

Long-term User and Community Impacts of High-speed Rail in the United States' Midwest Corridor

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ABSTRACT

This study contributes new insights in the debate over the viability of high-speed rail (HSR) in the United States and the value proposition for government investment. The modeling focus of this study is two-fold, and the modeling approach makes a case for a fundamental shift from the current perspective of HSR viability. First, the user and community impact assessment of HSR is conducted in the same manner as traditional transportation system evaluation (i.e., vehicle operating costs (VOC), travel time, safety, emissions, and energy consumption) to provide comparable conclusions regarding intercity transportation alternatives. Second, the model presented in this study analyzes both ridership and impacts within the same systematic framework to assess the long-term impacts on the individual transportation modes, total system metrics, and efficacy of alternate policies. Using this model, decision-makers can introduce various externalities to determine both the ideal and problematic conditions for the viability of a new HSR system.

1. INTRODUCTION

The Federal-Aid Highway Act of 1956, championed by Dwight D. Eisenhower, authorized the Interstate Highway System (IHS) with the intent of connecting the country through a nationwide transportation network. Upon completion in 1992, the IHS accumulated an estimated total capital cost of over \$475 billion (2012 dollars) [1]. In 2007, the federal government contributed over \$36 billion to highway

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improvements, maintenance, and operations, a 75% increase since 1995. State and local governments contributed an additional \$86 billion, a 17% increase since 1995 [2].

Despite seemingly large capital and recurring costs of the IHS, most Americans recognize it as a significant contribution in reducing intercity travel time, improving safety, reducing fuel consumption, reducing vehicle emissions, and spurring economic development. Although these benefits are not readily quantifiable, they are especially apparent over the long-term.

On a project-by-project basis, state-level Departments of Transportation (DOTs) use several user and community impacts to quantify the viability of a highway transportation project. These include fungible cost savings of travel time, safety, and vehicle operating costs [3]. By doing so, DOTs can evaluate alternatives and justify large capital expenditures in a transportation system that largely does not generate revenue.

Similarly, the benefits of commercial air travel are obvious. Commercial air travel is currently the safest mode of transportation per passenger-mile. Commercial jets transport passengers vast distances quickly, saving travel time and connecting people around the world. Because the industry is largely privately owned and operated, the federal and state/local governments contribute less funds than for the IHS, yet still spends \$27 billion and \$17 billion respectively on various subsidies annually [2].

However, today these historically successful modes are experiencing setbacks due to various factors, including rising demand. Travel delay costs due to congestion is estimated at \$70 billion [2] and \$31.2 billion [4] for highway and air travel, respectively. In addition to burgeoning travel time cost, road safety is a priority for the United States DOT [5]. Despite improvements in motor vehicle safety, the National Highway Traffic Safety Administration estimates that vehicle crashes cost the United States (US) over \$300 billion (2012 dollars) in medical, legal, and insurance costs, lost wages, and travel delays [6], over three times the value invested in the IHS by the federal and state governments.

Many countries have turned to high-speed rail (HSR) as an additional mode [7]; however, HSR in the United States is a contentious issue. Proponents see it as a necessary component of a sustainable nationwide transportation system which can increase safety, reduce total travel time, and simultaneously alleviate demand-related issues on the highway and in the air [8, 9]. Opponents see federal investment in HSR capital projects as wasteful government spending, often due to skepticism about estimates of ridership, revenue, and benefits based on current Amtrak operations, and predict a sustained subsidy for HSR operations over the long-term [10].

One key problem clouding the arguments is that HSR has largely been analyzed differently than other modes when evaluating transportation system alternatives. There must be a fundamental shift from the current perspective of HSR viability, which do not always consider the societal impacts over the long term. The research presented in this paper offers progress towards this shift in two ways. First, a user and community impact assessment of HSR is conducted in the same manner as traditional highway system evaluations (i.e., in terms of safety, travel time, and vehicle operating cost impacts) to normalize standards across transportation systems. Emissions and energy consumption impacts are also considered due to the increasing relevance of sustainability and energy security at the national level. Second, the model presented in this study incorporates a

tailored set of model parameters addressing future trends (e.g., population, fuel/energy prices) to assess the long-term impacts on the individual modes, the transportation system as a whole, and to inform policy making.

2. LITERATURE REVIEW

Because of the lack of an advanced high-speed rail network in the United States, most of the policy and research focus for HSR in the United States is ridership demand and revenue forecasting. One study investigates the potential HSR demand of US corridors based on criteria such as city and metropolitan area population size, distance, GDP, and existing transit systems [8]. A forecast for the California HSR project attempts to quantify demand and revenues for the project based on stated preference methodology [11]. However, reviews of the forecast identified some contentious issues regarding model development and validation, putting doubts on the credibility of the outcomes to support policy decisions [12, 13]. The following study presented in this manuscript uses the methodology and ridership predictions previously conducted which overcome the issues identified in the literature and include considerations of multimodal network design variables and the underlying economic, technological, demographic, and policy conditions [14]. Ridership is projected for the entire transportation system by determining the ridership change considering economic, demographic, and technological trends for 2012–2050.

Beyond ridership demand and revenue forecasts are the resulting user and community impacts of transportation systems that must be evaluated to determine the viability of a transportation system. This can include a number of externalities. Forkenbrock and Weisbrod (2001, p. 5) state in a NHCPR report, “There are three traditional system performance effects: (i) changes in travel time, (ii) changes in safety, and (iii) changes in vehicle operating costs. [15]” Monetary values can be attached to these particular externalities. In addition to Forkenbrock and Weisbrod (2001), Sinha and Labi (2007) provide surveys of the extensive research devoted to quantifying safety, travel time, and vehicle operating costs [3]. The methodology used for this research is modular and allows any monetary value to be incorporated for a range of possible impact.

In addition to the monetary factors used by State DOTs, there is also a great deal of research seeking to quantify the impact of HSR systems with respect to the environment and energy security. Chester and Horvath (2009) make a case for analyzing energy consumption and emissions impacts throughout the energy supply chain since HSR uses electricity instead of fuels directly [16]. The power plant profile of the study region is incorporated in this study’s methodology. Tol (2005) analyzes previously published research to determine the marginal damage cost of carbon dioxide (CO₂) emissions to quantify emissions in equivalent terms with other impacts [17]. However, because emissions and fuel consumption monetary conversions are often not applied in practice due to uncertainty and political reasons, this research uses physical values in lieu of monetary values.

While there has been significant research in evaluating the user and community impacts independently, there is little research which seeks to quantify all the impacts simultaneously using the same methodology. Campos and De Rus (2009) investigate atmospheric pollution, noise, and safety, but exclude travel time and vehicle operating

cost impacts and do not convert to monetary values [18]. AECOM and EDRG (2011) provide basic cost estimates, ridership forecasts, and resulting economic benefits of the proposed Chicago-Hub HSR network; however, the total economic benefit computed in this study is not consistent with the current, aforementioned transportation system evaluation methods [9]. Levinson et al. (1996) consider the safety, travel time, and various other costs of HSR, termed full cost, within the context of the existing transportation infrastructure in California for a HSR line from San Francisco to Los Angeles; however, the infrastructure is largely treated independently from one another [19]. Furthermore, the conclusions drawn about the full cost of HSR are based on a personal vehicle cost of \$0.13 per mile (2012 dollars). More recent gas prices and fuel efficiency of the vehicle fleet translates to a user cost of more than \$0.16 per mile in fuel costs alone (excluding maintenance, tires, depreciation, etc.) [2, 20]. This would make the full cost of HSR less expensive per mile than the full cost of the road mode. This illustrates the need to forecast the viability of HSR with new economic, technology, policy, and demographic information and projections of these over the long term.

The analysis framework developed in this study builds on standard transportation systems analysis approaches. Rather than focusing on the potential revenue, operating cost, maintenance, and capital investment, this paper identifies and quantifies user and community impacts not evident on a balance sheet. These impacts from HSR are addressed simultaneously with each other and consistent with current transportation system evaluation methods. By doing so, the study intends to shift the perspective of policymakers and planners toward a systematic, comprehensive impact assessment of the long-term viability of HSR in the United States.

The subsequent sections are organized as follows. The methodology section describes the process used for the impact assessment in detail. The monetary values used for the safety, travel time, and vehicle operating cost impacts vary from study to study, so the section gives specific attention to the data and source of conversion factors. The experiment section describes the no-HSR and HSR inclusive scenarios and the corresponding modal and system-wide impact assessment. Phenomena, trends, and implications of the experimental results are also discussed in detail. The final section concludes with important observations from the experiment and identifies areas of further research based on the results.

3. METHODOLOGY

The impact assessment of HSR is dependent on the total vehicle miles traveled per mode and the associated safety, travel, operating cost, emissions, and fuel consumption rates per mile traveled on each mode. The Long-term User and Community Impact Model (LUCIM) methodology used in this study for the impact assessment is detailed in Figure 1.

LUCIM uses three 'sub-models' to 1) describe the underlying exogenous environment at a certain time period, 2) project travel mode demand, and 3) analyze the resulting impact on the system as a whole. The focus of this particular study is the Impact Assessment (IA) model, which receives input from the Four-Step Travel Demand (FSTD) model in the form of miles traveled per mode and rate conversion data from the State of "World" (SOW) model to determine the resulting system-wide impacts for a particular time period given

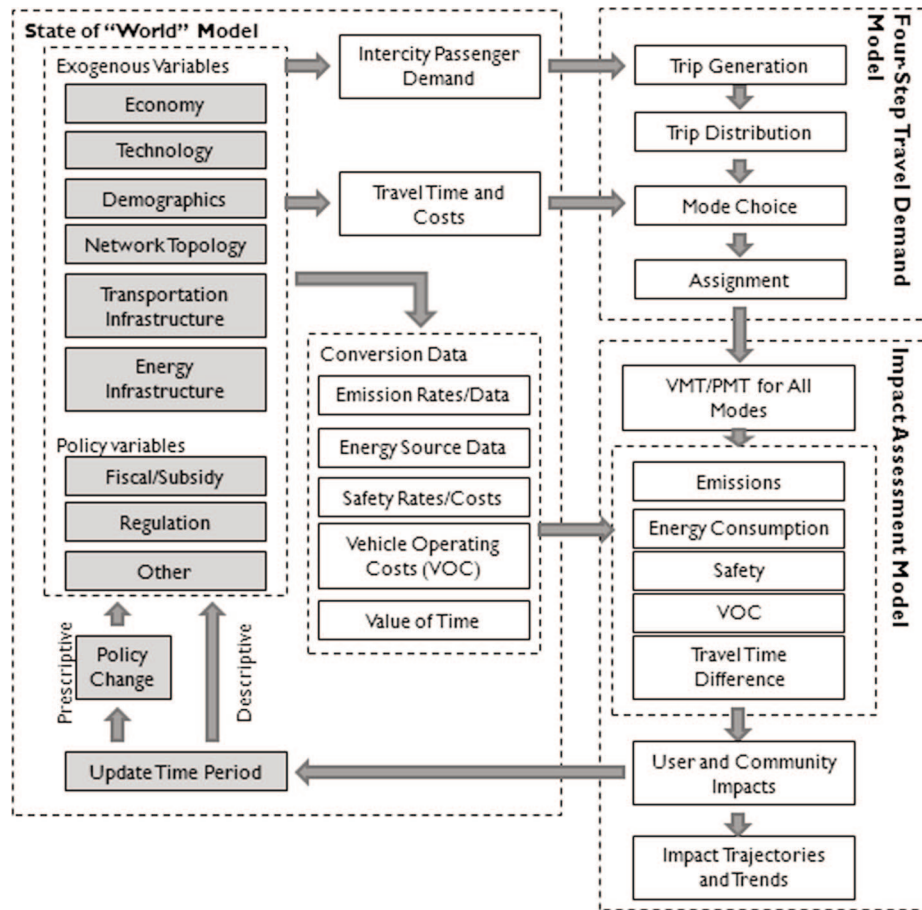


Figure 1. LUCIM conceptual framework (grayed boxes represent variables which change over time)

underlying exogenous factors. The HSR network for the Midwest corridor used for experiments in this study are shown in Figure 3. Peters et al. (2013) provides the details of the SOW and FTSD models necessary in understanding the ridership estimates used for the impact assessment detailed in this paper [14]. Important assumptions used in the model and experiments are tabulated in Table 1 to aid in interpreting the results.

Inputs from both the FTSD and SOW models will change each year based on economic, technological, and demographic trends. Impact conversion data will vary annually based on technological advances. For instance, vehicle safety, emissions and fuel efficiency have all improved over time; this evolution must be captured in order to reasonably forecast the impacts in the long term. Ridership levels will change annually based on the total intercity travel demand, fuel cost, and fuel efficiency of each mode.

**Table 1. Important restrictive assumptions of the proposed methodology
and the modular assumptions chosen for experiments**

Model assumptions (restrictive)	Implication
Four-step Travel Demand	+ Provides a consistent travel demand process across all modes – Constrains demand and mode choice format
Maximum Utility Paths	+ Effective for discrete choice mode choice model – Cannot account for specific route choices on a mode
Congestion effects neglected	* Result of data availability + Reduces computational burden + Congestion due to mode shifts may be prove to be small based on results considering intercity trips are a small portion of total trips and the shift is relatively small – Congestion around rail stations may increase – Congestion on current road and air links may reduce with HSR ridership
No land-use changes	* Result of data availability – New stations may change economic activity, population, and intercity travel patterns.
Dedicated HSR	+ Speeds which make HSR competitive likely necessitate dedicated lines. – Current HSR policy involves increasing current Amtrak speeds on shared lines.
No induced demand	* Result of data availability – The current methodology does not consider induced demand as a result of modal shift. Such secondary effects may be significant.
Experimental assumptions (modular)	Implication
HSR Speed	180 mph average speed used for comparison with MWHSRA and advanced HSR systems worldwide; rail energy consumption changes with speed
Value of travel time	ECONorthwest and Parsons Brinckerhoff Quade & Douglas (2002) [21]; assumes constant value of travel time across modes
Safety costs	Estimated \$3.4 million per fatality [6]; only fatality costs considered
Vehicle operating costs	FHWA (2002) [22] maintenance, repair, tires, and mileage-related depreciation; weighted average vehicle class; does not account for vehicle class changes over time; only road mode VOC considered
Vehicle emissions	[2]; growth regression; assumes no disruptive technologies of policies; Siemens Velaro train vehicle used as a representative HSR vehicle [23]
Fuel eff. trends	[2]; growth regression; assumes no disruptive technologies or policies; Siemens Velaro train vehicle used as a representative HSR vehicle [23]

Note: For restrictive assumptions (+) designates a benefit of assumption, (-) designates a limitation in assumption, and (*) designates assumption made based on available relevant data

Again, Peters et al. (2013) provides an in-depth description of the underlying methodology in ridership estimation based on various exogenous factors from the SOW model and provides the ridership estimates used for the experiments in this study [14]. However, it is important to note that any ridership estimates in terms of miles traveled per mode can be used within the impact assessment framework presented in this study to determine the resulting user and community impacts as a result of the introduction of a new mode, specifically HSR. The following sections outline the key ‘sub-models’ of LUCIM which drive the impact assessment.

3.1. State of “World” (SOW) Model

3.1.1 Economic, technologic, and demographic exogenous variables

Several exogenous variables are updated over time to reflect long-term changes in the multimodal transportation system. All projections in LUCIM utilize data from at least the past ten years to provide basic forecasts of economic, technologic, and demographic trends. As information about these forecasts evolves over time, new projections can be seamlessly incorporated to update knowledge about the impact on the multimodal intercity transportation system (e.g., unforeseen economic shock, disruptive innovation). These year-by-year trends will influence the trip generation, distribution, mode choice, and network assignment over time in the FSTD model. In addition to influencing the route choice behavior of individuals, technological trends will affect the impact of the miles traveled on each mode. For example, safety rates in terms of fatalities per mile traveled for personal vehicles have improved consistently over the past decade. Since accidents in air and rail modes are few and far between, but often catastrophic, it is difficult to determine accurate safety rate trends. An average fatality rate per mile traveled is used instead of a trend for these modes. Similarly, emissions and fuel consumption rates have improved for all modes of transportation [2]. All of these trends are modular in that they can be replaced by more up-to-date data or altered to test disruptive events and technological innovations on the multimodal transportation system. For example, replacing existing Amtrak diesel trains with more efficient diesel-electric equipment or simulating unanticipated price shocks to various energy prices can be seamlessly tested within this framework.

3.1.2. Energy infrastructure

One potential benefit of high-speed rail is electrification. Proponents of HSR see this as an opportunity to address energy security and environmental security simultaneously. While the HSR vehicle may not produce emissions or consume natural resources, the sources of electricity generation do. Therefore, it is important to address the energy infrastructure of the study region [16]. LUCIM accounts for the distribution of various electricity generating facilities (electricity mix) and the efficiencies of each type of facility to determine the fuel consumption and emissions due to increased electricity consumption. Trending the electricity mix and efficiencies over time can give greater insight into long-term, system-wide impacts of a new, electrified mode in the existing, largely petroleum-based transportation system. However, this particular study does not make any assumption on the future and instead uses the national electricity mix of

45% coal, 23% natural gas, 20% nuclear, 11% renewable, and 1% petroleum [24]. Projections for regional or future electricity mix can also be seamlessly incorporated within the model framework.

3.2. Four-Step Travel Demand (FSTD) Model

The FSTD model is used to project ridership on different transportation modes. Only intercity trips between different counties within a closed study region are considered. This process has four primary steps: trip generation, trip distribution, mode choice, and network assignment. The trip generation and distribution are a combined step in LUCIM. LUCIM uses published data and projections to determine a function for the intercity travel demand between each county-county pair in the study region of choice based on population. County population growth trends from the US Census [25] are used to extrapolate demand in the future. Next, the total multimodal door-to-door travel time and cost for the optimal route for each primary mode between each county-county pair is computed using a composite maximum utility search. The utility of a modal route is based on values of travel time and cost for five different income classes and two different trip purposes (personal and business trips) [26]. Additionally, alternative-specific constants are used for calibration with published ridership numbers. The values of the alternative-specific constants are consistent with personal vehicle as the most preferred mode, followed by air travel, then the current Amtrak system. A multinomial logit mode choice model is used to project the ridership share of each mode between each county-county pair. Total travel demand, ridership share, and distance traveled on each mode between each county pair gives both total vehicle and total passenger miles on each modal system in the study region for network assignment. Peters et al. (2013) provides a thorough treatment of the methodology and ridership results, which are used as inputs for the experiments in this particular impact assessment study [27].

3.3. Impact Assessment (IA) Model

The IA model uses trends from the SOW and FSTD models to compute the long-term user and community impacts of HSR over time in a singular framework. From the ridership distribution for each mode on each link in the network, the total vehicle miles traveled by automobile and passenger miles traveled by commercial air and rail can be estimated. This information allows for a traditional evaluation of the transportation system with respect to travel time, safety, vehicle operating cost (VOC), CO₂ emissions, and fuel consumption impacts. Monetary costs are applied to travel time, safety, and VOC impacts; the fungibility of emissions and fuel consumption impacts are excluded in a typical evaluation unless a particular policy measure (e.g., carbon pricing) is to be tested. Physical values of CO₂ emissions and fuel consumption are used instead. Policies like carbon pricing can be used to translate physical values to fungible values to compare alongside the other monetized costs.

Exogenous variables may have different effects on the impacts of HSR. For instance, in automobile and aircraft modes, the occurrence of fatal accidents and CO₂ emissions have decreased over time, while the fuel efficiency of both have largely increased. Below is a brief summary of each individual impact assessment. These impacts are

aggregated over a period of time to show the long-term user and community impacts of the incorporation of HSR under certain conditions.

3.3.1 Travel time impact

Both personal and business trip travel times have a monetary value in the eyes of the traveler which can quantify the public good of reducing travel time. ECONorthwest and Parsons Brinckerhoff Quade & Douglas (2002) estimate the value of in-vehicle, intercity, personal trip travel time at 70% of the travelers' wage rate and business trip travel time at 100% of total compensation (wage rate plus benefits) [21]. These rates are used for the median income of the five income brackets considered in the ridership model for the impact assessment of travel time. The rates can be adjusted seamlessly in the model as there remains discussion over the actual travel time value in HSR and air modes since travelers on these modes may conduct normal business tasks during long-duration intercity travel.

3.3.2 Safety impact

The National Safety Council (NSC) estimates the costs of various types of accidents based on loss of market and household productivity due to death or disability, property damage, and other less significant factors [6]. Only fatal accidents are considered in this study. The statistical estimate used by NSC and similar studies for societal costs is approximately \$3.4 million per fatality (2000 dollars). Because the rate of fatal accidents per vehicle mile traveled has consistently decreased in the past two decades, automobile safety rate trends are considered in the model to represent increased safety technology and policies over the long term. Yearly averages are used for commercial air and rail accidents as these occur with less frequency [2].

3.3.3 Vehicle operating cost impact

Introduction of HSR in America may shift ridership away from road travel, thereby decreasing the total system cost of operating a personal vehicle. Expenses of automobile drivers required to continually operate personal vehicles consist of three primary categories: fuel and oil, maintenance and repair, and tires [27]. Vehicle operating cost (VOC) does not include fuel cost since this is explicitly captured in the fuel consumption impacts and mode choice decision. Information on fuel consumption impact assessment can be found later in this section. In addition to maintenance, repair, and tires, studies have incorporated mileage-dependent depreciation as a vehicle operating cost on a per mile basis [22]. Data from 2005 shows that for medium-sized passenger vehicles maintenance and repair, tires, and mileage-dependant depreciation cost approximately 4.12, 1.58, and 12.50 cents per mile respectively (2005 dollars); however, these numbers vary by class of vehicle. An estimate based on a weighted average of vehicle class ownership nationwide is used to determine the average vehicle operating costs for automobiles.

From a traveler point of view, the components of operating cost in the personal vehicle mode (maintenance, repair, part replacement, and depreciation) is an external cost separate from the cost of a particular trip. However, operating costs for commercial air and train operators are covered by a portion of passenger fare revenue. Operating

costs for commercial air and train network are indirectly passed to the consumers as a contribution to the total price of the travel fare and are not considered user and community costs as they are not a separate expenditure for consumers.

3.3.4. Emissions and fuel consumption impacts

While it is generally believed that HSR could reduce both the emissions and consumption of fossil fuels due to the shift of travel demand away from the predominant petroleum-dependent transportation modes, use of electricity by HSR may raise questions to this theory when considering the entire energy supply chain [16]. Figure 2 shows the energy supply chain in the transportation sector as modeled in this study.

Increased consumption of electricity from the introduction of HSR could increase the demand for other fuel sources, so the emissions and consumption rates depend on the electric power plant mix used to provide energy to the trains. Emissions and fuel consumption for an electric-powered HSR system can be greatly reduced by incorporating renewable, low-emission electric power plants into the existing electricity generation supply chain. However, currently many states still rely overwhelmingly on coal to supply electricity [24], and the emissions and consumption benefits of HSR may not be fully realized. A trend of electricity generation distribution in the Midwest can be used in the study to determine the future electricity supply mix, as there is a push from both the federal and state governments toward use of renewable power sources. Experimental results show that emissions savings from the electrification of HSR may be low in comparison to total emissions produced in the transportation network as a result of the dominance of automobiles in intraregional travel. Future research may explore coordinated transportation and energy policy scenarios.

Another important electrification component is the performance of the high-speed train vehicles. While there is no widely accepted choice of train equipment for the proposed U.S. HSR system, the Siemens Velaro train is employed in Spain, China, Russia, and Germany. Siemens has shown interest in the U.S. HSR market [28]. Thus, specifications of electricity use per passenger mile traveled of the Velaro family of

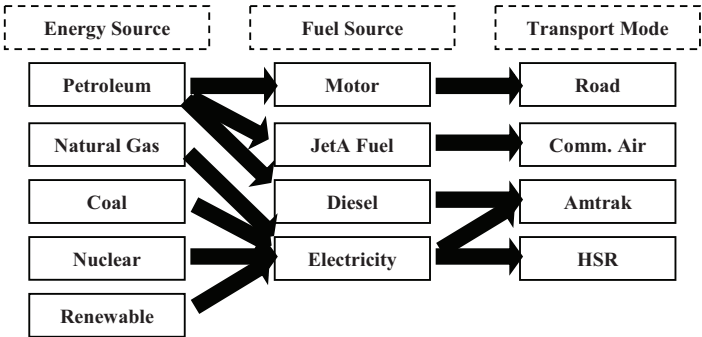


Figure 2. Domestic energy supply chain in transportation sector

high-speed electric multiple unit (EMU) trains are used in this study as a representative vehicle to determine the energy consumption and emissions impact of the HSR system [23]. Alternative train vehicles could also be tested.

Automobile, aircraft, and existing Amtrak emissions and fuel consumption per mile traveled per mode were calculated from data covering at least the past ten years to capture current trends in technology and policies combined with carbon emissions factors [2,29]. Adoption of electric vehicles (EV) is not considered in this analysis because forecasting EV impacts is highly uncertain due to current negligible market share and insufficient range to travel distances needed for intercity travel.

This study reports only carbon dioxide emissions and consumption of petroleum-based fuels (motor gasoline, diesel, and JetA fuel). However, other emissions (e.g., methane, sulfur dioxide, carbon monoxide, volatile organic compounds) or fuel sources (e.g., coal, uranium) can be incorporated seamlessly within this methodology and analysis with similar transportation statistics and data trends. Local population data along modal networks would be needed for an impact assessment for localized pollutants.

4. EXPERIMENTS

4.1. Forecast for Modal Ridership in Midwest

The Midwest High Speed Rail Association (MWHsRA) 2050 Vision for HSR proposed a dedicated HSR network that we use for the experiments [9]. Figure 3 shows both the Amtrak and HSR network with dots for stations and lines for the links (showing connectivity, but not geographically to scale).

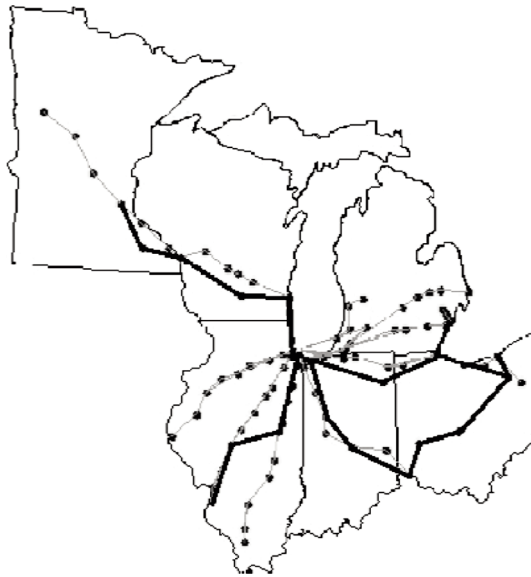


Figure 3. Midwest corridor Amtrak (gray) and HSR (black) experimental composite network

The methodology in LUCIM determines mode choice and ridership on the road, commercial air, Amtrak, and proposed HSR mode based on the sensitivity of travelers to total travel time and cost. The ridership results simulated using LUCIM from 2012 to 2050 for a case without HSR is shown in Figure 4. The model accounts for several exogenous factors during this time period, including population growth, fuel efficiency, and predicted fuel price trends [30]. Key experimental assumptions and information regarding these trends can be found in Peters et al. (2013) [14]. These trends contribute to an increase in total travel demand during the time period. The total annual passenger miles traveled (PMT) is the important result which drives the impact assessment; total annual PMT varies as a result of the increase in total travel demand over time as well as the different mileage of modal alternatives.

Ridership results (Figure 4) project a significant shift to the air mode until about 2020 followed by a gradual shift away from the air mode. This is primarily due to a leveling off in the rate of increase of EIA fuel cost projections at this point [30]. At 2020, projected automotive efficiency improvements surpass projected fuel cost increases, and the total cost per mile on the personal vehicle mode decreases contributing to the increase in personal vehicle ridership share.

4.2. Impact Assessment of High-Speed Rail in Midwest Corridor (2012-2050)

Although it is not otherwise reasonable to assume full HSR implementation in the next several years, much less 2012, projection reliability decreases with the time horizon, so these experiments simply illustrate the trend of HSR impacts over time. Since HSR is expected to offer superior level-of-service (LOS) (e.g., frequency, comfort, convenience) compared to the current Amtrak network, the experimental scenario assumes a LOS of HSR to be similar to air travel. This HSR scenario is compared to the no-HSR scenario. While any average speed for high-speed rail can be used, 180 miles per hour was chosen for these long-run experiments because newly-built and planned HSR systems in China, and elsewhere, are capable of such speeds [31]. LUCIM simulations have shown that the long-run HSR average speed elasticity of ridership decreases from 1.15 between 110 and

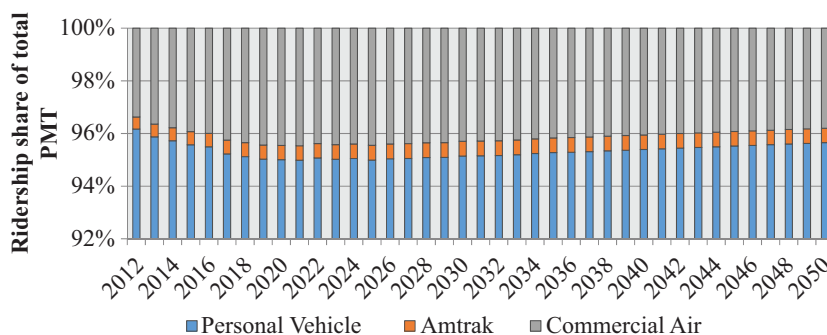


Figure 4. Ridership share of Midwest corridor intercity travel market with no HSR (34.5 billion system-wide PMT in 2012 and 51.1 billion system-wide PMT in 2050)

120 mph to 0.49 between 210 and 220 mph, translating to a shift increment to HSR of approximately 0.09% per 10 mph increase [14]. These ridership changes would contribute directly to the impacts. As more information becomes available regarding specific plans for HSR development in the United States, the model can be adjusted for planned average speeds on each individual link in the network.

Figure 5 shows the projected modal ridership share of the Midwest corridor in terms of percentage of total PMT. There is a significant shift to the commercial air mode, similar to the no-HSR case, but there is also a shift to both the Amtrak and HSR mode. In 2030, approximately 6.0% of intercity travel is via rail with 3.9% on Amtrak and 2.1% on HSR. The share of Amtrak travel grows significantly because LOS increases for short rail trips and Amtrak can be used as a feeder service for the HSR. Nearly 5% of vehicle miles traveled by personal vehicle and 10% of miles traveled on the commercial air mode are shifted to the rail mode, resulting in a significant change in the corresponding impact assessment of HSR (see Figure 6, 7, and 8).

Figure 6 shows the resulting total travel time, safety, and VOC savings from 2012 to 2050 in 2012 dollars. Annual monetized travel time and VOC savings are the most significant fungible impacts. Consistent with the rapid shift away from the personal vehicle mode in the first years of the experiment (shown in Figure 5), travel time savings increases rapidly, doubling from 2012 to 2017. Travel time savings are estimated to be \$33 million in 2012 and \$170 million in 2050 as mode share shifts to faster modes of travel. VOC savings exhibit a more modest increase from approximately \$125 million in 2012 to \$250 million in 2050. Safety is a factor of 10 lesser than travel time and VOC savings. The majority of safety savings result from a shift from the relatively less safe personal vehicle mode. Safety savings are derived from the change in predicted injuries and deaths due to different safety rates for modes. Because personal vehicles remain the predominant mode of travel, the total savings are

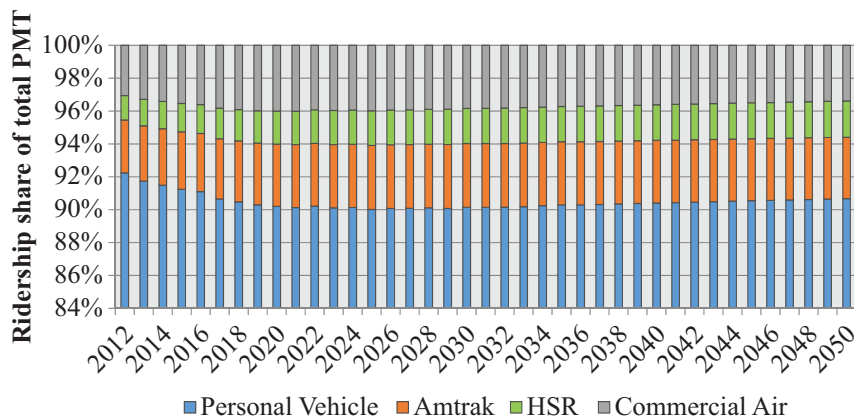


Figure 5. Ridership share of Midwest corridor intercity travel market for HSR (35.4 billion system-wide PMT in 2012 and 52.4 billion system-wide PMT in 2050)

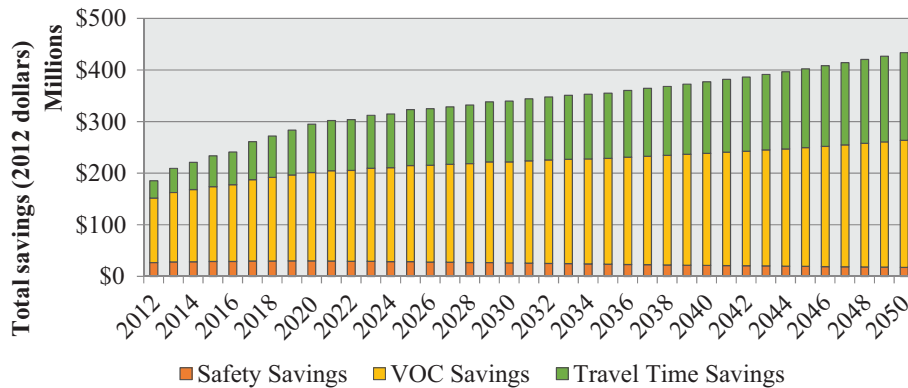


Figure 6. Annual monetized travel time, safety, and VOC savings from 2012 to 2050 for HSR compared to no-HSR case (2012 dollars)

relatively small. It is interesting to note that safety savings increase at first, but eventually decrease due to increasing safety in the personal vehicle mode.

As expected, HSR draws ridership away from petroleum-dependent modes and thus generates a net petroleum reduction compared to the no-HSR option (Figure 7). Petroleum usage for electricity generation in the nation is approximately 1% of total electricity generation [24]. It is an interesting observation that the attractiveness of the train option drives a shift to both HSR and the existing Amtrak system as a feeder for HSR. Amtrak ridership increases accordingly, therefore, consuming additional petroleum (diesel) and emitting more CO₂ than without HSR; however, the net petroleum consumption and CO₂ emissions savings are positive. Savings could be increased with the electrification of Amtrak trains in the Midwest. The estimated annual net savings of CO₂ is between 200,000 and 300,000 metric tons beyond 2020 (Figure 8).

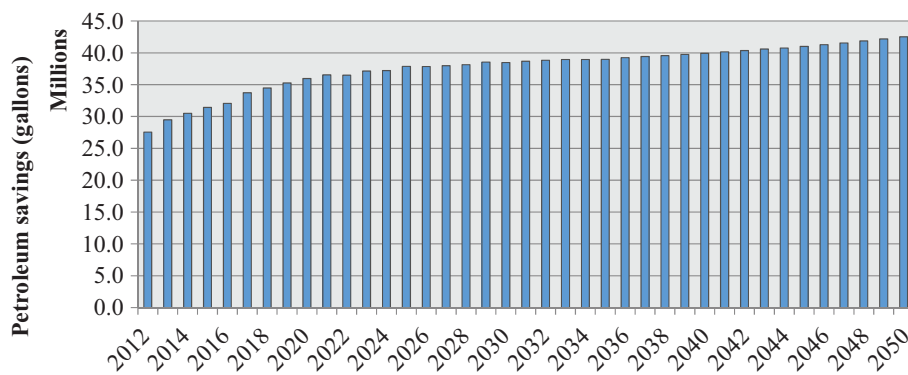


Figure 7. Petroleum consumption reduction from 2012 to 2050 for HSR with commercial air LOS characteristics compared to no-HSR case

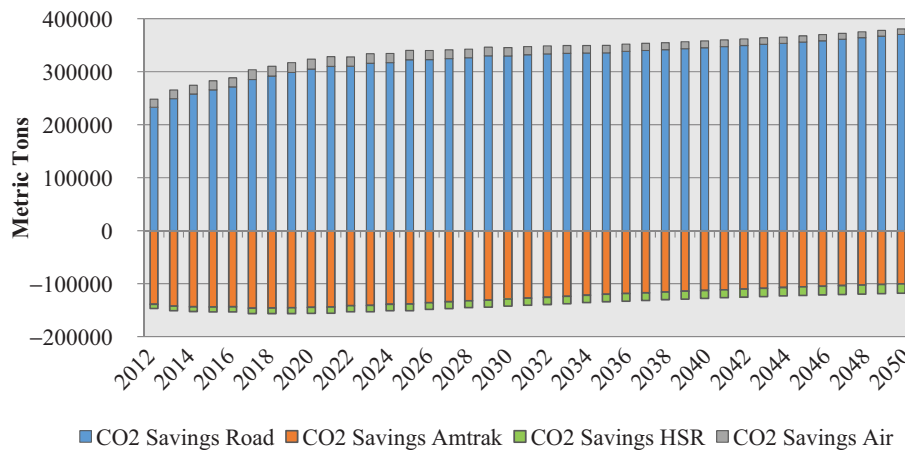


Figure 8. CO2 emissions reduction from 2012 to 2050 for HSR compared to no-HSR case

The total nationwide transportation sector (passenger and freight) in the United States consumes approximately 206 billion gallons of petroleum and emits 1.8 billion metric tons of CO₂ per year [2]. The fuel consumption and CO₂ savings from the HSR experiment case are 25.7 million gallons and 203,000 metric tons annually, respectively. The savings are slightly greater than 0.01% of the United States annual petroleum consumption and CO₂ emissions in the transportation system alone, signifying that while HSR does have energy and environmental benefits, they are relatively small even if HSR were extended nationally [2]. One reason for this is the prominence of freight and local passenger travel, neither of which is addressed by HSR. Freight transportation, accounting for 10% of vehicle miles traveled and more than one-fourth of fuel consumed, will not be directly affected by intercity passenger rail. Furthermore, long distance intercity trips account for only about 30% of the total passenger miles traveled in the United States [2]. Based on the experiments in this study, only 2.14% of these travelers will switch from their current mode choice. All these factors contribute to the inability of HSR to appreciably impact energy security and environmental sustainability with respect to the transportation system as a whole. However, the savings represent an incremental step in terms of a comprehensive approach to energy security and environmental sustainability in intercity transportation.

5. CONCLUSIONS

The approach adopted in this paper constitutes a shift from the current perspective of the viability assessment of HSR. Until now, high-speed rail has been evaluated primarily in the context of ridership and the ability to generate sufficient revenue to offset maintenance and operating cost. However, the long-term user and community impact assessment conducted in this paper has shown that when evaluated in a manner consistent with other accepted transportation system impact assessment methods, there exists significant long-term user and community impacts from HSR.

The proposed Chicago-Hub HSR network was used for the experiments in this study. The annual travel time, safety, and vehicle operating cost savings with an HSR mode double from \$200 million in 2012 to over \$400 million in 2050 based on the experimental assumptions adopted from previous HSR ridership forecasts. The scale of these potential fungible benefits alone would offset a portion of the maintenance and operating costs. These impacts must be included in consistent comparative analysis with highway and airport projects aimed at capacity expansion. Including revenue alongside the aforementioned societal benefits has the potential of making HSR a viable transportation alternative in the Midwest corridor. No conclusions with respect to whether HSR should or should not be built in the Midwest corridor can be made from this study, but further investigation of HSR in the operational context is warranted based on these findings.

In addition to the fungible benefits of HSR, proponents have argued that HSR could address energy security and environmental sustainability. While there are measurable benefits of HSR with respect to these issues, the magnitude of the impact pales in comparison to total fuel consumption and CO₂ emissions in the United States. Since intercity trips account for only about 10% of total miles traveled in the United States, and HSR will only account for a small portion of these trips from existing modes, this study suggests that greater impact in terms of energy security and environmental sustainability may be obtainable at the intra-city rather than intercity level.

The study of new and different scenarios are enabled by the flexibility of the LUCIM model used in this paper. Operational considerations can be incorporated in the model to more accurately estimate both ridership and impacts. Also, maintenance and operating cost factors may be added as they are specifically left out of this analysis. Finally, potential future policies such as gasoline tax, highway tolling, renewable power sources, and Amtrak electrification could be studied to test plausible scenarios and/or improve policy evaluations. This is especially true considering the emerging issue of funding our current transportation systems and the evolution of the multimodal transportation to meet future needs.

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