659	49,100	2,166	47.7	9,326	36,600	3.1	196	44
Hungary	Std	2005	7,730	120,400	6,953	44.0	8,537	44,600	2.0	194	58
Poland	Std	2005	19,507	218,000	16,742	155.1	45,438	127,700	3.2	293	77
Romania	Std	2005	10,781	91,500	7,960	67.5	16,032	67,100	2.2	238	87
Slovenia	Std	2005	1,228	15,700	777	16.3	3,245	8,100	3.3	199	49
EU 10 Total			61,678	744,400	45,188	575.7	142,816	412,200	3.0	248	61
Portugal	B	2005	2,839	130,600	3,412	9.6	2,422	8,600	2.1	252	26
Spain	B	2005	14,484	610,700	21,047	29.7	11,586	19,100	2.3	390	34
Austria	Std	2005	5,690	191,600	8,470	81.7	17,036	47,200	4.5	209	44
Belgium	Std	2005	3,542	186,600	9,150	61.0	8,130	37,200	4.9	133	49
Denmark	Std	2005	2,212	152,400	5,459			3,170	2.5		36
Finland	Std	2005	5,732	63,500	3,478	40.7	9,706	10,300	2.3	238	55
France	Std	2005	29,286	962,700	76,159	129.7	41,898	167,200	4.0	323	79
Greece	Std	2005	2,576	10,000	1,854	3.0	613	8,100	1.0	204	185
Ireland	Std	2005	1,919	37,700	1,781	1.5	303	5,500	1.1	202	47
Italy	Std	2005	16,225	516,800	46,144	68.7	20,131	99,100	4.1	293	89
Netherlands	Std	2005	2,813	321,100	14,730			27,300	5.2		46
Sweden	Std	2005	9,867	34,900	5,673		13,120	13,200	1.9		163
Switzerland	Std	2005	3,011	275,900	13,830	56.2	8,571	25,900	7.4	153	50
United Kingdom	Std	2005	15,810	1,082,000	43,200	103.9	22,110	83,000	4.1	213	40
Germany	Std	2005	34,218	1,785,400	72,554	274.6	88,022	224,600	4.7	321	41
EU 15 total			150,224	6,361,900	326,941	860.3	243,648	779,470	3.8	283	51
Mexico	Std	2005	15,747	6,727	1,799	59.6	72,159	10,000	4.7	1,210	267
Canada: Via Rail	Std	2005		4,097	1,430			3,059			349
Canada:Canadian National	Std	2005	31,894			212.6	262,589	22,246	8.2	1,235	
Canada:Canadian Pacific	Std	2005	21,962			120.4	183,100	16,448	8.3	1,520	
USA:Amtrak	Std	2005	1,100	24,164	8,681			19,177	7.9		359
USA:All Class I Railways	Std	2005	153,787			1,723.0	2,478,914	162,438	16.1	1,439	
North America Total			224,490	34,988	11,910	2,115.7	2,996,762	233,368	13.4	1,416	340
JP conventional railways	C	2007	9,830	8,672,166	226,918	36.2	23,166	121,930	25.4	640	26
JP Shinkansen	Std	2007	2,387	315,778	82,823			40,000	34.7		262
Japan Total			12,217	8,987,944	309,741	36.2	23,166	161,930	27.2	640	34
BR Tereza Christina	M	2007	235			2.6	200	235	0.9		
BR EFVM Vitoria Minas	M	2007	6,303			136.8	75,500	6,303	12.0		
BR MRS	B	2007	4,138			114.1	52,600	4,138	12.7	461	
BR Bandeirantes	B	2007	899			3.5	1,900	899	2.1	543	
BR EFC Carajas	B	2007	5,008			100.3	83,300	5,008	16.6	831	
BR Ferronorte	B	2007	1,413			6.9	9,400	1,413	6.7	1,362	
Chile	B	2005	2,700	18,591	859	9.8	1,671	5,000	0.9	170	46
AR FEPSA	B	2007	2,560			4.1	1,765	897	0.7	428	
AR Ferrosur Roca	B	2007	2,650			5.5	2,076	799	0.8	376	
AR NCA	B	2007	3,254			8.6	4,257	1,316	1.3	495	
AR BAP (now ALL)	B	2007	3,000			4.4	3,140	1,325	1.0	720	
AR All BG Pax Concessions	B	2007	687	339,479	6,548			9,988	9.5		19
BR Centro Atlantico (FCA)	M	2007	5,940			19.0	14,400	5,940	2.4		
BR Novoeste	M	2007	879			2.7	1,200	879	1.4		
BR Nordeste	M	2007	1,755			1.8	1,000	1,755	0.6		
BR ALL (old FSA)	M	2007	5,200			27.3	17,500	5,200	3.4		
AR Belgrano	M	2007	4,940			0.8	739	1,470	0.1		
Antofagasta & Bolivia	M	1989	750			1.7	432	562	0.6	261	
Boliva-Andina Network	M	1995	2,274	395	120	0.6	314	2,454	0.2	493	304
Boliva-Oriental Network	M	1995	1,424	355	164	0.8	464	1,440	0.4	595	462
Peru	M	1996	1,691	1,225	172	1.5	453	2,293	0.4	296	141
Colombia	N	1996	3,154	120	15	1.6	471	271	0.2	296	128
AR Mesopotamico	Std	2007	2,100			1,571.0	906	500	0.4		

Table 1. **The world's major railway groupings (2005 or latest available year)** (cont'd)

	Gauge*	Year	Total Route km	Passengers (000)	Passenger-Kilometers (000,000)	Freight Tonnes (000,000)	Freight Tonne-km (000,000)	Staff	Traffic Density** (000,000)	Avg Lgth of haul Frt (km)	Avg pax trip (km)
AR Urq	Std	2007	32	26,877	465			609	14.5		
Cuba	Std	1998	4,667	11,000	1,452	4.4	732	27,000	0.5	166	132
Uruguay	Std	2005	3,003	517	12	1.3	331	511	0.1	251	24
AR Bel N and S	M	2007	120	56,157	972			2,561	8.1		17
Ukraine	RB	2005	22,001	518,400	52,655	462.4	223,980	368,200	12.6	484	102
Kazakhstan	RB	2005	14,204	15,900	12,129	215.5	171,855	94,300	13.0	797	763
Belarus	RB	2005	5,498	141,000	13,568	125.1	43,559	78,300	10.4	348	96
Georgia	RB	2005	1,515		720	19.0	6,127	15,800	4.5	322	
Armenia	RB	2005	711	703	27	2.6	654	4,745	1.0	250	38
Azerbaijan	RB	2005	2,122	5,200	878	26.5	10,067	29,200	5.2	379	169
Uzbekistan	RB	2005	4,014	16,100	2,012	53.8	18,007	35,400	5.0	335	125
Pakistan	B	2005	7,791	78,200	24,237	6.4	5,013	86,807	3.8	782	310
Sri Lanka	B	2005	1,200	114,400	4,358	1.5	135	16,360	3.7	90	38
Bangladesh	B	2005	2,855	42,254	4,164	3.2	817	35,172	1.7	255	99
Indonesia	*C*	*2000*	*8,500*	*170,000*	*16,100*	*18.0*	*4,698*	*35,000*	2.4	*261*	*95*
Burma (Myanmar)	M	1991	3,336	53,180	3,939	1.8	449	28,811	1.3	256	74
Malaysia	M	2005	1,667	3,700	1,181	4.0	1,178	5,000	1.4	295	319
Philippines	M	2004	491		144	0.0	1	*2,000*	0.3	382	
Thailand	M	2004	4,044	50,873	9,332	13.8	4,085	19,000	3.3	296	183
Viet Nam	M	2005	2,671	12,800	4,558	8.7	2,928	44,200	2.8	337	356
Mongolia	RB	2005	1,810	4,300	1,228	14.1	8,857	15,200	5.6	628	286
Republic of Korea	Std	2005	3,392	921,300	31,004	44.5	10,108	29,300	12.1	227	34
Malawi	M	1999	710	349	19	0.3	56	952	0.1	163	55
South Africa	C	2005	20,247	3,100	991	182.2	109,721	32,516	5.5	602	320
Ghana	C	2004	977	2,340	85	1.9	242	3,777	0.3	129	36
Namibia	C	1995	2,382	124	49	1.8	1,082	1,944	0.5	615	392
TAZARA	C	2000	1,860	1,641	518	0.6	780	4,175	0.7	1,231	316
Zaire	C	2005	3,641	400	140	1.2	444	13,600	0.2	370	350
Zambia	C	1999	1,273	830	186	1.6	554	3,400	0.6	339	224
Zimbabwe	C	1997	2,759	1,598	583	12.0	4,871	12,025	2.0	406	365
Cameroun	M	1998	1,006	1,050	357	1.9	1,076	2,301	1.4	581	340
Cote D'lvoire	M	1995	639	718	181	0.5	312	3,628	0.8	645	252
Ethiopia	M	1991	781		157		50	2,616	0.3		
Kenya	M	2002	2,634	4,794	288	2.2	1,538	7,000	0.7	691	60
Mali	M	2000	734	700	204	0.8	279	1,500	0.7	349	291
Nigeria	M	2000	3,557	1,526	363	0.1	105	13,618	0.1	827	238
Senegal	M	2000	906	4,300	138	1.7	371	1,500	0.6	218	32
Sudan	M	2005	5,478	100	40	1.3	766	11,800	0.1	589	400
Uganda	M	2004	259			0.9	218	1,150	0.8	241	
Tanzania (TRC)	M	2006	2,722	694	433	1.7	1,970	9,000	0.9	1,152	624
Congo--CFCO	Std	2005	795	500	135	0.6	231	600	0.5	385	270
Gabon	Std	2004	731	217	92	3.5	1,949		2.8	557	424
Australia	Std, C &	2005			11,000		192,700				
New Zealand	C	1999	3,913	-	-	12.9	3,671	4,285	0.9	285	
Jordan	M+	2005	293			2.9	1,024	600	3.5	353	
Algeria	Std	2005	3,572	27,300	929	8.3	1,471	10,500	0.7	177	34
Egypt	Std	2005	5,150	451,100	40,837	10.1	3,917	91,400	8.7	388	91
Iran	Std	2005	7,131	19,400	11,149	30.3	19,127	13,700	4.2	631	575
Morocco	Std	2005	1,907	18,500	2,987	32.9	5,919	9,300	4.7	180	161
Saudi Arabia	Std	2005	1,020	1,100	393	2.6	1,192	1,600	1.6	458	357
Syria	Std	2002	2,450	1,417	364	5.9	1,812	11,500	0.9	306	257
Tunisia	Std	2005	1,909	36,804	1,319	10.8	2,067	5,226	1.8	192	36
Israel	Std	2005	899	26,800	1,618	7.5	1,149	1,600	3.1	153	60
Yugoslavia	Std	2005	3,809	13,500	852	12.6	3,482	22,300	1.1	276	63
Croatia	Std	2005	2,726	39,800	1,266	14.3	2,835	14,200	1.5	198	32
Bosnia	Std	2005	1,000	1,100		12.0	1,173	7,000	1.2	98	0
Albania	Std	2005	447	1,400	73	0.4	26	2,200	0.2	65	52
Turkey	Std	2005	8,697	76,306	5,036	18.9	9,078	30,991	1.6	479	66
FYROM	Std	2005	699	900	94	3.1	530	2,900	0.9	171	104
Total All Other Railways			258,311	3,343,434	275,889	3,454.4	1,165,056	1,389,965	5.6	337	83
			917,638	28,442,276	2,495,162	11,360.5	8,845,153	7,198,941			
red italics indicates estimate											
World Total			**917,638**	**28,442,276**	**2,495,162**	**11,360.5**	**8,845,153**	**7,198,941**	12.4	779	88
* Gauges		117									
Narrow (N)	914 mm										
Meter (M)	1000 mm										
Cape [C]	1067 mm										
Standard (Std)	1435 mm										
Russian Broad (RB)	1524 mm										
Broad (B)	1676 mm										

** Traffic density is expressed as the sum of net tonne-km and passenger-km divided by line km. This measure is conventionally called traffic units (TU)/km

Table 2. **World railways by gauge**

	Total Route km	Percent world total	Passengers (000)	Percent world total	Passenger-Kilometers (000,000)	Percent world total	Freight Tonnes (000,000)	Freight Tonne-km (000,000)	Percent world total	Staff	Traffic Density (000,000)	Avg Lgth of haul Frt (km)	Avg pax trip (km)
Standard Gauge	534,686	58.3	9,460,314	33.3	1,135,230	45.5	7,467.6	5,523,876	62.5	3,356,663	12.5	740	120
Russian Broad Gauge	142,226	15.5	2,078,126	7.3	257,004	10.3	2,349.3	2,381,895	26.9	1,832,245	18.6	1,014	124
Broad gauge	106,561	11.6	7,678,978	27.0	812,202	32.6	1,032.5	659,638	7.5	1,481,342	13.8	639	106
Meter Gauge	72,880	7.9	354,089	1.2	44,332	1.8	241.1	130,044	1.5	285,768	2.4	539	125
Cape Gauge	55,382	6.0	8,852,199	31.1	245,570	9.8	268.4	149,229	1.7	199,652	7.1	556	28
Narrow Gauge	5,903	0.6	18,570	0.1	824	0.0	1.6	471	0.0	10,271	0.2	296	44
World Total	**917,638**	**100**	**28,442,276**	**100**	**2,495,162**	**100**	**11,360.5**	**8,845,153**	**100**	**7,165,941**	12.4	779	88

* Gauges

Narrow (N)	914 mm
Meter (M)	1000 mm
Cape [C]	1067 mm
Standard (Std)	1435 mm
Russian Broad (RB)	1524 mm
Broad (B)	1676 mm

Table 3. **World railway systems ranked by activity**

PASSENGER TRAFFIC ACTIVITY RANKINGS

	Total Route km	Percent world total	Passengers (000)	Percent world total	Passenger-Kilometers (000,000)	Percent world total	Cum % World Total	Freight Tons (000,000)	Freight Ton-km (000,000)	Staff	Traffic Density (000,000)	Lgth of haul Frt	Avg pax trip
India	63,273	6.9	6,524,377	22.9	769,956	30.9	30.9	727.7	480,993	1,394,520	19.8	661	118
China	62,200	6.8	1,106,510	3.9	583,320	23.4	54.2	2,309.2	1,934,612	1,665,588	40.5	838	527
EU 15	150,224	16.4	6,361,900	22.4	326,941	13.1	67.3	860.3	243,648	779,470	3.8	283	51
Japan	12,217	1.3	8,987,944	31.6	309,741	12.4	79.8	36.2	23,166	161,930	27.2	640	34
Russia	85,245	9.3	1,338,723	4.7	172,217	6.9	86.7	1,281.3	1,858,100	1,161,900	23.8	1,450	129
EU 10	61,678	6.7	744,400	2.6	45,188	1.8	88.5	575.7	142,816	412,200	3.0	248	61
N. America	224,490	24.5	34,988	0.1	11,910	0.5	88.9	2,115.7	2,996,762	233,368	13.4	1,416	340
All Other	258,311	28.1	3,343,434	11.8	275,889	11.1	100.0	3,454.4	1,165,056	1,389,965	5.6	337	83
World Total	**917,638**	**100.0**	**28,442,276**	**100.0**	**2,495,162**	**100.0**		**11,360**	**8,845,153**	**7,198,941**			

FREIGHT TRAFFIC ACTIVITY RANKINGS

	Total Route km	Percent world total	Passengers (000)	Percent world total	Passenger-Kilometers (000,000)	Freight Tons (000,000)	Freight Ton-km (000,000)	Percent world total	Cum % World Total	Staff	Traffic Density (000,000)	Lgth of haul Frt	Avg pax trip
N. America	224,490		34,988		11,910	2,115.7	2,996,762	33.9	33.9	233,368	13.4	1,416	340
China	62,200		1,106,510		583,320	2,309.2	1,934,612	21.9	55.8	1,665,588	40.5	838	527
Russia	85,245		1,338,723		172,217	1,281.3	1,858,100	21.0	76.8	1,161,900	23.8	1,450	129
India	63,273		6,524,377		769,956	727.7	480,993	5.4	82.2	1,394,520	19.8	661	118
EU 15	150,224		6,361,900		326,941	860.3	243,648	2.8	85.0	779,470	3.8	283	51
EU 10	61,678		744,400		45,188	575.7	142,816	1.6	86.6	412,200	3.0	248	61
Japan	12,217		8,987,944		309,741	36.2	23,166	0.3	86.8	161,930	27.2	640	34
All Other	258,311		3,343,434		275,889	3,454.4	1,165,056	13.2	100.0	1,389,965	5.6	337	83
World Total	**917,638**		**28,442,276**		**2,495,162**	**11,360**	**8,845,153**	**86.8**		**7,198,941**			

Ratio of tonne-km to pass-km	3.54

Table 4. **Rail transport and total transport in major transport markets**

FREIGHT

	Rail Passenger Transport Rail Freight Transport (000,000 tonne-km)						Total Freight Transport Tonne-Km					Rail Modal Share in Freight				
	1970	**1990**	**2000**	**2006**	**2007**	**Ratio 2007 to 1970**	**1970**	**1990**	**2000**	**2006**	**2007**	**1970**	**1990**	**2000**	**2006**	**2007**
China	349.6	1,062.2	1,390.2	2,195.4	2,379.7	6.8	456.6	2,620.7	4,445.1	8,895.2	9,606.8	76.6	40.5	31.3	24.7	24.8
Russia	1,672.0	2,522.9	1,373.2	1,950.8	2,090.3	1.3	2,194.9	4,276.0	2,341.9	3,390.1	3,523.1	76.2	59.0	58.6	57.5	59.3
India	72.3	235.8	312.4	481.0	521.4	7.2	101.7	374.3	781.0	*1,414.7*	*1,489.6*	71.1	63.0	40.0	*34.0*	*35.0*
EU10	274.3	280.2	147.6	154.1	155.8	0.6	354.9	444.5	364.5	497.8	531.3	77.3	63.0	40.5	31.0	29.3
EU15	233.3	249.7	246.0	273.0	281.1	1.2	740.4	1,266.5	1,596.9	1,825.5	1,894.4	31.5	19.7	15.4	15.0	14.8
US	1,126.0	1,554.1	2,257.6	2,559.8	2,556.6	2.3	2,585.1	4,072.9	5,283.2	5,711.8	5,701.6	43.6	38.2	42.7	44.8	44.8
Japan	63.0	27.2	22.1	23.2	23.3	0.4	198.9	301.4	335.3	369.7	376.6	31.7	9.0	6.6	6.3	6.2

PASSENGER

	Rail Passenger Transport						Total Passenger Transport (000,000 passenger-km)					Rail Modal Share in Passenger Service				
	1970	**1990**	**2000**	**2006**	**2007**	**Ratio 2007 to 1970**	**1970**	**1990**	**2000**	**2006**	**2007**	**1970**	**1990**	**2000**	**2006**	**2007**
China	71.8	261.3	453.3	662.2	721.6	10.1	103.1	562.8	1,226.2	1,919.7	2,073.3	69.6	46.4	37.0	34.5	34.8
Russia	191.1	274.4	167.1	177.8	174.1	0.9	291.2	536.6	331.4	262.2	226.3	65.6	51.1	50.4	67.8	76.9
India	118.1	295.6	457.0	694.8	770.0	6.5	*1,000.0*	*2,270.0*	*3,520.0*	*5,000.0*	*6,000.0*	*36.0*	*28.0*	*18.0*	*15.0*	*14.0*
EU10	105.2	131.4	57.0	50.3	50.1	0.5	210.2	451.6	461.3	572.9	587.1	50.1	29.1	12.3	8.8	8.5
EU15	196.0	251.9	306.2	337.0	343.7	1.8	1,887.2	3,577.0	4,426.3	4,691.5	4,709.2	10.4	7.0	6.9	7.2	7.3
US	9.9	9.7	8.8	8.7	9.3	0.9	2,827.7	3,876.7	4,362.7	4,526.0	4,600.0	0.4	0.3	0.2	0.2	0.2
Japan	288.8	387.5	384.3	395.6	405.5	1.4	573.0	1,240.5	1,335.5	1,313.6	1,300.0	50.4	31.2	28.8	30.1	31.2

red italics	indicates estimate based on World Bank (2002) and Sundar (2010)
sources:	World Bank, "India's Transport Sector: The Challenges Ahead," Volume 1: Main Report, May, 2002, Table 3 Sundar 2009
Note:	The World Bank regards all India transport data as questionable.

Table 5. **Compound growth rates (%) in transport**

	Rail Freight Transport (000,000 tonne-km)			Total Freight Transport (000,000 tonne-km)		
	1970 to 2007	1990 to 2007	2000 to 2007	1970 to 2007	1990 to 2007	2000 to 2007
China	5.3	4.9	8.0	8.6	7.9	11.6
Russia	0.6	(1.1)	6.2	1.3	(1.1)	6.0
India	5.5	4.8	7.6	6.8	5.3	8.9
EU10	(1.5)	(3.4)	0.8	1.1	1.1	5.5
EU15	0.5	0.7	1.9	2.6	2.4	2.5
US	2.2	3.0	1.8	2.2	2.0	1.1
Japan	(2.6)	(0.9)	0.8	1.7	1.3	1.7

	Rail Passenger Transport (000,000 Passenger-km)			Total Passenger Transport (000,000 passenger-km)		
	1970 to 2007	1990 to 2007	2000 to 2007	1970 to 2007	1990 to 2007	2000 to 2007
China	6.4	6.2	6.9	8.4	8.0	7.8
Russia	(0.3)	(2.6)	0.6	(0.7)	(5.0)	(5.3)
India	5.2	5.8	7.7			
EU10	(2.0)	(5.5)	(1.8)	2.8	1.6	3.5
EU15	1.5	1.8	1.7	2.5	1.6	0.9
US	(0.2)	(0.3)	0.7	1.3	1.0	0.8
Japan	0.9	0.3	0.8	2.2	0.3	(0.4)

Source: Table Four

Table 6. **Examples of Innovation in Railways 1970 to 2007**

	Impact	
Technical Innovations	**Freight**	**Passenger**
High Speed Rail	Reduces freight/passenger congestion when new HSR tracks are built	Reduced weight, better aerodynamics: speed increase from 200 to 350 km/hr
Information Technology	Cargo management vastly improved. Costing systems permit better pricing. Digital Communications. Automatic equipment identification (AEI)	Efficient ticketing and reservations. Digital communications. Permits revenue maximization
Intermodal	Rails fully participate in containerization trends	Better connections to air and bus
Energy efficiency	US energy intensity reduced by half. AC traction on diesel locomotives.	A.C. traction, solid state controls. Shinkansen energy intensity cut by half.
Heavy haul/better infrastr.	Higher axle loads, longer trains, larger locomotives, rail metallurgy. U.S. operating cost/tonne-km reduced by 59% 1978 to 2007	Continuous welded rail reduces maintenance and energy.
Signalling	Higher traffic density and improved safety: accident rates down by 2/3	Improved capacity and safety, especially with mixed freight and passenger traffic.

Policy/Managerial	**Freight**	**Passenger**
Structure: monolith to owner-tenant or separation	US/Canada approach: freight dominant, passenger pays as tenant. E.U. freight operators can serve Europe-wide	EU model of infra separation permits franchising and cross-border operation. Introduces competition for markets as well as in markets
Private sector	Privatization of CN, concessioning in Latin America, privatization in UK and EU	Franchising in E.U., privatization of JNR
Deregulation	Staggers Act in U.S.: tariffs fell in real terms by half. Permits contract tariffs and customer investments.	Amtrak and VIA deregulated.

Table 7. **Future railway traffic**

	2000	2005	2007	2010	2015	2020	2025	2030	2035	2050	Ratio 2050 to 2000	GDP growth Rate 2035 to 2050 (%)**	Absolute growth 2005-2050	Percent growth 2005-2050
China GDP (2000=100)	100.0	133.7		174.5	223.1	276.2	336.2	406.3	485.7	837.6		3.70		
Frt Ton-Km Index	100.0	115.9		134.4	155.8	180.6	209.4	242.7	281.4	485.3				
Ton-Km Projection	**1,333,606**	**1,546,015**		**1,792,255**	**2,077,715**	**2,408,641**	**2,792,275**	**3,237,012**	**3,752,584**	**6,471,601**	**4.9**		**4,925,586**	**318.6**
Actual	**1,390,200**		**2,379,700**											
Passenger Index	100.0	115.4		133.1	153.5	177.1	204.4	235.8	272.0	469.1				
Pass-Km Projection	**441,468**	**509,303**		**587,561**	**677,844**	**782,000**	**902,160**	**1,040,784**	**1,200,708**	**2,070,707**	**4.7**		**1,561,404**	**306.6**
Actual	**453,300**		**721,600**											
RUSSIA GDP (2000=100)	100.0	117.1		134.1	159.1	188.2	216.5	245.6	282.2	414.7		2.6		
Frt Ton-Km Index	100.0	110.8		122.9	136.2	151.0	167.3	185.5	205.6	302.1				
Ton-Km Projection	**1,197,495**	**1,327,362**		**1,471,314**	**1,630,877**	**1,807,744**	**2,003,792**	**2,221,102**	**2,461,979**	**3,618,218**	**3.0**		**2,290,856**	**172.6**
Actual	**1,373,200**		**2,090,300**											
Passenger Index	100.0	109.6		120.1	131.6	144.3	158.1	173.3	189.9	279.1				
Pass-Km Projection	**167,100**	**183,135**		**200,708**	**219,967**	**241,075**	**264,208**	**289,561**	**317,347**	**466,385**	**2.8**		**283,251**	**154.7**
Actual	**167,100**		**174,100**											
India GDP (2000=100)	100.0	127.4		163.3	207.4	257.7	316.2	385.6	464.3	824.2		3.9		
Frt Ton-Km Index	100.0	115.9		134.4	155.8	180.6	209.4	242.7	281.4	499.5				
Ton-Km Projection	**305,201**	**353,812**		**410,165**	**475,493**	**551,227**	**639,023**	**740,803**	**858,794**	**1,524,481**	**5.0**		**1,170,669**	**330.9**
Actual	**312,400**		**521,400**											
Passenger Index	100.0	113.7		129.3	147.0	167.1	190.0	216.0	245.6	435.9				
Pass-Km Projection	**430,666**	**489,641**		**556,691**	**632,923**	**719,594**	**818,134**	**930,168**	**1,057,543**	**1,877,290**	**4.4**		**1,387,650**	**283.4**
Actual	**457,000**		**770,000**											
EU 10 GDP (2000=100)	100	119.2		140.7	165.7	194.3	226.1	260.5	315.2	513.0		3.3		
Frt Ton-Km Index	100.0	111.6		124.6	139.0	155.2	173.2	193.3	215.8	351.1				
Ton-Km Projection	**130,277**	**145,405**		**162,290**	**181,136**	**202,170**	**225,647**	**251,850**	**281,095**	**457,465**	**3.5**		**312,060**	**214.6**
Actual	**147,600**		**155,800**											
Passenger Index	100.0	107.2		114.9	123.1	132.0	141.4	151.6	162.5	264.4				
Pass-Km Projection	**65,908**	**70,639**		**75,709**	**81,143**	**86,967**	**93,209**	**99,898**	**107,069**	**174,248**	**2.6**		**103,609**	**146.7**
Actual	**57,000**		**50,100**											

Table 7. **Future railway traffic** (cont'd)

	2000	2005	2007	2010	2015	2020	2025	2030	2035	2050	Ratio 2050 to 2000	GDP growth Rate 2035 to 2050 (%)**	Absolute growth 2005-2050	Percent growth 2005-2050
EU 15 GDP (2000=100)	100.0	111.5		126.1	140.7	154.4	167.5	180.2	189.2	226.3		1.2		
Frt Ton-Km Index	100.0	104.1		108.4	112.9	117.6	122.5	127.5	132.8	158.8				
Ton-Km Projection	**247,612**	**257,858**		**268,528**	**279,640**	**291,211**	**303,262**	**315,810**	**328,879**	**393,317**	**1.6**		**135,459**	**52.5**
Actual	**246,000**		**281,100**											
Passenger Index	100.0	106.1		112.5	119.3	126.5	134.2	142.3	150.9	180.5				
Pass-Km Projection	**300,916**	**319,134**		**338,454**	**358,944**	**380,675**	**403,721**	**428,163**	**454,084**	**543,055**	**1.8**		**223,921**	**70.2**
Actual	**306,200**		**343,700**											
US and Canada GDP (2000=100)	100.0	112.6		128.5	142.7	156.9	171.7	187.5	203.9	262.6		1.7		
Frt Ton-Km Index	100.0	108.4		117.6	127.5	138.3	150.0	162.7	176.4	227.2				
Ton-Km Projection	**2,427,145**	**2,632,171**		**2,854,515**	**3,095,641**	**3,357,135**	**3,640,718**	**3,948,256**	**4,281,772**	**5,513,633**	**2.3**		**2,881,462**	**109.5**
Actual	**2,257,600**		**2,556,600**											
Passenger Index	100.0	104.1		108.4	112.9	117.6	122.5	127.5	132.8	171.0				
Pass-Km Projection	**47,947**	**49,931**		**51,998**	**54,149**	**56,390**	**58,723**	**61,153**	**63,684**	**82,006**	**1.7**		**32,074**	**64.2**
Actual	**21,000**		**24,700**											
Japan*** GDP (2000=100)	100.0	108.8		123.3	137.7	152.1	167.0	182.7	198.3	255.3		1.7		
Frt Ton-Km Index	100.0	104.8		109.9	115.1	120.7	126.5	132.6	139.0	178.9				
Ton-Km Projection	**156,391**	**163,917**		**171,805**	**180,072**	**188,738**	**197,820**	**207,340**	**217,318**	**279,840**	**1.8**		**115,923**	**70.7**
Actual	**22,100**		**23,300**											
Passenger Index	100.0	107.2		114.9	123.1	132.0	141.4	151.6	162.5	209.2				
Pass-Km Projection	**241,113**	**258,419**		**276,966**	**296,845**	**318,151**	**340,985**	**365,459**	**391,689**	**504,378**	**2.1**		**245,959**	**95.2**
Actual	**384,300**		**405,500**											
All Other Freight Tonne-Km	**672,398**	**733,930**		**801,149**	**874,586**	**954,818**	**1,042,482**	**1,138,270**	**1,242,940**	**1,800,147**	**2.7**	2.5	**1,066,217**	**145.3**
All Other Passenger-Km	**282,227**	**309,382**		**339,342**	**372,407**	**408,914**	**449,236**	**493,785**	**543,023**	**786,460**	**2.8**	2.5	**477,077**	**154.2**
Total World Rail Tonne-Km	**6,470,125**	**7,160,469**		**7,932,020**	**8,795,159**	**9,761,684**	**10,845,019**	**12,060,442**	**13,425,359**	**20,058,703**	**3.1**		**12,898,233**	**180.1**
Total World Rail Passenger-km	**1,977,346**	**2,189,583**		**2,427,428**	**2,694,223**	**2,993,766**	**3,330,377**	**3,708,972**	**4,135,147**	**6,504,528**	**3.3**		**4,314,945**	**197.1**
Percent Major Seven of Total														
Rail Tonne-Km	89.6	89.8		89.9	90.1	90.2	90.4	90.6	90.7	91.0				
Rail Passenger-Km	85.7	85.9		86.0	86.2	86.3	86.5	86.7	86.9	87.9				

* Based on Thompson 2007, Tables 5.2 (page 349) and 5.7 (pg 361).
** Uses slightly reduced GDP growth rates from Thompson 2007, Table 5.7.
*** I cannot reconcile the conflicts on the transport numbers for Japan.

Table 8. **Electricity: Upstream CO_2 emissions per kWh [kg-CO_2/kWh]**

Baseline2009	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
Brazil	0.09	0.08	0.07	0.06	0.08	0.10
France	0.10	0.10	0.10	0.10	0.11	0.12
Canada	0.22	0.22	0.24	0.28	0.36	0.43
Russia	0.38	0.34	0.27	0.23	0.23	0.24
Germany	0.39	0.39	0.39	0.38	0.42	0.45
Italy	0.45	0.45	0.45	0.45	0.48	0.52
Korea	0.47	0.37	0.29	0.32	0.34	0.36
Japan	0.48	0.43	0.36	0.32	0.34	0.35
UK	0.53	0.53	0.52	0.52	0.56	0.61
Eastern Europe	0.54	0.58	0.58	0.51	0.63	0.75
OECD Pacific	0.54	0.48	0.40	0.38	0.42	0.46
Mexico	0.58	0.47	0.40	0.49	0.52	0.56
World Avg	0.58	0.54	0.49	0.49	0.52	0.55
USA	0.64	0.59	0.52	0.49	0.49	0.48
Africa	0.72	0.63	0.49	0.42	0.51	0.59
Middle East	0.77	0.59	0.38	0.34	0.35	0.35
Australia and NZ	0.88	0.78	0.67	0.63	0.74	0.85
China	0.88	0.81	0.73	0.74	0.73	0.73
South Africa	0.95	0.83	0.65	0.56	0.67	0.78
India	1.06	0.86	0.69	0.74	0.77	0.79

Source: IEA Statistics

Table 9. **Railway freight traffic in 2007**

Rail System	Tonnes Originated (000)						Tonne-Km (000,000)						CO_2 Emitted from Burning Rail-Hauled Coal and Petroleum		
	Coal	Petroleum	All Other	Total	Coal as % of Total	Petroleum as % of Total	Coal	Petroleum	All Other	Total	Coal as % of Total	Petroleum as % of Total	CO_2 emitted from Coal (000 Tonnes)**	CO_2 emitted from Petroleum (000 Tonnes)	Total CO_2 emitted (000 tonnes)
China	1,543,700	153,190	1,443,110	3,140,000	49.2	4.9	*1,170,125*	*116,118*	1,093,457	2,379,700	49.2	4.9	3,962,163	459,570	4,421,733
US	797,250	40,554	916,975	1,754,779	45.4	2.3	1,081,868	57,059	1,489,732	2,628,658	41.2	2.2	2,046,274	121,661	2,167,934
India	336,832	35,879	355,039	727,750	46.3	4.9	208,489	23,405	289,477	521,371	40.0	4.5	864,535	107,637	972,172
Russia	295,900	233,200	798,600	1,327,700	22.3	17.6	590,700	330,100	1,073,900	1,994,700	29.6	16.5	759,477	699,600	1,459,077
EU 10	160,030	92,725	322,932	575,688	27.8	16.1	31,823	24,813	81,625	138,261	23.0	17.9	410,745	278,176	688,921
EU 15*	114,444	42,614	651,341	808,399	14.2	5.3	18,538	11,690	357,889	221,041	8.4	5.3	293,739	127,841	547,469
All Other	75,614	67,801	425,391	568,805	13.3	11.9	42,883	16,408	320,413	379,704	11.3	4.3	194,075	203,404	397,479
TOTAL	3,323,769	665,963	4,913,388	8,903,121	37.3	7.5	3,144,425	579,592	4,706,493	8,263,436	38.1	7.0	8,531,008	1,997,889	10,528,897

China ton-km estimated based on average length of haul.

Sources: UIC STC 2007, Table 64
AAR, "Railroad Facts 2009," pg 29, plus 2006 STB Costed Waybill sample to estimate length of haul
Indian Railways. "Yearbook 2007-2008," pgs 53-57
Russia, L.S. Thompson, 2007, "Regulatory Reform of Railways in Russia: An Update as of April 2007," ECMT, Table 3
China, Ministry of Railways of China, 2008, "Chinese Railways 2008," pp 33,34.

* Not all EU 15 countries reported to the UIC. SE not available, UK added from National Rail Trends

** Assumes that, on average, coal is about 70 percent carbon. See, e.g. www.eia.doe.gov/cneaf/coal/quarterly/co2_article/co2.html where coal ranges from 60% (lignite) to 80% (anthracite) carbon