ANALYSIS OF HIGH-SPEED RAIL'S POTENTIAL TO REDUCE CO2 EMISSIONS FROM TRANSPORTATION IN THE UNITED STATES

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ABSTRACT

Since the end of World War II, the passenger transportation system in the United States has been heavily based on the automobile for short haul travel and the airplane for long-haul travel. In this paper, we show that there is a growing potential for high speed rail in the United States caused partly by increasing congestion on the existing network and based partly on the higher speeds and higher service capabilities of new technology, high-speed rail. In defining the potential for high-speed rail over the next 40 years, we used two approaches: first, a bottom-up approach in which the major markets for high-speed rail as defined by the Federal Railroad Administration (FRA) were studied separately based on a projection of the specific demographics and demand patterns of those corridors; and, second, a top down approach in which the overall travel demand market for the United States was stratified into carefully defined distance profiles and demographic groups specific to high-speed rail. We conclude that there is in fact a potential market for high-speed rail in the United States, especially within the four decade time horizon chosen. Additionally we conclude that a 10,300 mile system would carry over 450 million passengers annually and would cost between 210 and $385 billion to construct. Such a system would moderately reduce carbon dioxide emissions, but would obviously have other benefits including time savings, improved safety, and reduced congestion which in combination could justify the system. We do not conclude that any of these systems should necessarily be built: rather, we conclude that HSR deserves to be taken seriously during the planning of the US transportation network in the coming decades.

Keywords: high-speed rail, passenger transportation, auto, air

THE BACKGROUND AND POTENTIAL FOR HIGH-SPEED RAIL (HSR)[1] IN THE U.S.

The United States currently has a well-developed transportation network, with high automobile ownership, a dense network of good highways and an extensive network of air services. By contrast, there exists a very limited intercity rail passenger system. The result is that intercity passenger services in the United States carry less than 1% of common carrier intercity passenger travel.

This was not always the case. Although in the years leading up to World War II the railway role in passenger service had been declining, the war years re-established intercity passenger service because of wartime fuel rationing and priority for war-related travel.

After the war, rail passenger service declined rapidly with the advent of the Interstate Highway System and the development of jet aircraft. By the end of the 1960s, the US freight railroads, which had been required to provide passenger service in addition to freight service, were in very weak financial condition as a result of their losses on passenger service. Figure 1 shows the development of rail passenger service in the United States before and after World War II.

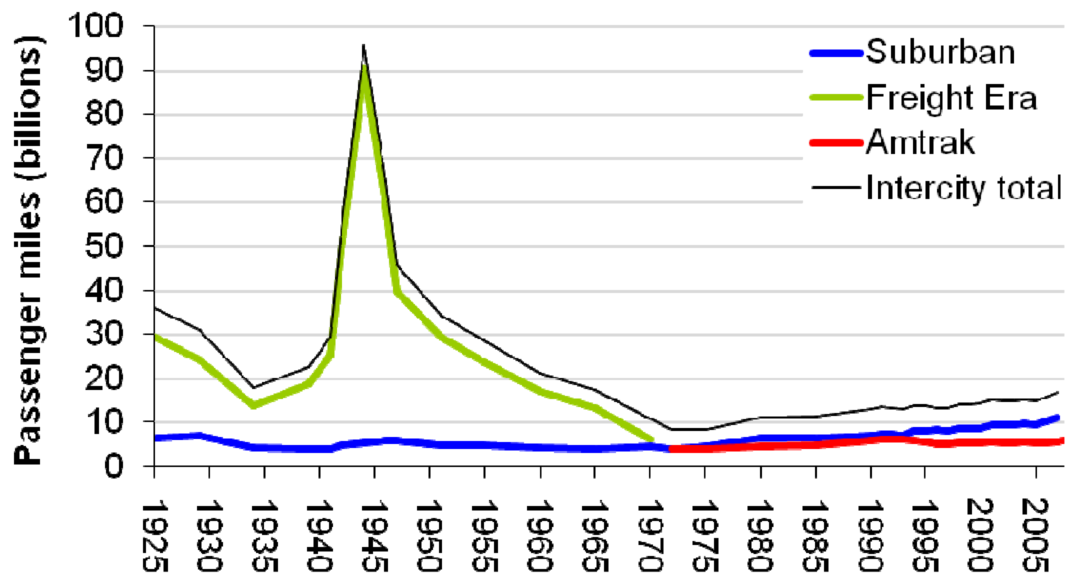


Figure 1 – Rail Passenger-Miles in the U.S.

By 1970, it had become clear that some action would need to be taken by the government if freight railroads and rail passenger service were both to survive. The response was to create a government national rail passenger carrier, later named Amtrak, which would have the responsibility for providing intercity passenger service. As Figure 1 shows, the creation of Amtrak did in fact help arrest the decline of rail passenger service in the United States, although the growth since 1971 has been relatively slow. It is also worth noting that the suburban passenger railways in the United States actually generate slightly more passenger-

[1] In this paper, "High Speed Rail" will be defined as passenger rail service with a cruise speed of 150 miles per hour or greater, whereas "conventional" rail passenger service will be defined as less than 150 mph. In practice, conventional rail passenger options will be operated at speeds of about 110 miles per hour or less.

miles than does Amtrak, and the passenger-miles traveled on the suburban passenger railways have been growing as fast as or slightly faster than Amtrak's.

In very broad terms, Amtrak provides three types of service. First, it operates a collection of 15 long-haul, overnight trains that constitute what is called the "national system". For the most part, these long-haul trains operate on a frequency of one train per day in each direction, although there are a few services that operate three times per week. These trains usually have sleepers and diners and almost always operate overnight. Second, it operates a collection of 25 or so shorter haul trains that operate during the day. The short-haul trains are often partially supported by state funding and operate at frequencies of at least one train per day and sometime operate in multiple frequencies per day. The third type of Amtrak service, and the only one that is sometimes called "high-speed" rail, is the Northeast Corridor (NEC), encompassing services between Washington, DC, and Boston, MA, via New York City.

Amtrak has never been funded fully enough to permit adequate maintenance of its infrastructure in the NEC and all of its rolling stock fleet. In recent years, the US DOT has spent over 30 times as much on highways, 15 times as much on aviation and 10 times as much on urban transport as on intercity passenger rail. Since its inception in 1971, total federal budgetary costs for Amtrak have been over US$40 billion, whereas the Interstate Highway System alone has cost more than $450 billion (both in 2008$). State and local funding for roads and highways is roughly double federal funding, and roughly matches federal funding for aviation and mass transit. State funding for Amtrak has been limited to partial compensation for losses on a limited number of short haul trains. This is not meant to argue that Amtrak should receive the same funding as highways and airports; rather, it suggests that a part of Amtrak's past difficulty in growing its market has been due to inadequate investment in its assets, a problem that has not happened to the same degree in highways and airports.

In overall terms, US GDP (in constant dollars) has slightly more than tripled since Amtrak was established in 1971. During the same period, total US passenger-miles by all modes have increased by 2.6 times and total ton-miles by all modes have increased by 2.4 times. Amtrak's traffic (passenger-miles) has only grown by 36 percent.

A more serious issue for intercity passenger service emerges from the fact that, while rail freight traffic (ton-miles) has grown by 2.3 times since 1970, total route length operated has actually been cut in half as a result of improved technology and a tight focus on minimizing investment. As a result, traffic density, and potential congestion on Amtrak lines, has more than quadrupled since Amtrak was formed. Amtrak's on-time performance has been continually threatened, especially on the longer haul routes where there are major freight flows that share track with and often enjoyed priority over passenger rail.

Congestion has not been confined to the rail network. In fact, as Figures 2 and 3 show, traffic density on the highway network has steadily climbed to a point where most major urban areas, including those discussed later in this paper as candidates for HSR, have reached a "congested" level.

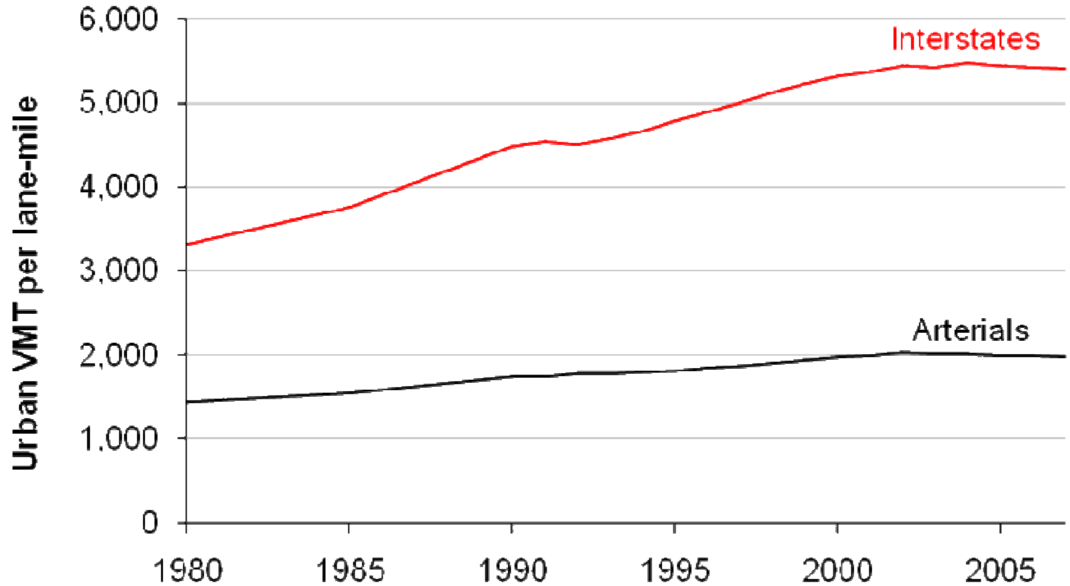


Figure 2 – US Urban Vehicle Miles Traveled / Lane-Mile

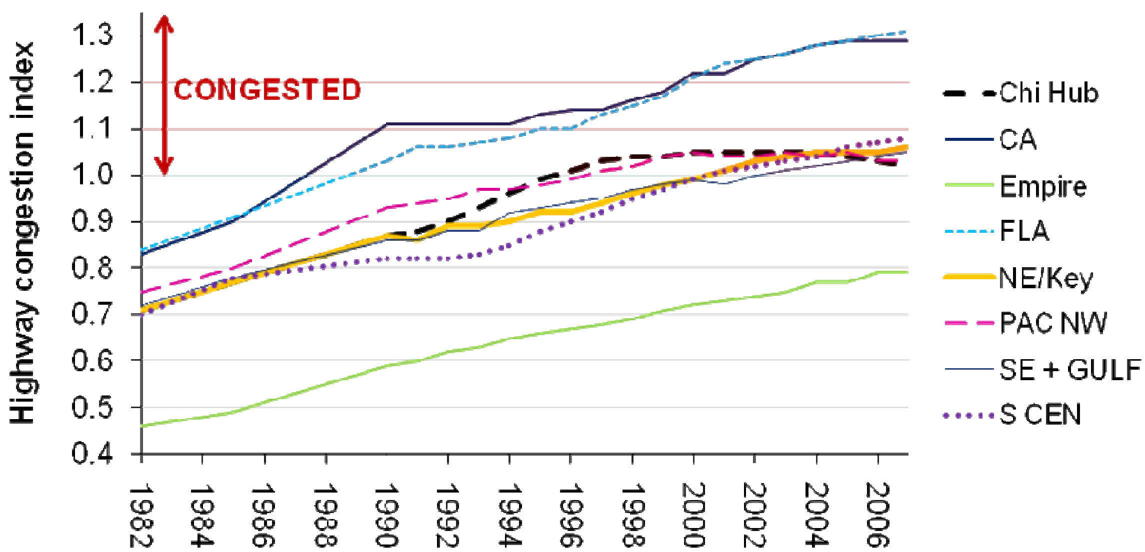
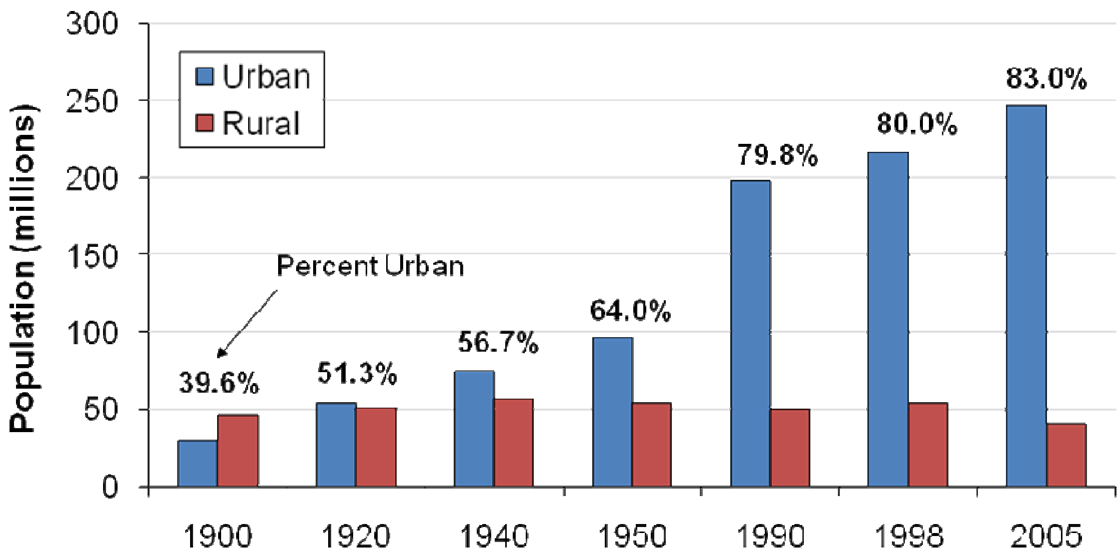


Figure 3 – Highway Congestion Index in the HSR Corridors

The FAA's "FACT-2" (U.S. DOT 2007) report identifies a number of major airports that are also in need of enhanced capacity. In these congested airports, airlines sometimes have to choose between long haul and short haul flights, and the increasing average trip length in air travel suggests that long trips will be favored over short trips.

Increasing urbanization has also significantly altered travel patterns in the US. As Figure 4 shows, the percentage of the US population living in urbanized areas has grown steadily, reaching 83 percent by 2005, and with a continuing upward trend appearing likely.



Sources: US Dept of Commerce, "Historical Statistics of the US: Colonial Times to 1957," Washington, DC, 1960
U.S. Bureau of the Census "Population Trends in Metropolitan Areas and Central Cities," Washington, DC

Figure 4 – Urbanization in the U.S.

The result of these developments is:

- Many urban areas are increasing outwards in size and population, resulting in acute road congestion
- Intercity travel between these urban areas is increasingly limited by urban road congestion and, in some of the largest areas, by airport congestion.
- While intra-urban mass transportation needs have been the focus of significant federal and local funding, intercity rail transport has not grown in line with either population or GDP because of limitations in federal and local funding and because operation of passenger trains on freight rights-of-way, which is how Amtrak operates, is increasingly hindered by increasing freight traffic density on the main lines carrying rail passenger traffic.

These facts imply that there is an opportunity for high speed rail (HSR) to play a role in the future transport network of the U.S. In reaching this conclusion, we explicitly acknowledge that there will be a continuing role for more conventional rail passenger service, partly because some markets will not justify higher speeds, and partly because conventional service is an appropriate stepping stone to high speed service in markets where there is no rail passenger service at all. With this said, the demand for conventional rail passenger services will be inherently limited by their lower speed and, especially, by the need to operate on freight lines where capacity is limited.

Road, highway and airport/airway congestion can be expected to grow in the larger urban conglomerations as income grows. As this congestion grows, there will almost certainly be a "sweet spot" of trip distances that will be appropriate for high speed rail. The exact dimensions of the sweet spot will vary with each corridor, but should range between a low of 100 miles and a high of 600 miles. Travel in this distance range is heavily affected by existing congestion in highways around major metropolitan centers and airports, congestion which (on present trends of traffic and capacity growth) could be aggravated in future. Below about 100 miles, use of the automobile and conventional rail passenger services will almost certainly dominate the market. Above about 600 miles, air services will dominate the market.

Figure 5 displays a comparison between the total trip times in minutes as a function of distance for five different options: air; highway; rail at 110 mph; rail at 150 mph; and, rail at 220 mph. For air, this figure is based on an airport access time of 40 minutes, a security and boarding time within the airport of 45 minutes, and an airport egress time of 30 minutes. The on-airplane travel time is based on a regression against the scheduled trip times for Southwest airlines.[2] The highway trip time is based on 15 minutes to get from origin to highway, 15 minutes to get off the highway to destination and an average highway cruise speed of 60 mph. The railway trip time is based on a station access time of 30 minutes, a boarding time of 15 minutes, a station egress time of 20 minutes, and uses acceleration and deceleration rates typical of high-speed trains.[3] The rail trip time also included two stops between origin and destination with a dwell time at each stop of 1.5 minutes. None of these trip times includes an allowance for congestion delays or delays or uncertainty due to weather. As a result, they are almost certainly unfavorable to rail.

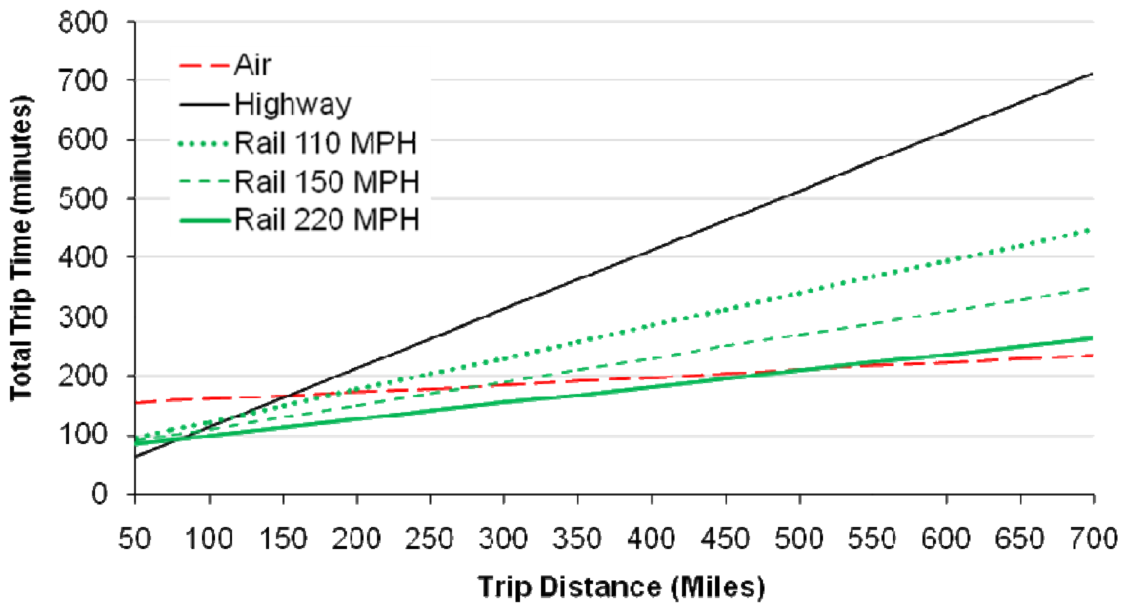


Figure 5 – The Role of Speed

As Figure 5 shows, highway travel is actually as fast as or faster than any of the alternatives below 100 miles. Interestingly, even conventional rail is faster than airline travel up to about 200 miles. Rail at 150 mph retains a trip time advantage up to about 300 miles. Rail at 220 mph retains a clear advantage up to about 500 miles and, given the added comfort and safety of rail, probably remains competitive up to at least 600 miles under the conditions stated.

Beyond these generalities, however, there is a dilemma. While we are thoroughly familiar with the advantages and disadvantages of highways and air travel, and part of the US population is familiar with conventional rail passenger service, there is no real high-speed rail in the United States at present in addition, the time required to plan and construct high-speed rail systems in any one area, much less in many areas, is so long that it is difficult to conduct

[2] A linear regression based on the the Southwest Airlines schedule yields a trip time of y (minutes) =.1245(miles)+34.25, with an R^2 of 0.9756

[3] See, e.g., SNCF California study, pg 53.

credible analyses based on today's circumstances. While we can credibly argue that there is a potential role for high-speed rail in the United States, deciding exactly what that role might be is clearly beyond definition at this point. Instead, what is needed is a **vision** (not yet a plan) for the role that high-speed rail might play in the United States over a time horizon sufficient for high-speed rail systems to be planned and built, accompanied by a general picture, within a reasonable time frame, of what effect that vision might have on travel and transport-related emissions of CO_2.

ASSESSING THE ROLE OF HSR: BOTTOM-UP VERSUS TOP-DOWN APPROACHES

We have approached this issue from two directions: one is a bottom-up approach that looks at specific corridors and assesses how they might develop, while the other is a top-down approach that looks at the overall travel patterns and needs of the U.S. and develops generalized estimates of HSR travel without attempting to assign that travel to a specific market.

The bottom-up approach

There are a number of candidates for use in defining the bottom-up vision. The US Federal Railroad Administration (FRA) has developed various approaches to the definition of corridors for HSR beginning in 1981, continuing through the "Commercial Feasibility Study" of 1997 and most recently with its "Vision Statement" in 2009.[4] The most evolved version of the FRA's corridor system includes eleven corridors, as shown in Figure 6.[5] This set of corridors has no time frame for implementation. The US High Speed Rail Association (http://www.ushsr.com/hsrnetwork.html) has identified a much more ambitious network of HSR corridors for implementation by 2030. In addition to these nationwide concepts, there are a number of studies focused on particular corridors or networks, including studies by the California High Speed Rail Authority (see, e.g., the 2008 and 2009 Business Plans), by the SNCF, which is a potential operator of HSR systems in the US (see the California, Texas, Midwest Hub and Florida studies), the Midwest High Speed Rail Association (220 mph service from Chicago to St Louis), and the Midwest Regional Rail Initiative studies of 2004 and 2000, which focus on 110 mph services among all of the cities in the Midwest Hub. Taken together, these form the background for analysis.

[4] US Department of Transportation, Federal Railroad Administration (2009). Vision for High-Speed Rail in America, Washington, DC.

[5] For legal reasons, the FRA identified only 10 corridors. The Northeast Corridor (Washington, DC to Boston, MA) was excluded for political reasons, but is recognized as the only existing US HSR system and as one of the most promising in terms of future investment.

▪▪▪▪▪▪ Indicates link added in this analysis

Figure 6 – The Ten FRA Designated Corridors and the North East Corridor

Our approach has been to review all of these (along with a few earlier studies) to develop a comprehensive picture of the corridors in an HSR system that the U.S. might develop by 2050 and then develop a corridor-by-corridor picture of how that system might perform when fully in operation. This system, shown in Figure 6, includes all of the FRA's corridors, but adds a few links (Jacksonville to Orlando, Cleveland to Pittsburgh and Cleveland to Buffalo) that would have significant connection benefits among corridors. These added links are shown in Figure 6.

The analysis of the corridors proceeded in a number of steps. For the purposes of this analysis, we assumed that all corridors would consist of a wholly separated right-of-way (no mixing of traffic among HSR, conventional rail, commuter rail, and freight) with all cruise speeds set uniformly at 220 mph. Though this speed is greater than most of the planned corridors (California plans 220 mph top speeds), it appears well within the technology that will be available in 2050, and appears likely to create the most favorable role for rail, especially given that the cost of a 220 mph right of way will not be vastly greater than a 150 mph right-of-way.

The major cities and urbanized area served by each corridor were identified and their 2000 and 2008 population defined as taken from Census data.[6]. These populations were then projected to 2020, 2030 and 2050 by using the State population growth rate projected by the Census Bureau.[7] Rail distances were taken from the relevant HSR studies, or were estimated from the Professional Railroad Atlas. Air distances were taken from a web-based air distance calculator.[8] Highway distances were taken from Google Maps.

A number of further steps were taken to calculate passenger demand.

- First, the projected population, rail mileage and estimated demand for each corridor project were taken from available studies.

[6] For compilation, U.S. Census Bureau, Population Division, Population Estimates Program.
[7] U.S. Census Bureau, Population Division, Interim State Population Projections, 2005. Internet release April 21, 2005.
[8] http://www.webflyer.com/travel/mileage_calculator/

- Next, these results were reduced to a “demand factor” for each corridor. This factor is an index based on two variables: the expected number of passenger trips per capita and the expected number of passenger trips per route mile.
- The demand factors for each study were then examined and a representative factor was developed for each corridor. Where multiple estimates were available for each corridor, the average was used. Where no other information was available, a projection was developed for the corridor using the demand factor (e.g., from a gravity model) from the most similar corridors in terms of length and population density.
- Next, the eleven demand factors were each multiplied by both their respective population and route lengths to yield demand estimates in terms of passenger trips for all 11 corridors.
- For subsequent use, these estimates of passenger trips were converted to passenger miles using an average rail trip length based either on the average trip lengths (passenger-miles/passenger trips) developed in the individual studies or based on a reasonable ratio to the maximum trip length in the corridor.
- Finally, the sources of the passenger-miles carried on the HSR system were calculated. These were either based on the modal split and diversion estimates from the corridor studies or were based on estimates from the most similar corridors where no other data were available. The results are shown in Figure 7.

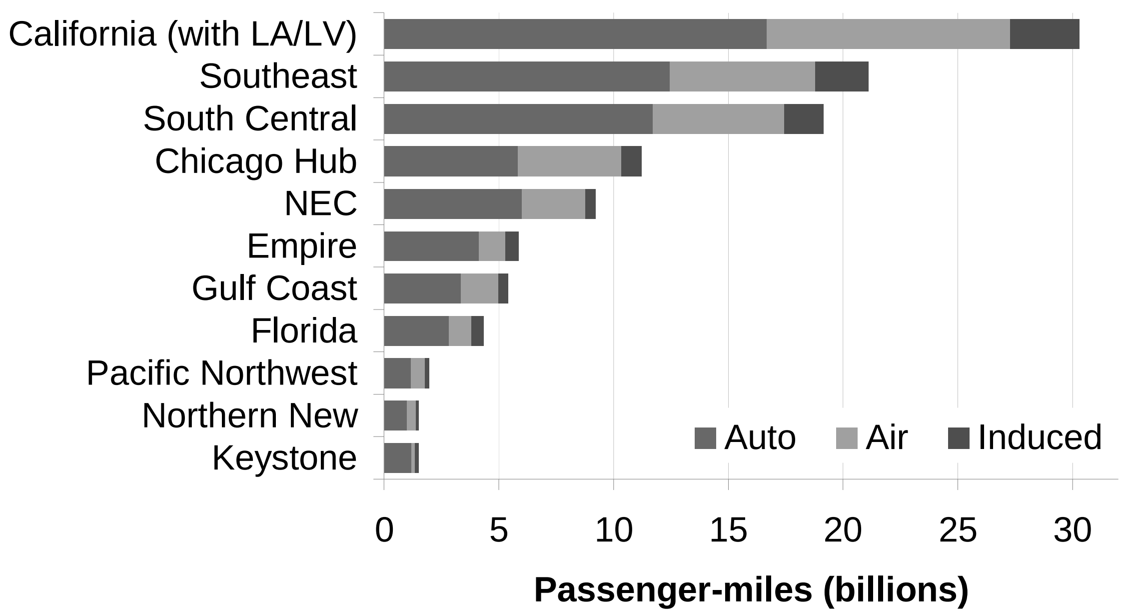


Figure 7 – Estimated Million of Passenger Miles in 2050 and the source of Rail Traffic

The CO_2 emissions are estimated at the next stage. In developing this table, passenger-miles by source were taken from Figure 7 and multiplied by emissions factors as shown in Table 1.[9]

Table 1. Adopted CO_2 Emission Factors

	Low	Midrange	High
Rail*	15.1	51.5	71.9
Auto**	96.6	115.4	134.2
Air***	175.5	186.8	198.1

* Rail low is based on 0.030 kWh/seat-km and 188 grams CO_2/kWh; Rail mid range is based on 0.04 kWh/seat-km and 480 grams CO_2/kWh (IEA projection for US in 2050); Rail high is based on 0.049 kWh/seat-km and 547 grams CO_2/kWh
** Auto low is based on 90 grams CO_2/vehicle-km; Auto Midrange is simple average of high and low; Auto high is based on 125 grams CO_2/vehicle-km
*** Air low is based on 109 grams CO_2/passenger-km ;Air high is based on 125 grams CO_2/passenger-km

The emissions results are presented in five cases:

1. using all of the lowest emissions factors for all modes;
2. using the mid-range emissions factors for all modes;
3. using the highest emissions factors for all modes;
4. using the lowest factor rail and highest for all other modes (most favorable to rail); and,
5. using the highest factor for rail and the lowest for other modes (least favorable to rail).

These combinations return a range of savings of between 4.4 and 13.9 million metric tonnes CO_2.

Next, capital costs were estimated. These estimates are based on a number of existing studies and converted to 2009 dollars. From these, the capital costs for the individual corridors were estimated based on the ranges and, where no other data existed, on the basis of the most similar corridor.

Table 2 displays the overall results, including miles of HSR line, 2050 population, 2050 trips, lowest and highest estimates of CO_2 savings, and low and high estimates of investment costs for each corridor.

Table 2 – Summary of the bottom-up analysis

	HSR Line Miles	**2050 Corridor Population (million)**	**2050 Corridor Trips (millions)**	**Total CO_2 savings (metric tonnes)**		**Investment Cost (2009$ Millions)**	
Corridor				**Low**	**High**	**Low**	**High**
California	1,088	54.1	101.0	1,292,113	3,878,697	35,904	63,104
Pacific Northwest	467	14.5	12.3	76,070	245,354	7,005	9,340
Florida	478	31.6	28.9	135,212	509,228	7,170	26,768
Chicago Hub	2,137	39.1	66.0	544,612	1,502,751	49,151	74,795
South Central	1,202	33.0	63.9	759,691	2,416,287	14,424	52,888
Southeast	1,659	33.2	84.4	795,858	2,604,359	29,862	49,770
Gulf Coast	1,024	22.0	21.6	219,380	688,417	18,432	30,720
NEC	457	54.5	35.0	289,370	874,338	11,425	26,049
Keystone	486	16.6	9.9	34,030	166,381	11,178	17,010
Empire	630	28.1	22.6	188,070	722,979	12,600	17,010
Northern New England	665	15.3	9.9	54,681	185,283	13,300	17,955
TOTAL	10,293	277.0	455.5	4,389,087	13,794,074	210,451	385,409

[9] These factors were developed during the top-down studies and will be discussed later in this paper,

In overall summary, the bottom-up analysis suggests that, by the year 2050, the U.S. could construct 11 HSR corridors, very much in line with the "Vision" of the Obama Administration. These projects would include about 10,300 miles of line and would serve areas with a combined population of nearly 280 million people (74 percent of the total US population in 2050). They would generate slightly over 450 million trips and would reduce national CO_2 emissions by between 4.4 and 13.8 million metric tonnes annually depending on the assumptions used. They would have an investment cost of between $210 billion and $385 billion (2009 dollars).

BROAD BRUSH ESTIMATE OF CO_2 IMPACTS OF SHIFTS TO HSR [10]

We explored a second approach to projections to complement our top down projection of all US travel. A "baseline projection" was built from US Energy Information Agency (EIA) and Federal Aviation Agency (FAA) projections of both travel and the fuel intensity of vehicles. A second projection was built from the "Global Scenario" of Schipper et al (2010), work carried out by Global Metropolitan Studies (GMS) for the ITPS. We have labeled these two scenarios as "broad brush" projections designed at the national, aggregate level to focus on what travel might switch to HSR, and how that switch would affect CO_2 emissions.

Our first step identified present travel in the HSR range of 150-1000 km (100-600 miles). We used the FAA's T-100 database of all air tickets (FAA 2009a) to calculate air passenger-km travel between all city pairs that would be linked under current Federal Railroad Administration (FRA)-designated HSR corridors, and where the flight distance is in the HSR range. This city-specific intercity travel as a proportion of overall travel within the HSR range (about 1/3) was applied to automobile travel data in the HSR range, found in the 2001 National Household Travel Survey (NHTS, found in US DOT 2002), to give automobile travel between HSR cities in the HSR range. The NHTS data were also used to identify the proportions of travel that were for work purposes and for non-work purposes in both the air and auto sectors.

From these data we created for each scenario two plausible sets of mode shift: a high and a low for both work related and other travel. The shares of these trips shifting to HSR are shown in Table 3. The high is close to what has been reported for various city pairs in Europe (Kaageson 2009; Nash 2009, Preston 2009), while the low was created as a relatively pessimistic case.

[10] This section is based on Kosinski, A. Schipper L. and Deakin E., 2010, *Potential Contributions of High Speed Rail to Reducing CO_2 Emissions in the US Transport System by 2050*. Unpublished Draft, Berkeley, Global Metropolitan Studies.

Table 3 - Assumptions of HSR Passenger kilometer shifts from air and LDV in 2050 by trip purpose

	Purpose		"high HSR" scenarios		"low HSR" scenarios	
	non-work	work	non-work shift	work shift	non-work shift	work shift
Air	50.5%	49.5%	25%	100%	10%	25%
LDV	85.4%	14.6%	3%	2%	1%	1%

We then created two broad projections of total travel for the US. One is based on FAA and EIA projections of air travel and car use to 2030 (EIA 2009). These were extrapolated to 2050 at similar rates. The other projection was that carried out by GMS for the ITPS study of CO_2 in transportation in 2050 (Schipper et al 2010), which included a projection of travel activity for the US to 2050 (US FAA 2009b). The FAA and EIA projections show rising air and car use, while the GMS projections show a decline in car use and relatively constant air travel despite a 60% increase in per capita GDP. While the latter scenario may seem improbable, it is important for testing the impact of HSR in a world without increases in travel. Since intercity bus and rail travel represents less than 0.8% of passenger km traveled in the HSR range (NHTS 2001, found in US DOT 2002), this sector of travel was ignored for simplicity.

Table 4 - PKT by mode, 2005 and 2050 projections

	Scenario	unit	LDV (2005)	LDV (2050)	air (2005)	air (2050)
Travel	BASELINE	Pass-km/capita	20,993*	26,257	2,903*	5,975
	ALTERNATIVE	Pass-km/capita	21,650	17,679	3,165	5,001

* 2008 data

FUEL AND CARBON INTENSITY OF THE MODES LOSING SHARE TO HSR ("FROM MODES")

Reductions in CO_2 emissions from mode shift to HSR depend as much on the projected emissions of the "from modes" as on the projected emissions from HSR. Emissions from either "from mode" depend on the amount of travel (in passenger-km), the utilization factors (in passenger-km/vehicle km), the fuel use per vehicle/km for each mode, and the carbon content of fuels.

Fuel intensity of aircraft and light duty vehicles (cars and personal light trucks or SUVs) is likely to fall, as the EIA projection indicates through 2030. For the Baseline scenario, we used the EIA values of fuel intensity of vehicles and projected the same rates of change to 2050, holding utilization constant (82% for air, 1.5 persons/vehicle for LDV). This left the carbon intensity of LDV travel at 48% of its 2005 value. Using EIA's projections we found that the fuel intensity of air travel would fall to less than 50% of the 2005 value. We did not change the CO_2 content of fuels for this scenario.

The Global GMS scenario used work on future fuel intensities of vehicles by the International Council for Clean Transportation (Meszler 2010). This work held that by 2050 LDV vehicle carbon intensity would be only 27% of its 2005 value, largely because of a high assumed penetration of fuel cell vehicles. The CO_2 intensity of these feed stocks was roughly 1/3 below that of oil (on an energy basis) resulting in even further declines in CO_2 intensity of car travel to 18% of the 2005 value. Air travel fuel intensity foreseen by ICCT fell by 1/3 over its 2005 value. The fuel remained the same (kerosene) so there was no further savings of carbon.

The energy intensities (in $kgCO_2$/capita) are also obtained from Carbon in Motion (Schipper et al., 2010). The resultant carbon emissions for each mode (in gCO_2/pass-km) are shown Table 5.

Table 5 – Carbon intensities and per capita carbon emissions 2005 and projected to 2050

	Scenario	unit	LDV (2005)	LDV (2050)	air (2005)	air (2050)
Carbon emissions		$kgCO_2$/capita	3,957	683	515	544
Carbon Intensities of Travel	BASELINE	gCO_2/pass-km	250*	88	177*	91
	GLOBAL	gCO_2/pass-km	183	34	163	109

*2008 data. Note that the emissions intensities of actual travel that shifts are higher, as noted in the text.

Two further assumptions were required to characterize the CO_2 intensity of the “from modes”. First, the air travel in the HSR range is roughly 50% more fuel intensive than that of all air travel, both because the trips involve a higher ratio of climbing and landing and because the planes used tend to be smaller (Babakian et al. 2002). We assumed that the decline in travel translates directly into a reduction in flights offered, and not simply planes flying with more empty seats. For car travel in the HSR range, we assume that shift comes predominantly from business and work related trips, which tend to have low utilization factors, rather than family trips. We assumed an overall utilization of 1.1 persons/vehicle, or 0.9 vehicle-km per passenger km shifted.

CARBON INTENSITY OF HSR TRAVEL

The other key parameter in estimating the impact of mode shift to HSR is the emissions intensity of HSR. Here we consider operations only, but note that in systems with relatively few departures the CO_2 impact of building and maintaining the system and trainsets may be as great (on a passenger-km basis) as that of operations (Chester and Horvath 2010). For the emissions from HSR, we used actual and projected intensities of train-sets, expressed as [electric energy]/seat-km. We assumed that passenger weight is be trivial compared to the weight of the train-sets. We then utilized projected load factors, or assumed load factors, to estimate the number of seat-km that will be traveled to yield passenger kilometers traveled (PKT). We used national average emissions per kWh delivered to end user, as noted above.
The CO_2 intensity (emissions/pass-km) of HSR is :

IHSR = (kWh/seat-km * MJ primary energy/kWh * CO_2/unit of primary energy) / (utilization factor, % of seats)

The intensity of a trainset is expressed as kWh/seat-km. Thompson compiled a number of values of energy intensity of Shinkansen from Japan Rail publications. The first Shinkansen (zero series) required 0.072 kWh/seat-km with a top speed of only 220 km/hr, while the most recent Nozomi 700N required 0.037 kWh/seat-km at that speed and 0.049 kWh/seat-km at 270 km/hr (Noda 2009). Thus the energy intensity of the Shinkansen has been falling, to a point where the recent Nozomi 700N uses about 50% as much energy at a higher speed than the original Shinkansen and 32% less at 22% higher speed. For simplicity we adopted with Thompson the low-mid range value of 0.04 kWh/seat-km, but examined a wider range of electricity intensities as well. Given the technical progress of all HSR, it is likely the decline in intensity exhibited by the Shinkansen will be continued. We adopted Thompson's occupancy factor of 60% of seats filled, but we also examined occupancy as low as 33% or as high as 75% for sensitivity.

Often ignored in discussions of electric traction is the CO_2 released in the production of electricity itself. In 2007, electricity generation in Sweden, France and Brazil released less than 90 gCO_2/kWh because of a high degree of nuclear power, hydropower, or renewable energy, while in China and India more than 725 gCO_2/kWh is released from either of their highly coal-dependent power systems (IEA, 2009b). Emissions in the US in 2005 were close to 687 gCO_2/kWh when losses in transmission and distribution are included (EIA, 2009). This represents the total emissions required to provide 1 kWh at the average end user (in this case the catenary of the rail system).

The CO_2 emissions per kWh were projected by taking the 2005 shares of fossil fuels used in electricity production (49% coal, 11% oil, 13% natural gas) at 685 gCO_2/kWh (EIA, 2009). For the 2050 base case we used a 50% share of energy from coal, 3% from oil, and 15% from gas. We assume a 5% decline in primary energy to electricity, consistent with historical progress. Together these parameters yield 547 gCO_2/kWh or 20% below the 2005 value. This is not inconsistent with EIA's own projection (J. Conti, EIA, private communication) of their 2030 lowest cost fossil projection of 606 gCO_2/kWh.

We also constructed an alternative, reducing the coal share to 20%, the oil share to 3%, and the natural gas share to 10%, thus reducing the fossil fuel component of primary inputs by more than half. We also assumed that losses in the chain from the production of electricity from primary energy to final electricity delivered to the catenary would decline 15%, representing both improved generation efficiencies and reduced losses in transmission and distribution. This reduced the 685 gCO_2/kWh emitted in 2005 to 188 gCO_2/kWh, or only 27% of the 2005 value. The US EIA's own 2030 "low" case, estimated in response to recent legislation (J. Conti, EIA, private communication) gives a 2030 value of 237 gCO_2/kWh, which is consistent with the "low" case that we constructed. Estimates from the International Energy Agency provided to the project sponsor (ITPS, 2010, private communication) had approximately 250 gCO_2/kWh, so our two cases bracket cases of minimal improvement to great progress in reducing emissions from electric power.

HSR CO_2 emissions were then projected bottom up as the product of total passenger-km shifting to HSR multiplied by the projected electricity use per passenger-km multiplied by the projected ratio of CO_2 emissions to electricity provided at the rail catenary.

The key HSR-related assumptions used in this study are summarized in Table 6. The high and low emissions assumptions, which alternatively could be considered "poor" performance and "good" performance, were used for sensitivity analyses. The middle column values were used in the analyses presented here unless otherwise stated.

Table 6 - Key assumptions regarding HSR Carbon Intensity (C_{hsr})

	High Emissions Assumptions	Used in Study	Low Emissions Assumptions	Comments
HSR electricity intensity, kWh/seat-km	0.06	0.04	0.03	from survey by Thompson (TGA, 2010)
HSR occupancy, %	33%	60%	75%	
gCO_2/net-kWh delivered to trainset	638	547	188	Projected from US DOE, EIA

OVERALL EMISSIONS IMPACT OF SWITCH TO HSR

We can describe the overall reduction from less LDV travel as follows:

C_{ldv} = *reduction in PKT * VKT/PKT * CO2/VKT* = $PKT_{ldv} \times I_{ldv}$

where I_{LDV} is the carbon intensity of LDV travel given in Table 5. The reduction from less air travel is then:
C_{air} = *reduction in PKT x seat-km/PKT x CO_2/seat-km*= $PKT_{air} \times I_{air}$

Thus if travellers switch only from cars air travel (i.e., ignoring the very small volume of bus and conventional rail travel), then the net CO_2 savings is

$C_{ldv} + C_{air} – C_{hsr}$

If the shares of HSR riders who <u>previously</u> took LDV or air trips are known, then a simple relationship can be calculated for the "average" switcher, which depends on these shares, the carbon intensities of the "from modes" and that of HSR, as Kaageson (2009) pointed out. If L is the share of HSR travel that switched from LDV and A is the share switching from air travel (A + L = 100%), then the impact of the switch per average passenger-km transferred is just:

$L * I_{ldv} + A * I_{air} - I_{HSR}$

For this study the impact of one passenger-km shifting ranged from 50 to 116 g CO_2/passenger-km. The range is large because of the range of both L and A as well as all three CO_2 intensities.

SUMMARY OF BROAD BRUSH PROJECTIONS: CHANGES IN TRAVEL AND CO_2 EMISSIONS

In this broad brush treatment, we use high and low projections of HSR use to demonstrate the impact on CO_2 of such a switch. As such, we use overall projected travel for 2050 and scale the 2001 patterns to the same relative 2050 levels.11 These projections give a good estimate of the bounds of CO_2 savings from switches to HSR. The Baseline travel projections for 2050 are given in Table 7, and the Global travel projections are shown in Table 8.

Table 7 – Baseline scenario travel projections for all trip lengths for modes projected

Year		2001	2008	growth rate	2030	2050
PKT (millions)	LDV (NHTS)	6,675,686	6,383,028	1.67%	9,180,173	12,774,011
	air (T-100)	739,907	882,785	2.63%	1,561,753	2,623,289
	Total	**7,928,297**	**7,820,146**			

Table 8 - Global scenario travel projections for all trip lengths

Year		2005	growth rate	2050
PKT (millions)	LDV	6,559,838	0.37%	7,761,355
	Air	958,865	1.86%	2,195,538

The mode shift percentages assumed in Table 3 applied to the projections of total travel in Table 6 resulted in the shifts to HSR seen in Table 9a. Table 9b shows that the shift within the HSR range is appreciable, but overall the figures are relatively small compared with total travel in passenger-km. Figure 8 summarizes these projections.

Table 9a - Mode diversion or shift to HSR in 2050

		Baseline scenario		Global scenario	
	"from" mode	high HSR	low HSR	high HSR	low HSR
Shift to HSR, 2050 (PKT millions)	Air	100,421	28,160	84,046	23,569
	LDV	35,454	12,426	21,541	7,550

Table 9b - Mode diversion or shift to HSR in 2050

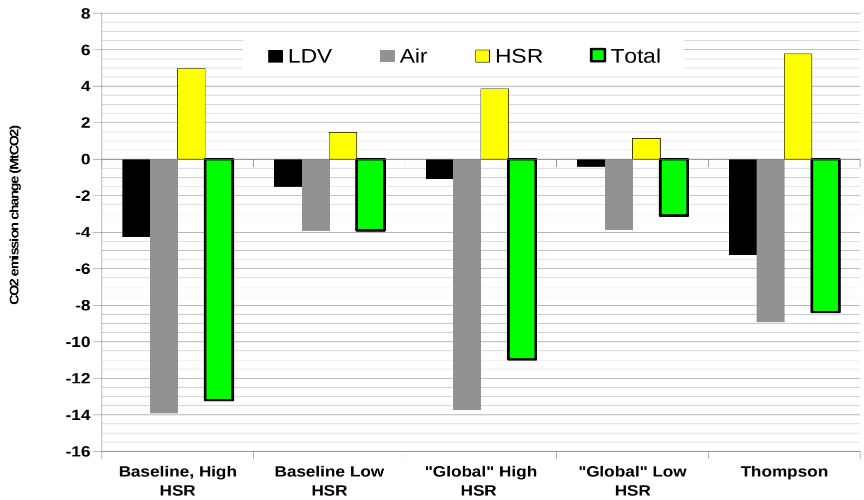
	2050 HSR mode share of PKT			
	in HSR range only		all trips	
	high HSR	low HSR	high HSR	low HSR
HSR from air	21.3%	6.0%	3.8%	1.1%
HSR from LDV	1.0%	0.3%	0.3%	0.1%
Total HSR	**22.2%**	**6.3%**	**4.1%**	**1.2%**

The changes in CO_2 emissions from each scenario are shown in Figure 8. For comparison, total emissions in the Baseline scenario before shift were 1136 MMT and in the Global scenario 507 MMT, as shown in Figure 10. The bottom-up projections are also shown here,

[11] Our original intention was to use the 2008/9 NHTS as a better indicator of travel patterns. Unfortunately only part of that survey, the "travel day" or one-day recall of travel was carried out. "Travel Period", which covers travel longer than what occurred in the day covered in "Travel Day" was not fielded. Thus most long-distance travel lasting more than a day was not covered, unless by chance the interview person returned the day of the interview.

and can be seen to lie between the higher and lower HSR shifts projected for each scenario in the broad-brush approach.

Figure 8 - CO_2 changes by mode in 2050



WHEN DOES HSR SAVE CO_2? SENSITIVITIES

The foregoing portrayed the savings in CO_2 from implementation of HSR by estimating the level of travel and emissions intensity travel of the "from" modes (LDV and air) and comparing with the intensity of the "to" mode (HSR). In general, HSR travel saves CO_2 compared with other modes when the emission per passenger-km of HSR are below those of the modes travellers would have taken. Since there are no certain levels of any of these parameters, it is important to identify explicitly the uncertainties any planners face, as well as possible weaknesses in any approach.

Using the assumptions in this study, the high shift to HSR case reduces CO_2 emissions by 13.2 million metric tonnes (MMT) of CO_2 from the baseline case with high growth in travel (the fourth bar, "total" in the first group in Figure 8) and the smaller (though substantial) decline in the CO_2 intensity of LDV and air travel. In the Global scenario of Schipper et al. (2010) the savings are 11 MMT of CO_2. The reason the savings are so close for such widely differing scenarios is that the savings from air travel dominate, and air travel emissions differ relatively less in the two scenarios than do those of LDV travel.

Table 10 below summarizes a number of cases where we change one or more parameters and report the change in total CO_2 savings. These are summarized in the text below. They are inserted in both our Baseline "Global" case of overall projected travel in 2050.

Table 10 - Sensitivity of Results to Changes in Assumptions in the Broadbrush Scenarios

Variant	Value (s) used in sensitivity analysis	Impact on Base Case (13.9 MMT savings)	Impact on Global Case (11 MMT savings
Triple the mode shift of current "High"		-41.9	-15.8
Frozen 2005 LDV and Air Intensities		-17.9	-22.6
High US Electric CO_2	684 gm/kWh	-11.2	-10.0
Low US Electric CO_2	188 gm/kWh	-16.4	-13.5
Low Occupancy Variant	33%	-9.1	-7.8
High Occupancy Variant	75%	-14.2	-11.7
High Electric Intensity	0.05 kWh/seat-km	-12.1	-10.1
Low Electric Intensity	0.03 kWh/seat km	-14.4	-11.9
Most CO_2 intensive HSR (low occupancy, high intensities	50.62	-2.7	-4.1
Least CO_2 intensive HSR (high occupancy, low intensities)	7.52	-17.1	-14.0
Highest Savings: Frozen 2005 intensities, lowest HSR CO_2		-23.8	-25.6
Medium Savings: EIA projected 2050 Intensities with		-17.1	-13.4
Lowest Savings:		-7.4	-4.1

Note: (-) denotes savings relative to no HSR. Compare to values at top of columns.

Very High Shift to HSR

As a test we increased the shift to HSR to reflect the highest seen in corridors in Europe and Japan, resulting in roughly 7.3% of travel in the baseline scenario and 7.1% of travel in the Global scenario move to HSR. The total CO_2 reductions came to 2.9% of emissions in the Baseline scenario and 3.2% of emissions in the Global scenario. Again we emphases that these savings are relatively small both because the "from" modes are considerably less CO_2 intensive in 2050 in either scenario and because the amount of travel occurring in the HSR distance intervals and regions is a small share of total travel in passenger km.

CO2 emissions from electric power production

In this study we use national averages. Were an HSR system to use its own, captive electric power, the figures from that system could be used. When estimating the CO_2 intensity of a regional system, such as California, Florida or another region, the CO_2 intensity of an average kWh reflecting regional trade should be used, but this was beyond the scope of this study.

If the higher intensity for electricity production for the US in 2050 is taken, emissions savings become 85% and 91% of the savings in the Baseline Case and Global Case, respectively less because of the increase in emissions from HSR. If the lowest intensity is taken, the savings grow by 25% and 23% respectively.

Variation in efficiency or energy intensity of trainsets (kWh/seat-km)

Our projections used an average energy intensity of 0.04 kWh/seat-km, slightly above the most recent Nozomi. Given the technical progress made by Japan Rail trainsets, it is not unreasonable to expect a continued decline in the electric intensity of HSR, particularly if an increasing number of trainsets are double-decked. The lowest electricity intensity, 0.03 kWh/seat-km, increases savings by roughly 9% in either case, while the higher intensity, 0.05 kWh/seat-km, decreases savings by about 8%

Taken together, the range of both electricity intensities and CO_2 emissions per kWh can yield a very lower value of CO_2/seat-km for trains in Sweden, France or Brazil, to high values if the most energy intensive trainsets run in the US with more than half the electricity generated by coal as at present.

Variation in HSR occupancy factors

As important as the overall CO_2 intensity of trainsets (in gCO_2/seat-km) is the train occupancy factor. Occupancy factors in Japan fall in the 60-70% range (Noda, 2009). For the US case, a low occupancy factor (say 33%) and high carbon intensity of electricity generation (the present value), combined with the least efficient trainset (taking the most energy intensive Nozumi value of 0.06 kWh/seat-km) gives a carbon intensity of travel of almost 120 g/passenger-km, only 25% below the 2005 value for domestic air travel. At the other end, taking a 75% occupancy factor, a low projected CO_2 intensity of electricity production (188 gCO_2/kWh) and a projected low energy intensity of 0.03 kWh/seat-km gives a CO_2 intensity of HSR travel of under 10 gCO_2/passenger-km, well below any current mode available in the US today or among those projected for the US.

The impact of changes in occupancy are also shown in Table 8. At the lower occupancy of 33%, CO_2 savings are cut by roughly 30% in either scenario, while at the higher, 75% occupancy figure, the savings rise 8% and 7% in the two scenarios.

From these variants we have created a “Worst HSR savings case”. With the high CO_2 intensity of electricity production, high HSR electricity intensity, and low occupancy, CO_2 intensity of HSR travel is over 50 gCO_2/pass-km, while in the reverse case it is only 7.5 gCO_2/pass-km, vs 38 gCO2/pass-km in the projections. The worst case cuts CO_2 savings by 20% in the Baseline case and 37% in the Global case, while the “best” HSR leads to about 30% more savings in either case.

SENSITIVITIES FROM AUTOMOBILE AND AIR TRAVEL

Since the CO_2 "savings" depend on the CO_2 intensities of the modes from which travelers shift, the intensities of these modes bear scrutiny. In our aggregate analysis we have made no allowances for circuity. In reality this may be a simplification that underestimates the emissions from HSR. Chester and Horvath (2010) show that the route proposed for HSR between San Francisco and Los Angeles uses an HSR distance of 710 km, compared to 610 km for autos or 540 km for air travel. These differences are significant. Further, they do not calculate the energy and emissions associated with getting to the HSR station or airport. In large dense population centers with good mass transit coverage to the HSR terminal, it can be assumed that a large share of riders might take transit to or from stations or even walk, while in more sprawling cities automobiles could be the dominant mode taking passengers to and from HSR stations just as they are to and from airports. While we have not addressed these issues explicitly in our aggregate approach, they should be considered in any detailed estimate of impacts of HSR.

Future CO_2 emissions from other modes

Our basic projections foresaw CO_2/vehicle-km for cars at 64 g in 2050, less than 25% of the 2005 value for cars and light trucks. Using a more conventional projection of improvements in LDV emissions of approximately 50% means a much larger savings of CO_2 emissions, since the majority of travelers shifting to HSR originally drove. Note that we assume that the occupancy of vehicles shifting to HSR was 1.1, vs. the average projected for 2050 of 1.65. This was because of our presupposition that most shifters will be business travellers or smaller families. Shifting a family of four from a car to HSR is costly if the family has to buy four tickets.

For air travel, the projections from Schipper et al (2010) and those extrapolated from US EIA foresaw a decline of approximately 43% and 33% respectively. Using the EIA value for air travel intensity raises the CO_2 savings per passenger-km by about 25%. We also assumed that the fuel intensity of short-haul aircraft most commonly used for the range of journeys of question (600-965km) is 50% higher than the average for the US as a rough average of calculations by Babakian, Lukachko and Waitz (2002).

If US LDV and air travel intensities are frozen at their 2005 levels, CO_2 savings rise more than double in the Global projection and are 38% higher in the Base case projection, where the CO_2 intensities of travel do not fall as much as in Global. With these variations, we can compose a "most CO_2" savings case, which is where HSR has the lowest intensity and other modes have the highest. Using the 2005 intensities for other modes, HSR saves 23.8 MMT of CO2 in the Baseline case and 25.6 MMT of CO_2 in the Global case, more than double what was obtained in the original calculations. If we keep HSR with low CO_2 intensities but use the EIA base case intensities for other modes, savings are 130% and 123% of the respective projections. If HSR has the highest intensities tested while the Global intensities reflect LDV and air travel in 2050, savings shrink dramatically (as noted).

Marginal vs. average emissions and life cycle assessment

In this study we have dealt with average emissions from different modes of transport. That is, for car travel, we reduce emissions in proportion to vehicle use because a trip not taken means a car left at home. For air travel, we have assumed that less travel results in fewer aircraft miles; hence we have reduced emissions proportional to the reduction in travel.

Experiences with Europe (Nash, 2009) supports this assumption, where entire short-haul routes have been abandoned or traffic cut significantly.[12] However, at the margin, planes may simply be flown with fewer passengers. This seems likely for some OD pairs. We have not explicitly considered how travellers get to the airport vs the HSR terminal.
We have not carried out a Life Cycle Assessment (LCA) of the emissions from both operating the HSR system as well as building it. Chester and Horvath (2009) show that over the decades of operation of a HSR system using estimates of California parameters, the share of emissions from constructing the system of stations, guideways, and trainsets can be as much as half of the lifetime LCA emissions of the system. This occurs if there are relatively few trains per day and relatively few passengers per train. In their formulation a full train emits 71 gCO_2/passenger-km for California conditions, of which roughly one quarter is the fixed cost of the system and the rest is operations.

This translates into about 108 gCO_2/pass-km for the 66% load factor discussed above, of which about 80 gCO_2/pass-km is for operation. Chester and Horvath (2009) give 35,000,000 passengers/year as their “volume”, based on estimates from the California High Speed Rail Authority. If total travel is greater, then the emissions from fixed investments such as stations and rolling stock are spread over more passengers and passenger-km and hence this contribution to the total LCA is smaller. If the same number of passenger-km are carried with fewer seat-km, i.e., fewer running trains with higher occupancy, then the operational energy and emissions per passenger-km decline, as do the energy and emissions associated with making the trainsets. Conversely if trains run with low occupancy then both the operational emissions and fixed emissions per passenger-km rise. In citing figures relating operation to fixed investment emissions (and emissions related to other than operating trains alone, such as maintenance and heating/cooling of stations), it is important to give the assumed values for occupancy and passenger-km that lead to the operational and fixed components of emissions per passenger-km. Analyses or comparisons of modes that fail to give these figures, or use figures from one region or country’s experience to portray another’s, are highly misleading. This is particularly true of the simple comparison of modal CO_2 intensities or citing only of the shares of operational and fixed emissions.

It also would be true that for corridors that are capacity constrained, e.g., some highways and airports, costs of expanding the capacity for these modes in the absence of HSR likewise would have to be accounted for, or the impacts of greater delays would have to be calculated.

SUMMARY OF IMPACT OF SENSITIVITIES ON CO_2 SAVINGS FROM HSR: WHICH MATTER MOST?

The wide variation in CO_2 savings projected in Table 10 is a reminder that many uncertainties cloud this work. It is difficult to say which parameters to this work matter the most. The CO_2 intensities of LDV and air travel, the degree to which travellers will shift to HSR, and the CO_2 intensity of HSR travel itself are all critical parameters. CO_2 intensities depend on technological parameters as well as vehicle occupancy. We have varied the intensity of LDV travel, the HSR occupancy, and the CO_2 intensity of electric power projection each by over a factor of two, while the intensities of train sets and air travel varied

[12] Consultation of expedia.com shows there is one early morning non-stop round trip between Paris and Brussels in 2010, as compared to as many as ten round trips ten years ago. Air France even has a dedicated train from Charles de Gaulle airport to Brussels station.

by somewhat less than a factor of two. Cleary all must be scrutinized in any calculation of the impact on CO_2 emissions of shifts to CO_2.

For those concerned about CO_2 emissions, an outcome where both HSR and other modes have low intensities while shifting to HSR is the highest is the best (this is the case we illustrated in detail in Table 10). What saves the most CO_2 overall in the US, however, may not reflect the maximum savings that can be tied to HSR, because the CO_2 intensities of the modes shifting to HSR will also have fallen. Projections of CO_2 from HSR that assume a low-CO_2 profile of HSR because of technological progress in trainsets and electric power production should consider that for consistency similar progress would occur to reduce emissions from light duty vehicles and air travel.

Comparing the two approaches

It is clear that both approaches have strong points and questionable points. While the bottom-up approach deals specifically with each corridor separately, it requires comparisons of analyses conducted under different assumptions in different corridors at different times. It also requires projections of variables such as population or of energy intensities based on technology that does not exist today and that are inherently questionable. By comparison, the top-down approach is based on reasonable extrapolation of aggregate national behavior and demographic patterns, but it does not look at conditions in specific corridors. In both approaches, we have therefore used scenarios that attempt to give a range of outcomes rather than a deceptively exact projection for either approach. Even so, we certainly encourage the reader to keep in mind the inherent approximations involved.

With this said, the results obtained by the two different approaches are surprisingly similar, as was shown in Figure 8. The two approaches used somewhat different assumptions about CO_2 emissions intensity, but the two sets of top-down "Broad Brush" projections bracket the bottom-up approach results.

At least at the level of abstraction used in both approaches, it seems reasonable to argue that a system of HSR services would have a significant demand and would contribute to a modestly national goal of controlling CO_2 emissions. This does not mean that all of the systems necessarily should be built, certainly in the immediate future. It does establish, though, that a future U.S. transport network ought to make optimal use of HSR as an option to highway and air in and between densely inhabited urban markets.

ISSUES IN IMPLEMENTATION

The analysis above indicates that HSR can be an attractive option in the right circumstances, both in finding a strong passenger market demand and in helping in reducing CO_2 emissions from transport. In this case, the "right circumstances" include a number of conditions:

- Rail must offer competitive trip times (see Figure 5). For the line haul portion of the trip, the competitive part can extend from 100 miles for conventional rail competing with autos, and upwards of 600 miles for 220 mph rail competing with air service.
- The trip time model also emphasizes that there must be good access to rail service. In general, because rail can serve from center-city to center-city, it will have an advantage over air on access times, so long as there is appropriate urban transport connected to the rail station. Where inadequate urban transport exists, rail's advantage will be reduced accordingly.
- As stated earlier, air and auto have been given the benefit of the doubt by excluding a number of "hassle" factors, such as traffic jams, airport security and weather delays, all of

which tend to affect air and highway much more severely than rail. While these factors do not always add trip time, they do add unpredictability that causes travellers to add time to be sure of making the trip.

These “right circumstances” are dependent on a number of policy issues that go well beyond HSR planning and construction. Having good access to the rail stations is based on urban planning that takes advantage of the higher density of development that rail permits and that provides the kind of mass transport – buses and transit -- that are needed. A comparison of the pattern of development in many contemporary U.S. cities (without good rail service) with cities in Europe or Japan, where good rail service exists, shows that coordinated planning of the entire transport network is critical. Fortunately, if an HSR network is to be developed by 2050, U.S. managers have time to react.

More broadly, there are a number of other transport policies that need improvement, including improved transit for station access and multi-modal station. Much of this will be needed with or without HSR implementation.

A more difficult issue relates to the need for identification and support for the social values developed by HSR. While the market benefits (passenger ticket revenues minus operating and capital costs, combined with property development benefits) for HSR are significant, they do not always cover the total costs of the system. At the same time, HSR does have social benefits, for example reduction of CO_2 emissions, reduction of petroleum import needs, reduction of highway and airport congestion, reduction of other air pollution and reduction in transport accident costs that benefit the public but cannot be collected from passenger ticket revenue. In many cases, while the private benefits will not cover total costs, the combination of public and private benefits may justify the system. In fact, most of the European (and some Japanese) HSR systems are justified on this basis, and the need for appropriate support is recognized.

Mass transit in the U.S. is justified on this basis, as is Amtrak service. The challenge will be to extend the approach to HSR systems many of which will be commercially unprofitable but that are economically viable with appropriate public support.

A related issue will be congestion charging for use of highways and possible airports. Many transport economists argue that highway congestion could be significantly reduced if users had to pay the congestion costs they impose during congested times of day. An unexpected impact of congestion charging might be a shift in road use demand to HSR for trips that originate or terminate during congested periods because highway usage costs for shorter trips would be increased. Congestion tolling might also make airport access more expensive during congested periods whereas HSR, with good public access to stations, might not be adversely affected.

Thus, if HSR is to be successfully implemented, some changes in transport policy will help. A more balanced approach to modal funding, including payment for social values generated, will be needed. Neither Federal nor State or local funding should support a particular mode other than to compensate for benefits or charge for costs external to the mode. Transit oriented development should be improved in order to respond to the ever growing percentage of the population that lives in urbanized areas. A potential adverse impact of HSR, entirely new (induced) demand that would not travel otherwise, should be the focus of pricing policies to ensure it occurs in less congested times.

WORLD EXPERIENCE WITH HSR: A BRIEF REVIEW

Although the HSR system envisioned here extends the current state-of-the-art slightly (only a small part of the new Chinese HSR operates at 350 km/hr – the other world systems operate at a maximum of 270 to 300 km/hr), HSR is well established and fully proven outside the U.S. The world's first HSR system, the Shinkansen system in Japan, was inaugurated in 1964 in time for the Tokyo Summer Olympic games. Since that time, demand on the Shinkansen lines has grown steadily, and a number of other countries have added HSR lines. Table 11 shows the current state of play.

There are some definitional problems in this Table, partly due to differences in the definition of HSR and partly due to the fact that the passengers and passenger-km are not clearly separated between true HSR and services that are at less than HSR speeds.[13] Allowing for this, though, in all, there are at least 8 countries with true HSR today, and a number of other countries that are set to join the club. China, in particular, is in the process of constructing up to 12,000 Km of HSR line operating at speeds up to 350 Km/hr, and has already inaugurated service on 600 Km of line, with about 3,700 Km to be in operation in the very near future. The projections for the U.S. in 2050 in this study (16,000 Km, 455 million passengers and 177 billion passenger-km) do not look at all unachievable compared with current world totals or, especially, compared with the likely world totals in 2050.

Table 11 – HSR Systems Around the World in 2008

Country	**Km Line >250 Km/hr**	**Passengers* (thousands)**	**Passenger-Km* (millions)**
Japan	2,387	310,237	81,658
France	1,692	116,054	52,564
Germany	865	74,700	23,333
Korea	240	38,016	10,158
Taiwan	345	30,581	6,566
Italy	532	23,882	8,878
Spain	1,244	22,955	10,490
Belgium	174	9,697	1,079
World total	7,479	626,122	194,726

* May include some traffic generated on non-HSR lines

Source: UIC, International Railway Statistics, 2008 edition, Tables 10 and 50

The method of funding, construction and operation of HSR systems differs significantly among these countries. Although most of the Shinkansen system was originally built by the old Japanese National Railway (JNR), a State entity, the old JNR was broken up and the major parts privatized in 1987. Today, most of the Shinkansen system is privately owned and operated, though construction of new lines is financed by national and local

[13] For example, the TGV in France operates at high speed from Paris to Lyons and then at more conventional speeds to Lausanne. How would we accurately account for the passengers and passenger-km generated by the high speed train on less than high speed lines? A similar problem exists in Germany and Italy. Only the Japanese and Taiwanese numbers are purely HSR because HSR services are clearly separated in those countries..

governments. The French TGV, German ICE and Spanish AVE were planned and built by public entities, but now operate under an E.U. mandated open access regime under which competition (private and public) may well arise for the publicly operated trains. The planned Chinese systems will be joint-ventures between the national railway (Ministry of Railways of China) and the local or provincial Government.

This diversity means that the U.S. model is not at all fixed. It seems clear that there will be no Federal ownership or operation of HSR (though Amtrak has indicated a desire to be considered as a contract operator for other owners). Amtrak owns most of the Northeast Corridor (NEC) infrastructure, and operates the HSR services; but, some of the NEC infrastructure is State owned, and there are a number of State or locally funded commuter operators as well as private freight railroads operating on the NEC infrastructure. State ownership and operation of HSR is possible, and there are precedents for such entities (the Florida Toll Road Enterprise, for example): this said, the two states furthest along in planning of their HSR systems (Florida and California) have indicated a desire at least to have private operators. One potential approach is concessioning or franchising along the model adopted in Latin America or the E.U. This could, however, be based on a number of different degrees of public versus private investment and operating support. Finally, it would be possible in principle to construct HSR on a totally private basis, with no public role whatsoever. This seems impractical, partly because of the impact that construction has on the public, and partly because there are few opportunities for HSR where the purely private benefits are clearly great enough t o support the system.

CONCLUSIONS

We draw a number of conclusions from this analysis. While none of these can be reduced to exact quantities, the general import seems clear.

The economic model for the US passenger transport network after World War II was heavily based on the automobile for short trips and on the airplane for longer trips. These trends became especially dominant with the advent of the Interstate Highway System beginning in 1956, and the introduction of jet aircraft in 1959. Intercity rail passenger service withered away to the point where, by 1970, passenger deficits threatened the private freight railroads with bankruptcy. As a result, Amtrak was established to permit direct public support for socially needed intercity passenger services.

Amtrak has never been fully funded, and intercity rail passenger services have never acquired a significant role in passenger transport. In the past, Amtrak's market development has also been limited by the relatively low population density and the longer distances in the U.S. in conjunction with strong Federal and State support for autos and airplanes that was not fully compensated by charges or taxes paid by passengers.

The view of the coming decades is different. Population growth and increasing urbanization in the U.S. will mean that the kind of dense markets that prevail in Europe and Japan will emerge in the U.S. in a number of large "corridors." This, combined with increasing congestion on highways and at airports, will create the opportunity for alternatives to emerge. In addition, technology in rail passenger transport has evolved, permitting much higher speeds. By contrast, there is little prospect for increases in auto speeds or in the cruise speed of aircraft engaged in short haul trips. There is good reason to argue that the next decades will require or at least encourage a new approach.

Given the demographic and technological trends, there are likely to be significant markets (100-600 miles) where HSR could offer advantages in and between the large cities on the major corridors. This advantage is shown both in the relative trip times of the alternative modes under predicted conditions, but also when hassle factors and uncertainties are taken into account.

The issue can be approached from two directions: a bottom-up approach in which potential developments in specific corridors are examined and projected forward to 2050 (the target year for this analysis): and, a top-down approach in which the total market for HSR is estimated as a share of national transport. The first approach evaluates the specific corridors identified by the FRA and concludes that these corridors (with three specific interconnecting links added) would find a large market and yield significant savings in CO_2 emissions by 2050. The second approach reaches essentially the same conclusions, though both approaches recognize that, depending on assumptions and scenarios adopted, the outcome will be subject to a significant range of variation.

HSR is a well proven option in many countries outside the U.S. There is no doubt that the proposed technology is available and feasible and that the extrapolations of the technology to 2050 used in this paper are well within reasonable bounds. The performance of HSR systems is adequately documented, though there is less hard information publicly available than might be desired. The competitive ability of HSR in the right markets is clear, and the benefits in emissions and safety are manifest, though more significant in some markets than others. The Japanese Shinkansen, for example, has carried over 10 billion passenger trips without a single fatality due to an operating collision – a safety record unparalleled by any other mode. HSR can indeed deliver better passenger services and make a contribution to reduction of congestion, pollution, CO_2 emissions, urban noise and accidents on highways and air.

HSR deserves a place in transport planners' options for the coming decades. This does not mean that any of the corridors studied should necessarily be built in the near future. That decision will rest on corridor-by-corridor economic analysis depending on each corridor's costs and benefits. It does mean that HSR should be added to the choices available and that Federal and State policies should be examined to make sure that they do not bias the system against any particular option.

Just as HSR did not emerge in the U.S. in the past because transport policies and funding worked against it, the future potential for HSR will rest on policies and programs that promote it or, at least, are neutral as between HSR, highway and air. Among other issues, this will include development of better urban transport, balancing of support policies and, especially, clarification of public policy toward support of services that deliver public benefits.

Finally, we need to emphasize that the target year, 2050, is not that far away taking into account the time needed to plan, fund and construct major transport infrastructure facilities. Forty years is about the same as the time needed to plan and complete the Interstate Highway System. It is not necessary to construct the corridor systems immediately, but the planning for all should start soon and construction of some should begin once the planning is complete.

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