USDOT Region V Regional University Transportation Center Final Report

NEXTRANS Project No. 055PY03

Incorporating High Speed Passenger Rail into a Multimodal Network Model for Improved Regional Transportation Planning

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Funding for this research was provided by the NEXTRANS Center, Purdue University under Grant No. DTRT07-G-005 of the U.S. Department of Transportation, Research and Innovative Technology Administration (RITA), University Transportation Centers Program. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

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TECHNICAL SUMMARY

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Final Report, May 14, 2014

Title

Incorporating High Speed Passenger Rail into a Multimodal Network Model for Improved Regional Transportation Planning

Introduction

With increasing demand and rising fuel costs, both travel time and cost of intercity passenger transportation are becoming increasingly significant. Around the world, high-speed rail (HSR) is seen as a way to mitigate the risk of volatile petroleum prices while alleviating demand on highways and at airports. Ridership is the critical element in determining the viability of a large capital, long-term transportation investment in terms of costs, revenue, and the resulting societal impacts. This research provides a systematic, consistent methodology for analyzing system wide modal ridership. The proposed methodology can be used to estimate the modal ridership under the proposed HSR network scenarios. The study analyzes the potential for high-speed rail as a part of the existing multimodal transportation system in a region in terms of ridership. Although this study does not explicitly consider capital costs, capital investment (e.g., network design and HSR speed), along with exogenous demographic, technological, economic, and policy trends, are used to project ridership over time. Population, fuel efficiency, HSR speed, and fuel price trends are the important variables considered for this study. The application of the methodology is two-fold, and the modeling approach makes a case for a fundamental shift from the current perspective of HSR viability. First, a user and community impact assessment (i.e., travel time, safety, and vehicle operating cost savings) of HSR is conducted in the same manner as traditional transportation system evaluation to provide comparative conclusions regarding intercity transportation alternatives. Emissions and energy consumption impacts are also considered due to the increasing national relevance of environmental sustainability and energy security. 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. Although the methodology is extendable and modular to incorporate any mode in any region, experiments are conducted for the Midwest corridor in the United States. Average HSR speed is tested to demonstrate the model's ability to capture the sensitivity of ridership to a specific design consideration. This study represents an important step toward a consistent, comprehensive economic analysis of HSR in the United States.

Findings

Experimental results show that if operational characteristics were improved to match that of air service in terms of frequency, comfort, etc., HSR has the potential to attract a ridership of the order of 50 to 60 million annually. MWHSRA predicted ridership of 35 and 44 million annually for 130 mph and 160 mph average speeds, respectively. The LUCIM-predicted 6% market share of intercity travel in the Midwest is a little lower than the 7-8% ridership shift predicted in a California HSR study. Considering the difference in underlying assumptions in the models, study areas, and the inherent error in prediction in the long-term, these results are surprisingly similar. The projected ridership is at a level high enough to warrant future research in HSR in the Midwest corridor. Furthermore, the results demonstrate that there will be a continual ridership shift to passenger train as fuel costs increase for the alternative modes in the long-run until the point where vehicle efficiency can offset these costs. An important capability of the proposed model is the capability to capture multiple HSR design characteristics (e.g. average speed, fare price, projections in exogenous variables). A sensitivity analysis of the HSR ridership with respect to the average HSR design speed was performed. The result of this sensitivity analysis suggests that mode shift to HSR increases by approximately 0.09% per 10 mph increase in average speed.

The projected ridership level shows that 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. 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 capacity expansion projects. The revenue generated along with 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 CO_2 emissions in the United States. Since intercity trips account for only about 30% 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 intracity rather than intercity level.

Recommendations

The research addressed in this project suggests that user and community impacts from construction of a new mode may be significant when considering ridership shifts in the regional, multimodal transportation network. It also suggests that these impacts should be considered in the cost-benefit analysis alongside other costs (e.g., capital, maintenance, operating) and revenue of the new mode. This warrants further research and refined cost projection to provide a clear picture of high-speed rail in a specific region. This methodology can be used as an integral part in a comprehensive study of a proposed high-speed rail system.

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ACKNOWLEDGMENTS

The authors would like to thank the NEXTRANS Center at Purdue University for funding this research. They would also like to acknowledge the help and support from Dr. Datu Agusdinata and colleagues at the NEXTRANS Center and the System of Systems Laboratory in the Purdue University School of Aeronautics and Astronautics in assembling the wide database necessary to conduct the study. The authors are solely responsible for the contents of this report.

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CHAPTER 1. INTRODUCTION

1.1 Background and motivation

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) (Cox and Love, 1998). In 2007, the federal government contributed over $36 billion to highway improvements, maintenance, and operations, a 75% increase since 1995. State and local governments contributed an additional $86 billion, a 17% increase since 1995 (BTS, 2011).

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. 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 significantly less funds than for the IHS, yet still spends $27 billion and $17 billion respectively on various subsidies annually (BTS 2011).

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 (Sinha and Labi, 2007). By doing so, DOTs can evaluate alternatives and justify large capital expenditures in a transportation system that largely does not generate revenue.

However, several of these user and community impact savings are threatened by increasing demand on the transportation system. Vehicle-miles traveled on interstates in the United States (US) increased 20% from the Interstate Highway System (IHS) completion in 1991 to 2009. Over 30% of these vehicle-miles traveled are under congested conditions, an estimated average increase of 35% more time per person since the completion of the IHS despite a 50% increase in urban interstate lane-miles. The total cost of travel time and fuel cost is estimated to be over $78 billion a year or about $713 per auto commuter (BTS, 2011). The National Surface Transportation Policy and Revenue Commission estimates that an annual investment of over $130 billion is needed for improvements and maintenance to accommodate these trends (NSTPRSC, 2007).

Similar to the IHS, airports in the United States are facing increasing economic loss as a result of increasing demand. Departures from commercial airports have more than doubled since 1975 (BTS, 2011). The total 2007 cost of delays from congestion was estimated to be $31.2 billion dollars, $16.7 billion of which was attributed to passenger travel delay (Ball et al., 2010). The Federal Aviation Administration predicts 3% demand growth per year and the cost of meeting this capacity through new airports and current airport improvements to be $30-60 billion over the next twenty years.

Other countries are mitigating the transportation system risks of increasing demand by investing in electrified high-speed rail (HSR) (high-speed defined as speeds 125 mph or higher). In Europe, there are currently about 6,600 km (4,100 miles) in operation, 2,500 km (1,500 miles) under construction, and 8,700 km (5,400 miles) planned (UIC, 2011; Campos and De Rus, 2009). China alone has constructed over 9,600km (6,000 miles) of HSR lines and plans a total of 16,000km (10,000 miles). The plan is expected to cost well over $300 billion (Amos et al., 2010). The only operating HSR line in the United States is the Amtrak Acela Express line connecting Boston to

Washington D.C. This accounts for only 456 miles of the 21,178 miles of Amtrak routes, but over 10% of the total ridership.

Proponents see HSR in the United States as a viable option to shift ridership away from the current intercity transportation modes (road, air, and Amtrak), thereby reducing demand and demand-related problems across the entire system. Since HSR can be electrified, it may also be resistant to volatile petroleum prices that are characteristic of both personal vehicle and commercial air modes.

From the opposing perspective and considering the current ridership levels on existing intercity rail (Amtrak), it may seem difficult to reason the high ridership projections based on a non-US experience without rigorous analysis and justification in the US context. This is especially true when considering the vastness of the IHS and the current cost for the road user. If ridership, and therefore revenue, is not sufficient to offset the cost of HSR, then the government is forced to subsidize the project. Amtrak is currently subsidized with about $1.5 billion annually from federal, state, and local budgets. However, as the proponents of HSR point out this is low in magnitude compared to $122 billion and $45 billion total government expenditures for highways and air modes, respectively (BTS, 2011).

1.2 Study objectives

Motivated by the aforementioned strategic perspectives, this initial study seeks to understand the role of the commonly-used criterion in the current discourse, ridership, to analyze the long-term and systemwide ridership of a proposed HSR network in the context of the existing multimodal transportation system in a region. Beyond ridership, one key issue clouding the debate is that HSR has largely been treated differently than other modes when evaluating transportation system alternatives. There must be a fundamental shift from the current perspective of HSR viability, which focuses on profitability without considering the societal impacts over the long term. The aim is to develop a formal, systematic methodology to enable policymakers and planners to make informed decisions when evaluating the introduction of an alternative mode in an existing transportation network. Key elements of the proposed methodology are the capabilities to both (1) predict ridership and (2) capture comprehensive systemwide, user and community impacts.

The ridership prediction includes considerations of modal accessibility and multimodal network performance. It is projected over the long-term by determining the ridership sensitivity to economic, demographic, and technological trends. Hence, the study provides both policymakers and planners an ability to robustly perform the systemwide impact analysis of a HSR option in a specific geographical region while factoring in the plausible long-term evolution of the ambient and relevant factors. Experiments are presented in this study to illustrate the capability of the systematic methodology.

The research presented in this study performs the user and community impact assessment of HSR in the same manner as traditional highway system evaluations (i.e., in terms of safety, travel time, and vehicle operating cost impacts) to normalize different standards across transportation systems. Emissions and energy consumption impacts are also considered due to the increasing national relevance of sustainability and energy security at the national level. These impacts are presented by incorporating a tailored set of model parameters addressing future externality 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.

1.3 Organization of the research

The subsequent sections are organized as follows. Chapter 2 discusses previous efforts and gaps in predicting ridership on HSR in the United States. The methodology, which is used to represent the multimodal network, predict future scenarios, and determine ridership, is discussed. Monetary values used for the safety, travel time, and vehicle operating cost impacts vary from study to study, so the discussion gives specific attention to the data and source of conversion factors. Chapter 3 validates the methodology by demonstrating its ability to “predict” ridership in the multimodal network retroactively by comparing to past data. It also illustrates the ability to capture ridership trends related to dynamic exogenous factors. Chapter 4 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. Chapter 5 concludes with important observations from the experiment and identifies areas of further research based on the results.

CHAPTER 2. METHODOLOGY

This chapter introduces an improved methodology for predicting ridership and associated user and community impacts in the multimodal, intercity transportation network. Section 2.1 summarizes the previous work in this field from the United States experience, and Section 2.2 identifies specific gaps in previous research which the proposed methodology overcomes. Section 2.3 introduces the methodology through three sub-models: (i) the State of "World" model (Section 2.3.1), (ii) the Four-step Travel Demand model (Section 2.3.2) , and (iii) the Impact Assessment model (Section 2.3.4). Section 2.4 summarizes the methodology used in the experimental scenarios which follow.

2.1 Previous work

While much of the European research related to HSR focuses on estimating elasticity given the existing rail network, due to the uncertainty with respect to network design, technology, etc. most of the policy and research focus for HSR in the United States have been on demand and revenue forecasting. A study by the America 2050 planning group investigates the potential HSR demand of US corridors based on criteria such as city and metropolitan area population size, distance, GDP, and existing intra-city transit systems (Hagler and Todorovich, 2011). However, it does not consider the existing intercity transportation network which has significant implications for both ridership and the resulting impacts.

Others study the competition between the air and rail modes in great detail, but largely ignore the potential competitive, complementary, and other implications associated with the road network (Adler et al., 2008; Dobruszkes, 2011). A study on HSR ridership for California (Cambridge Systematics, 2007) estimated between 7-8% HSR ridership in the interregional markets; it suggests that 6% of automobile traffic, 33% of commercial air, and 27% of conventional rail would shift to HSR. These ridership numbers were projected using a two-step nested logit model for determining ridership on both the egress and main modes by considering time, cost, trip length, station-specific constants, and level-of-service (LOS) variables. However, Brownstone et al. (2010) found several methodological issues with the study including: (i) arbitrary division of trips into long and short trips resulting in estimation discontinuity, (ii) absence of an airport/station choice model, (iii) incorrect use of a nested logit model (given choice-based data) in lieu of a multinomial logit model for the main mode choice model, and (iv) over use of station-specific variables. These findings were corroborated by an independent peer review panel (Koppelman et al., 2011).

Joshi (2010) uses a door-to-door travel framework and a multinomial logit model based on time and cost for several different income classes and trip purposes to estimate ridership on an on-demand air service (ODAS) introduced to the existing intercity transportation network. The proposed study uses this door-to-door travel framework as a building block to address the HSR ridership problem. The coefficients for the variables (total time and cost) in the utility function of the different modes are obtained from a study by Ashiabor et al. (2007). They calibrate these coefficients using the data obtained from the 1995 American Travel Survey (BTS, 1995) along with a stated preference survey data which is further explained by Baik et al., (2008) .

Beyond ridership demand and revenue forecasts, user and community impacts of transportation systems 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 NHCRP report, "There are three traditional system performance effects: (1) changes in travel time, (2) changes in safety, and (3) changes in vehicle operating costs." 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.

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, as it is seen as a solution to these increasingly relevant national strategy goals. 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. 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 (CO_2) emissions to quantify emissions in equivalent terms with other impacts. However, because emission 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. 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. 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 of one another. 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.) (BTS, 2011; EIA, 2012a). 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.

2.2 Research Contributions

The proposed methodology in this study integrates demand and supply side characteristics to analyze the ridership potential of HSR in the context of the existing multimodal transportation system. It explicitly addresses many issues identified in previous HSR studies. A door-to-door framework with multinomial logit mode choice model (discussed in detail in Section 2.3.2.2) overcomes the methodological issues discussed above by specifically avoiding the division of long and short trips by only considering intercity trips, correctly using a multinomial logit model for the main mode choice, and avoiding station specific variables for calibration. A station choice model is incorporated into this study's model to further address issues highlighted by Brownstone et al. (2010) and Koppelman et al. (2011). Unlike previous studies which predict ridership under a specific scenario, a key contribution of the proposed methodology is the ability to forecast informed HSR ridership scenarios based on various design considerations and dynamic exogenous factors by incorporating changes to the existing multimodal network characteristics over time.

The user and community impacts are derived from the ridership projections in a consistent framework adopting standard transportation systems analysis approaches. Rather than focusing on the potential revenue, operating cost, maintenance, and capital investment, this study identifies and quantifies user and community impacts not evident on a balance sheet. These impacts from HSR are addressed simultaneously with each other in a manner 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.

2.3 *Methodology for LUCIM Model*

As illustrated in Figure 2.1, the conceptual framework for the proposed methodology contains three primary models: (i) the traditional Four-Step Travel Demand (FSTD) Model, (ii) the State of “World” (SOW) model, and (iii) the Impact Assessment Model. Although other demand planning models exist for passenger rail, the FSTD model was chosen for demand planning consistency across all modes.

Due to the need for dynamic data and route information to accurately account for congestion, travel time is considered static and, thus, this study considers demand shifts, but not congestion effects explicitly. The study region (shown in Figure 2.2) includes Ohio, Indiana, Michigan, Illinois, Wisconsin, and Minnesota, the primary footprint of the proposed Midwest High Speed Rail Association (MWHSRA) Chicago-Hub HSR plan, disaggregated at the county-level; however, this methodology is extendable to any geographic area at any level where sufficient data exists. For instance, areas of influence serviced by stations could be used granted the necessary area-to-area demand data is available.

The existing air, road, and Amtrak modes, as well as the proposed HSR mode, are used to develop multimodal composite networks (that is, networks consisting of multiple modes). The performance (time and cost) for a particular year of travel between each county on these composite networks depends on economic, technological, policy, and demographic factors included in the State of "World" (SOW) Model. A utility function is proposed for each individual mode based on time and cost for several income classes and travel purpose (business or non-business). The total ridership on each utility maximizing modal path for each county pair and income class is distributed using a multinomial logit model. This process is conducted for each year of analysis, and the various trends of variables in the SOW will impact the modal ridership distribution in the transportation system. The modeling framework is called the Long-term User and Community Impact Model (LUCIM). The inherent modular nature allows different data sources, data trends, and parameters to be replaced and tested with more reliable and/or up-to-date data or be altered to investigate the effects of disruptive events and innovations on the multimodal transportation system. Table 2.1 and Table 2.2 highlight the restrictive assumptions characteristic of the model proposed in this study and the primary limiting assumptions that were made in order to conduct experiments, respectively. The experimental assumptions are modular in that they can be relaxed provided better data are available.

2.3.1 **State of “World” (SoW) model**

2.3.1.1 Economic, technological, and demographic exogenous variables

Economic variables include the income of travelers, transportation fuel price fluctuations/trends, and fare structure changes (air and rail modes). The Energy Information Agency (EIA) publishes motor gasoline, airplane fuel (JetA), and electricity price trends each year under low, reference, and high scenarios (EIA, 2011). The study uses the reference EIA projections for JetA and motor gasoline, shown in Figure 2.3, in LUCIM. In the figure, the lines to the left of the dashed vertical line are actual prices. The trends to the right are EIA projections from 2012 to 2035 and further regression after 2035.

While in reality there exist operating and maintenance costs, we assume the vehicle mode choice decision is only based on the immediate cost of travel (i.e., fuel cost). Toll and congestion pricing can be easily incorporated in the cost structure, but this particular analysis ignores these currently potential, but unimplemented policies. To address the study objectives, the function for fare price is dependent on both distance and fuel costs. All operational considerations are considered constant in the planning context. Amtrak fares are based on a regression of the actual fares of various legs in the region coupled with Amtrak-published data on total revenue and per-mile revenue (Amtrak, 2011a). Air fares are computed using a function based on great circle distance and JetA fuel prices as part of a concurrent study by Purdue University and NASA (Moolchandani et al., 2012). The HSR fare function is generated based on a study that analyzes the fixed and variable costs of HSR (Adler et al., 2008). In summary, the round-trip fare and cost functions used in this study are:

Personal Vehicle $c_{iji}^{PV,y} = \frac{p_{Gas}^{y}}{mpg^{y}} \cdot \left(2 \cdot d_{ij}^{m}\right)$

Amtrak $c_{iji}^{Amtrak,y} = \$21.52 + 0.2017 \cdot \left(2 \cdot d_{ij}^{m}\right)$

Commercial Air $c_{iji}^{Air,y} = f\left(d_{ij}^{GC}, p_{JetA}^{y}\right)$

HSR $c_{iji}^{HSR,y} = \$47.03 + 0.2560 \cdot \left(2 \cdot d_{ij}^{m}\right)$

where ${c_{iji}}^{m,y}$ is the travel cost for a round-trip from origin station i to destination station j on mode m in year y, ${d_{ij}}^{m}$ is the one-way distance from i to j on mode m, ${d_{ij}}^{GC}$ is the one-way great circle distance, mpg^{y} is the miles per gallon in year y, and ${p_{Gas}}^{y}$ and ${p_{JetA}}^{y}$ are the prices of a gallon of fuel for motor vehicle and JetA fuel in year y, respectively. Access and egress modes are accounted for in the composite networks (Section 2.4.2.2.2). Hence, the functions are for modal legs of a trip not representative of the total trip cost. Because the fare structure of a new mode and the price responses in the other modes remains largely uncertain, alternative functions for travel cost can be seamlessly integrated in the model.

An important technology variable for this particular study is fuel efficiency. Fleet-wide fuel efficiency and emission trends can be generated from data published by the Bureau of Transportation Statistics (BTS) (BTS, 2011). The fuel efficiency of personal vehicles and commercial air have generally increased, which may make these modes more attractive in terms of travel cost over time.

The demography of the region directly impacts the demand between each origin and destination in the network though population trends. For instance, as population increases the demand increases accordingly. The United States Census Bureau's County Intercensal Estimates from 2000 to 2010 are used to extrapolate county population trends (USCB, 2011). Although some shifts in populations across counties is captured, in this study it is assumed there is no population or economic activity which may potentially agglomerate near the new HSR stations over time. This assumption may potentially underestimate passenger rail ridership and would require more detailed economic activity models.

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. 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.

2.3.1.2 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 (Chester and Horvath, 2009). 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 current electricity mix of 45% coal, 23% natural gas, 20% nuclear, 11% renewable, and 1% petroleum (EIA, 2012b). Projections for future electricity mix can also be seamlessly incorporated within the model framework.

2.3.1.3 Network topology and transportation infrastructure

The road network for the six-state region is constructed using link distances and connectivity from the National Transportation Atlas Data from 2010 (BTS, 2010a) for highways and major arterials. An average intercity travel speed of 55 miles per hour is assumed. Road congestion, and resulting travel time, remain static over time for several reasons. This particular analysis considers the planning context at a high level of aggregation. Dynamic traffic conditions, scheduling, etc. at a level much more disaggregated than the county-level considered in this analysis are required to accurately estimate such congestion effects. Furthermore, intra-county and short trips (under 50 miles), which account for over 90% of miles traveled, will likely not be affected significantly by the introduction of HSR. Thus, total demand can be captured, but potential congestion relief in interregional and local level would require further investigation.

In addition to airports in the study region, SLO and CVG are included because of the proximity to the study region. The 2010 flight segment data from the Air Carrier Statistics database (BTS, 2010b) was used to construct the air network connectivity and estimate the average link travel time. Amtrak route guides available on the Amtrak website provide connectivity, distance, and fare information (Amtrak, 2012). Amtrak has an average speed of 45 miles per hour in the Chicago area. The proposed HSR network is created as a dedicated rail system from the MWHSRA Vision (AECOM and EDRG, 2011) with an average train speed of 180 mph, which is similar to the fastest average speeds of newly-built HSR systems around the world and the speed proposed by the MWHSRA. Sensitivity analysis with respect to average speed is conducted in this study.

2.3.2 Four-step Travel Demand (FSTD) model

2.3.2.1 Trip generation and distribution

The projections for the inter-county demand used to calibrate the trip generation and distribution steps of the FSTD Model are obtained from the Transportation Systems Analysis Model (TSAM) model. Data were provided for origin and destination county-to-county demand in years 2002 and 2025. The TSAM model uses data from the 1995 National Travel Survey along with gravity models to predict county-to-county demand across the United States (Trani et al, 2003). Since the proposed study only uses demand in the six-state study region, the analysis is performed only for trips which both originate and end within the region. Hence, travel on the infrastructure where either the origin, destination, or both counties are outside of the region, is excluded. The study also excludes intra-county travel such as most commuting or small personal trips (grocery, appointments, etc.). This is appropriate for the evaluation of HSR as an intercity transportation mode; HSR is not expected to draw ridership from intra-county trips.

A gravity model is used to interpolate and extrapolate demand in between and beyond the TSAM demand for 2002 and 2025. Carrothers (1956) presents the fundamental form of the gravity model which reasons that the number of interactions (demand, in our case) is directly correlated with the population of two centers and inversely proportional with the distance between them and other frictional factors. This reasoning has been applied to modal trip distribution and travel demand specifically (Alcaly, 1967). The model used to estimate county-to-county demand in this study takes the following form:

$$D_{ij}^{y} = I_{ij} \frac{Pop_i^y \cdot Pop_j^y}{GCD_{ij}}$$

where D_{ij}^{y} is the travel demand from county i to county j for year y, I_{ij} is the impedance between counties i and j, GCD_{ij} is the great circle distance between counties i and j, and Pop_i^y and Pop_j^y are the population of counties i and j at year y, respectively. The impedance is unique for each county pair and represents the relative attractiveness or difficulty for interaction. The projected population of the individual counties (Pop_i^y) for the period 2000-2010 is available from the United States Census estimates. A regression for each county was used to extrapolate this population before and after the available U.S. Census estimates. In this way, county population growth is included as an explicit variable in analysis. This allows an opportunity to study potential population agglomeration effects near stations and land use changes which may prove to be significant in the long-term.

2.3.2.2 Mode choice

2.3.2.2.1 Utility and discrete choice model

To estimate mode choice, the utility of modal paths is computed for the travelers. Capon et al. (2003) found that 100% of intercity mode choice utility functions used in previous studies in evaluating road, train, and air modes include travel time and cost, 60% include frequency, and 40% include accessibility. The proposed study includes time and cost as variable components of modal utility from year to year. Furthermore, the sensitivities of time and cost will change based on the income level and trip purpose (business or non-business). Accessibility is incorporated explicitly in the door-to-door framework which includes road network access and egress at modal facilities (rail stations and airports). The following commonly-used utility function is used to compute the relevant utilities:

$$U_{ij}^{m} = \beta_m + \beta_c^{s,p} \cdot \text{total cost}\left(\$\right)_{ij}^{m} + \beta_t^{s,p} \cdot \text{total time}\left(\text{hr}\right)_{ij}^{m} + \varepsilon_{ij}^{m}$$

where $U_{ij}{}^{m}$ is the utility for a trip on mode m from origin county *i* to destination county *j*, β_m is the alternative-specific constant (ASC), $\beta_c{}^{s,p}$ and $\beta_t{}^{s,p}$ are the coefficients for time and cost, respectively, for income class *s* and trip purpose *p*, and $\varepsilon_{ij}{}^{m}$ is the estimation error resulting from unobserved factors for a trip from county *i* to *j* on mode *m*. The ASC describes the average utility of various level-of-service (LOS) features of the mode that are not specifically addressed in this analysis such as comfort, safety, etc. (Koppelman and Bhat 2006). Frequency is incorporated implicitly in the ASCs for each mode as it remains constant throughout this analysis; this study focuses on the planning and not the operational context. The same ASC for commercial air was used for the HSR system in this study. There is similarity between commercial air and the proposed HSR modes in terms of frequency, comfort, and other LOS characteristics. There is room for improvement in this particular assumption especially in testing LOS characteristics explicitly. The value of βm is calibrated in a similar fashion to incremental logit models where a known ridership proportion at some time is used to calibrate the model and the variable aspects of the utility are changed to determine the change in ridership (Dehghani and Harvey, 1994). A regional mode-specific survey is desirable to provide accurate time and cost sensitivities. As there has been no specific HSR survey for the Midwest corridor, we use values for five income levels and two trip purposes (business and non-business) for the entire United States derived from the 1995 American Travel Survey (BTS, 1995) in previous literature (Ashiabor et al., 2007, Baik et al., 2008) for the maximum transferability. These values were originally estimated for a nested logit model, but can be used for a multinomial logit in our case where there is only one route choice per mode choice (Brownstone and Small, 1989). It is important to note that alternative models (e.g., nested and mixed logit model) or additional variables (e.g., treating frequency and comfort explicitly) can be incorporated provided the coefficients are available. The model choice for this study was chosen due to the current availability of appropriate and relevant data.

2.3.2.2.2 Composite Networks

Personal vehicle travel can be represented by an individual mode (road) network. A path-based algorithm is used to determine the maximum utility road path for each county pair in the study region by factoring the travel time and cost on each link. However, travel by commercial air or passenger rail requires the road infrastructure to access and egress their modal infrastructures. Hence, a composite network is used to merge these modes. Additionally, a station choice model is introduced by searching nearby stations or airports in order to determine route alternatives that could ensure the maximum utility for the traveler.

The procedure for finding the maximum utility path in the commercial air and rail composite networks has three main steps. First, the four closest stations to the origin and the four closest stations to the destination are identified to incorporate aspects of station selection that have been neglected in previous studies (Brownstone et al., 2010). Four is an arbitrary number; however, it was chosen to reflect the viable options for station access points. For instance, even in Chicago (Cook County, IL), the number of viable airports/stations to choose from for regional travel is rather limited. Second, the maximum utility path between each viable origin and destination station is found in the individual modal network. The access and egress road utility and the modal utility for each path are combined, resulting in a total of sixteen path alternatives. Third, of the sixteen alternatives, the path with the maximum total utility is selected as representative path for the modal alternative. This procedure ensures a single modal alternative for each county pair, reduces computational time, and has been shown to return the actual maximum total utility path despite the simplification from a viable shortest path procedure. For the rail composite network is that the Amtrak network and the HSR network are combined into one rail network with some unique and some shared stations based on the MWHSRA network. In the study experiments, for the case with no HSR, the HSR network is simply removed. For example, Figure 2.4(c) shows the maximum utility path for Edgar County, IL and Kosciusko County, IN has three legs by rail, Crawfordsville-Lafayette via Amtrak and Lafayette-Gary-Fort Wayne via HSR. The maximum utility path does not have the most adjacent rail station for either origin or destination county due to the gain in total utility by driving to the HSR station. This illustrates the need for the station choice in the model.

Composite networks with combined road, passenger rail, and commercial air are excluded in this analysis due to the structure of the mode choice model. Using passenger rail as an access mode to the commercial air mode is not a likely action considering trips with both origin and destinations limited to the six-state region. Still, as a result the model may underestimate total passenger rail ridership. Furthermore, Only the maximum utility path for each mode (road, passenger train, and commercial air) is used in the discrete choice model. This assumption implies that the user focus is on the mode choice and not a route choice, and is consistent with our study objective of tracking modal ridership versus specific route ridership. A multinomial logit (MNL) model is used to determine the ridership distribution on each mode, as follows:

$$P_{ij}^{m} = \frac{\exp\left(U_{ij}^{m}\right)}{\sum_{k} \exp\left(U_{ij}^{k}\right)}$$

where $P_{ij}{}^{m}$ is the probability of choosing mode m on a trip from county i to county j.

2.3.3 **Trip Assignment**

To analyze the impacts of the HSR mode, it is necessary to determine the total passenger-miles traveled (PMT) per mode. The PMT for a mode is computed as:

$$R_{ij}^{m} = P_{ij}^{m} \cdot D_{ij} \qquad PMT_{ij}^{m} = R_{ij}^{m} \cdot d_{ij}^{m}$$

where $R_{ij}{}^{m}$ is the total number of travelers who choose mode *m* from county *i* to county *j* and $PMT_{ij}{}^{m}$ is the total passenger-miles traveled on mode *m* from county *i* to county *j*. The total system miles traveled on each mode is the sum of the $PMT_{ij}{}^{m}$ values over all county pairs *ij* on mode *m*. Using this information the systemwide modal ridership and the corresponding user and community impacts can be determined. The model currently does not factor potential capacity constraints, but the ridership changes resulting from the experiments and the load factors of both train and air modes are small enough that capacity issues may not be particularly relevant in the planning context. Expanding the model to include capacity constraints to fully analyze congestion effects in specific contexts represents a future objective.

2.3.4 **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), CO_2 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 CO_2 emissions and fuel consumption are used instead.

Exogenous variables may have different effects on the impacts of HSR. For instance, in automobile and aircraft modes, the occurrence of fatal accidents and CO_2 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.

2.3.4.1 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). 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.

2.3.4.2 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 (Blincoe et al., 2002). Only fatal accidents are considered in this study because the total cost of these dominates non-fatal accidents. 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 (BTS, 2011).

2.3.4.3 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 (AAA, 2012). 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 (FHWA, 2002). 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 can vary by class of vehicle. An estimate based on a weighted average of vehicle class ownership 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 in the impact assessment as operating costs as they are not a separate expenditure.

2.3.4.4 Emissions and fuel consumption impacts

While it is generally believed that HSR could potentially 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. Figure 2.5 shows the energy supply chain in the transportation sector. To address this, LUCIM includes a multi-tier energy supply chain to draw conclusions regarding the impact of HSR.

Increased consumption of electricity from the introduction of HSR could increase the demand for other fuel sources, so the emission 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 (EIA 2012b), and the emissions and consumption benefits of HSR may not be fully realized. The 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. 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 US HSR system, the Siemens Velaro train is employed in Spain, China, Russia, and Germany. Siemens has shown interest in the U.S. HSR market (Warner, 2010). Thus, specifications of electricity use per passenger mile traveled of the Velaro family of high-speed electric multiple unit (EMU) trains are used in this study as a representative vehicle to determine the energy consumption and emission impact of the HSR system (Siemens, 2010). Alternative train vehicles could also be tested.

Automobile, aircraft, and existing Amtrak emission 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 emission factors (BTS, 2011; EIA, 2007). 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 petroleum-based fuels (motor gasoline, diesel, and JetA fuel) since these are the focus of current policy discussions. 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.

2.4 Summary of Methodology

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; this is performed by the SOW, FSTD, and IA models, respectively. In doing so, ridership is projected on the intercity passenger transportation system (i.e., passenger rail, personal vehicle, and commercial air modes) and user and community impacts (i.e., travel time, safety, and operating costs), as well as emissions and energy consumption, are forecasted over the long-term in a consistent framework.

Table 2.1 Important restrictive assumptions characteristic of the proposed methodology

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.

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

Table 2.2 Important modular assumptions chosen for the experiments

Experimental Assumptions (modular)	**Implication**
Modal Costs	Assume only fuel costs in road mode; fare structures taken from literature
Speed	180 mph average speed used for comparison with MWHSRA and advanced HSR systems worldwide (sensitivity analysis performed)
EIA fuel price trends	High gasoline prices predicted in this particular outlook; no feedback to prices
BTS fuel eff. trends	Simple growth regression; assumes no disruptive technologies or policies
Multinomial Logit	Limits single modal alternative with single route; No combined road, air, train trips
Alternative-specific constant	*Result of data availability Limits analysis to time and cost (i.e. treats frequency, comfort etc. implicitly)
County-to-county demand	*Result of data availability Counties may be an arbitrary area designation. Area of influence may be more appropriate in the station context.
Six-state boundary	Reduces computation time without sacrificing many trips. Some trips may originate or terminate outside the experimental six-state boundary.
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); assumes constant value of travel time across modes
Safety costs	Estimated $3.4 million per fatality (Blincoe et al 2002); only fatality costs considered
Vehicle operating costs	FHWA (2002) 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	BTS (2011); growth regression; assumes no disruptive technologies of policies; Siemens Velaro train vehicle used as a representative HSR vehicle (Siemens 2010)
Fuel eff. trends	BTS (2011); growth regression; assumes no disruptive technologies or policies; Siemens Velaro train vehicle used as a representative HSR vehicle (Siemens 2010)

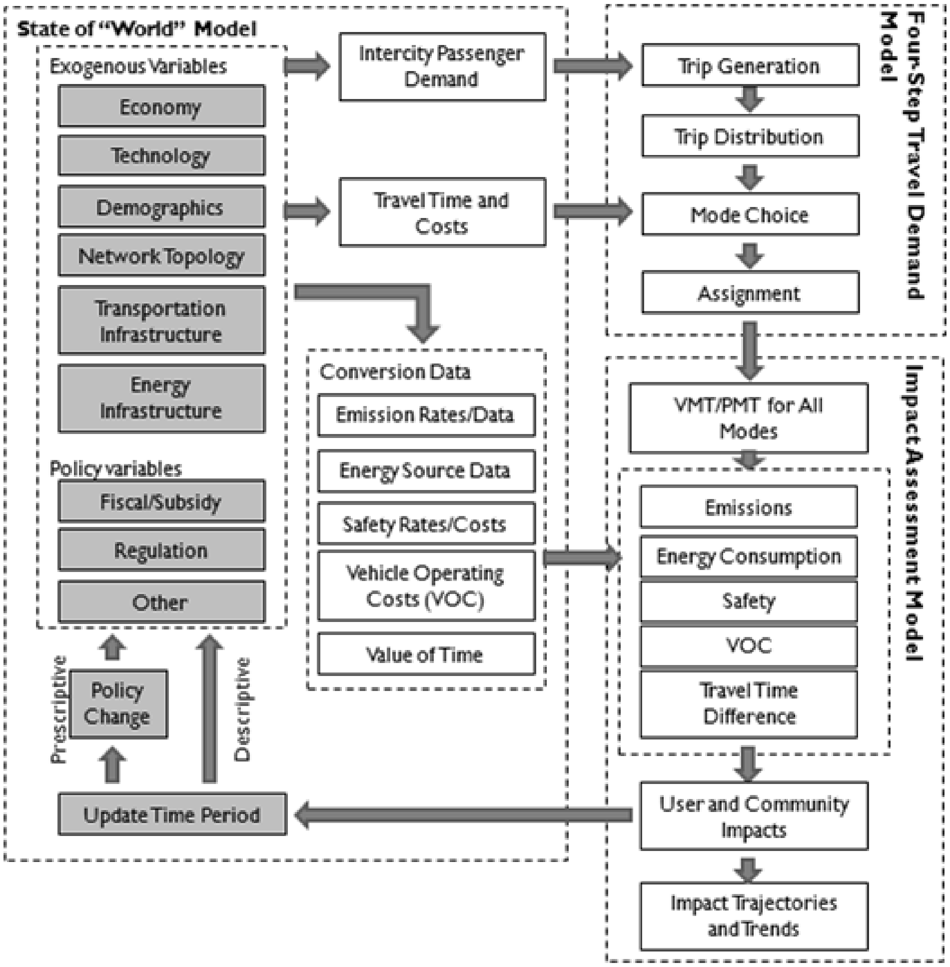

Figure 2.1 LUCIM conceptual framework (grayed boxes represent variables which change over time)

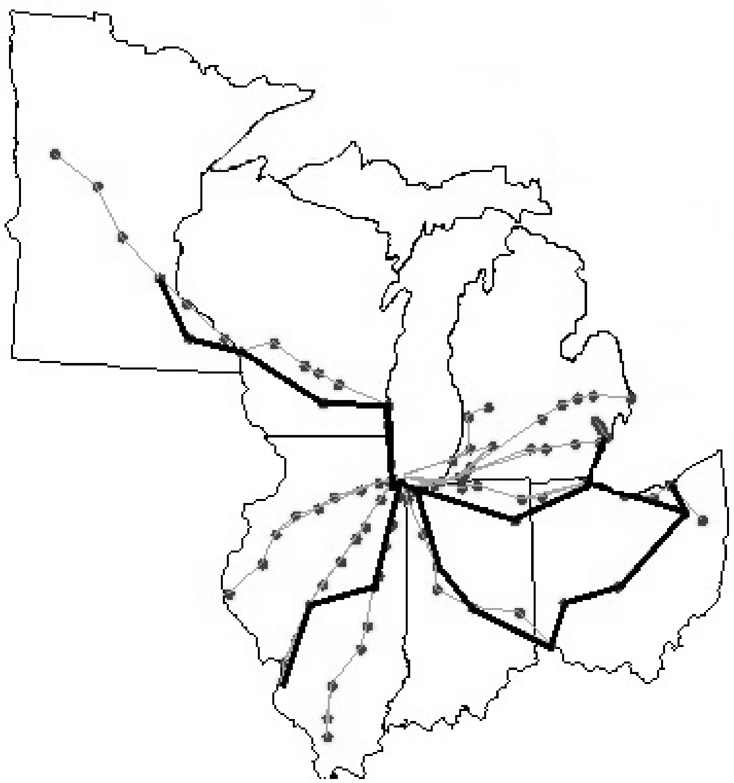

Figure 2.2 Midwest corridor Amtrak (gray) and HSR (black) experimental composite network

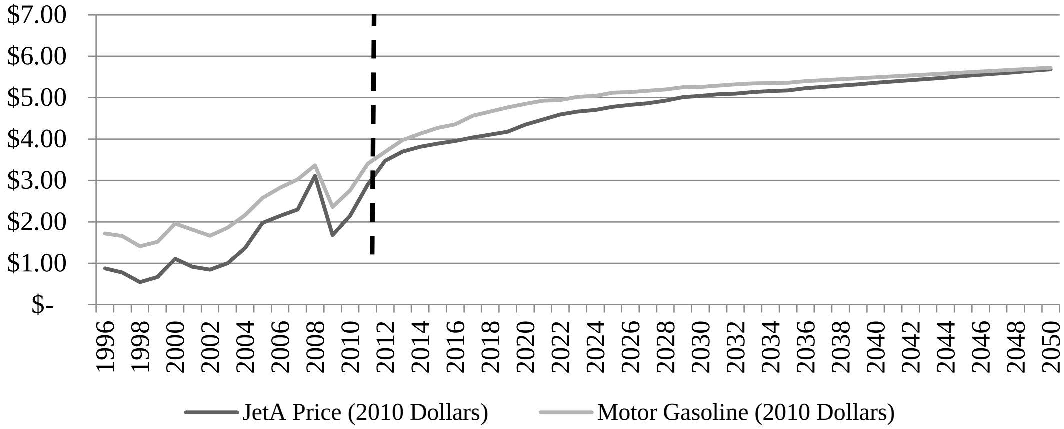

Figure 2.3 Petroleum product prices by year

Figure 2.4 (a) rail network in study region (Amtrak in gray, HSR in black); (b) maximum utility rail paths (showing connectivity, not geographic path) for stations near Edgar County, IL and Kosciusko County, IN; (c) maximum total utility path between origin and destination county

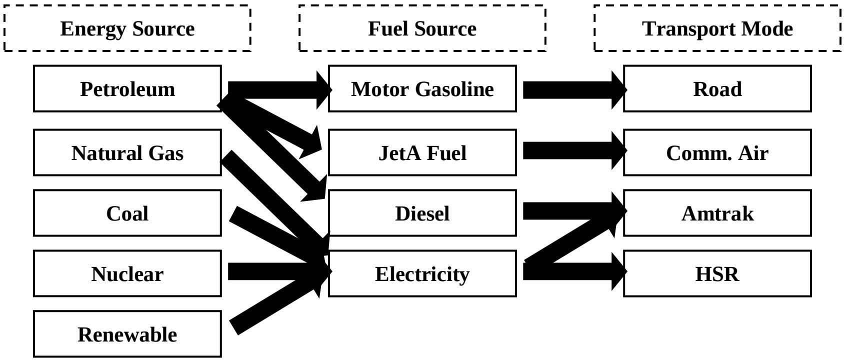

Figure 2.5 Domestic energy supply chain in transportation sector

CHAPTER 3. VERIFICATION AND VALIDATION OF MODEL

Chapter 3 studies the proposed methodology's practical application and ability to accurately predict ridership and forecast long-term impacts. Section 3.1 details a systemwide validation by comparing existing multimodal ridership data and ridership estimates from LUCIM with exogenous variables from the same year. Section 3.2 tests the ability of the model to capture trends in ridership based on exogenous variables used in the model. There are several limitations which remain in the validation process; most notably is lack of ridership data across all modes. Section 3.3 reviews these limitations in the context of the LUCIM model.

3.1 *Systemwide validation*

A primary objective of this study is to predict systemwide modal ridership for personal vehicle, intercity passenger rail, and commercial air. The ridership share, combined with total passenger-miles traveled on each mode, is a critical element in determining impacts and assessing alternative strategies in the multimodal transportation system. Figure 3.1 shows the LUCIM-predictions of past ridership shares based on actual fuel prices and fuel efficiency. Data for modal ridership distribution for intercity travel for demand completely contained in the six-state region are not readily available for all years. However, the 2001 National Household Travel Survey (NHTS) provides very similar data at an aggregate level over all modes (USDOT, 2005). This database defines intercity travel in terms of roundtrips of 50 miles or more between origins and destinations at the zip code-level. Based on this data, filters for the origin and destination states have been used to bound the raw data to demand within the study region. By doing so, the mode choice for the bounded, intercity trips from NHTS provides sufficient data to compare observed and LUCIM-predicted modal ridership share for validation at a regional aggregate level.

Table 3.1 compares the observed versus predicted modal shares based on observed exogenous variables such as county population, fuel efficiency, and fuel cost in 2001. The LUCIM modal shares for 2001 closely predict the actual ridership distribution based on PMT in the six-state region. This validates the ability of the model to reasonably capture the modal ridership share for the systemwide transportation network.

3.2 Trend validation

Another goal of the study is to capture the long-term trends as a result of changes in exogenous and policy factors. The lack of disaggregate data for the study region requires validation of trends based on a comparison of regional LUCIM results to observed nationwide data over time. This is done by tracking the ridership changes in passenger train over time. Figure 3.2 compares the observed nationwide Amtrak PMT with LUCIM predictions for the six-state study region. While they are not directly comparable due to the different levels of aggregation, the trends correlate well. There are inflection points at 2008 and 2009 due to gasoline price fluctuation for both the actual PMT and LUCIM-predicted PMT. Hence, LUCIM can robustly capture trends in train ridership over time due to intercity traveler sensitivity to county population, fuel efficiency, and fuel cost (Figure 2.3).

3.3 Validation Limitations

The results from Sections 3.1 and 3.2 illustrate that aggregate and trend comparisons between LUCIM predictions and actual data suggest robust predictive power for LUCIM in the context of the study objectives to determine the systemwide ridership distribution across modes for intercity passenger travel over the long-term. In that sense, the validation process achieves its objectives, and indicates that LUCIM can aid in analyzing the viability of a proposed HSR system in the Midwest corridor. Also, due to the focus on systemwide analysis, link-level and route ridership are outside the scope of the current study.

Disaggregate-level validation, while not necessary due to the study scope, can provide insights on the level of robustness associated with the predictive power of LUCIM. We explore this aspect using Amtrak’s Michigan service lines composed of the Amtrak's Blue Water, Wolverine, and Pere Marquette routes. These are the only routes that originate and end in Michigan. The 2010 Amtrak report states that the total ridership for these routes is 797,000 (Amtrak, 2011b). The LUCIM prediction of trips that originate and end in Michigan underestimates this by about 11% (at 707,000). As discussed in Section 2.4.2.1, this is because LUCIM only considers intercity trips between counties within the six-state study region and does not include trips that originate or terminate outside the region or pass through the region. All other routes in the study region are much less bounded, and could be even more prone to "out-of-region" problems than the Michigan service lines case.

A complete disaggregate validation could be performed if the level of regional disaggregation was based on population/station centers rather than counties, but the available data to build the model is limited at this level. It should be reiterated that the formal methodology presented in this study allows for any level of disaggregation and is not limited to county-level data. Also, since the purpose of this study to analyze the long-term systemwide aggregate ridership shifts due to HSR, counties offered the lowest level of disaggregation with sufficient data at the sacrifice of the ability to validate individual station ridership. Despite this limitation, the aggregate and trending validation provides sufficient reassurance that LUCIM can forecast long-term systemwide ridership with HSR.

Table 3.1 Comparison between observed and LUCIM-predicted PMT in the study region

Mode	**Ridership share of total PMT**	
	2001 NHTS	**2001 LUCIM Predictions**
Personal Vehicle	97.00	97.21
Commercial Air	2.62	2.44
Amtrak	0.38	0.35

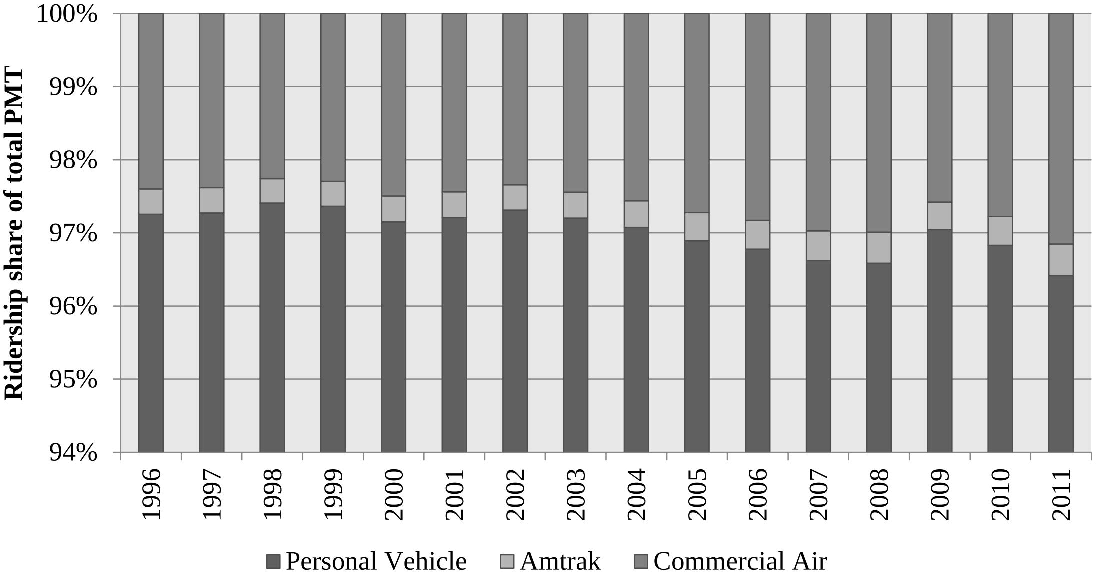

Figure 3.1 LUCIM ridership predictions for 1996 to 2011 based on observed population, fuel efficiency, and fuel price

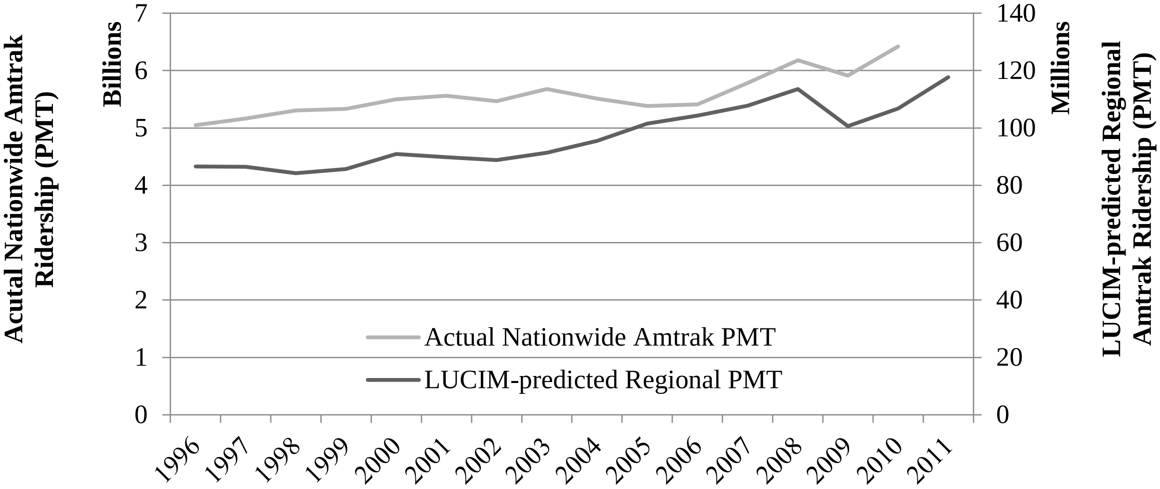

Figure 3.2 Comparison of actual nationwide Amtrak PMT trend versus LUCIM-predicted trend for the study region

CHAPTER 4. EXPERIMENTS AND DISCUSSION

Chapter 4 presents the experimental scenarios which demonstrate the capability of the methodology and provide an example given the stylized Midwest corridor network and assumptions described in Section 2.3. Section 4.1 summarizes the experimental scenarios and discusses their importance. Section 4.2 describes and shows results for the experimental scenario without a HSR network. Section 4.3 describes the experimental scenario with the stylized HSR network and provides a with-without comparison in ridership estimates. Section 4.4 provides a detailed impact assessment in terms of travel time, safety, vehicle operating cost, CO_2 emission, and energy consumption savings given the with-without comparison.

4.1 <u>Experiment summary (include IA)</u>

Two experiments were conducted to compare various HSR scenarios. First, an Amtrak-only scenario without HSR (no-build) is used as a baseline case for comparison with the second experiment where HSR is introduced with an alternative-specific constant (ASC) identical to commercial air travel. This may be a meaningful preliminary experiment considering the planned expansion of service and frequency for HSR. The two scenarios show the ridership shifts for all modes in the multimodal transportation network. Sensitivity analysis of HSR ridership is performed to illustrate the capabilities of the model to test important design considerations. All experiments cover the period 2012 to 2050, with the baseline demographic, economic, and technological trends discussed in Section 3.1. The ridership from these two experiments are used to determine the travel time, safety, and vehicle operating costs in dollars and CO2 emission and petroleum consumption in physical units (metric tons and gallons).

4.2 2012-2050 No-build scenario

The first experiment assumes that no HSR is built from 2012 to 2050. Figure 4.1 shows the ridership distribution in PMT during this period. There is a strong shift from the road mode to the air mode due to rising fuel prices dominating the increase in fuel efficiency of passenger vehicles. This is due to the greater fuel price sensitivity in travel cost than for the air mode. A large shift to the air mode may magnify the issues arising from the current air capacity problems. Ridership by personal vehicle increases due to lower cost of travel as fuel efficiency continues to increase and fuel price increases level off. The rail mode ridership share reaches a maximum of 0.56% in 2029. This is a 30% increase from 2011 and 50% increase in passenger-miles traveled; however, the ridership share remains small in comparison to the other intercity modes.

Figure 4.2 illustrates the ridership growth in the commercial air and passenger rail mode in relation to the rising cost of fuel (Figure 2.3) and improved fuel efficiency. Ridership on Amtrak lines grew 6.5% from FY2010 to FY 2011 and 2.7% for just the first six months of FY 2012. The results from LUCIM show sustained growth in passenger rail and air modes due to rising fuel costs.

4.3 2012 - 2050 High-speed Rail with commercial air alternative-specific constants

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 a trend of potential 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. Average speed for each segment on the proposed HSR network must be input to compute travel time. While any average speed for high-speed rail can be used, 180 miles per hour was chosen over all segments for these long-run experiments because newly-built and planned HSR systems in China, and elsewhere, are capable of such speeds (Amos, Bullock, and Sondhi, 2010). Cost for each route is derived from the formula in Section 2.3.1.1.

Figure 4.3 shows the results from the LUCIM model with the proposed HSR network. The majority of the total rail ridership is in the Amtrak mode. This is a result of Amtrak use as a feeder to the HSR system (Figure 2.4(c)). The total rail ridership peaks in 2029 at 6.0% of the total intercity PMT with 3.9% from Amtrak lines and 2.1% from HSR. Furthermore, most of the additional ridership is from a shift from the road mode compared to the commercial air mode.

Figure 4.4 shows the sensitivity of the HSR ridership with respect to the average HSR design speed. The long-run HSR average speed elasticity of ridership decreases from 1.15 between 110 and 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. 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.

4.4 Impact assessment of high-speed rail in the Midwest Corridor (2012-2050)

Figure 4.5 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 (Figure 4.3), 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. Because personal vehicles remain the predominant mode of travel, the total savings are 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 4.6). Petroleum usage in electricity generation is approximately 1% of total electricity generation. 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 CO_2 than without HSR; however, the net petroleum consumption and CO_2 emission savings are positive. Savings could be increased with the electrification of Amtrak trains in the Midwest. The estimated annual net savings of CO_2 is between 200,000 and 300,000 metric tons beyond 2020 (Figure 4.7).

The nationwide transportation sector in the United States consumes approximately 206 billion gallons of petroleum and emits 1.8 billion metric tons of CO_2 per year. The fuel consumption and CO_2 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 CO_2 emissions in the transportation system alone, signifying that while HSR does have energy and environmental benefits, they are relatively small (BTS, 2011). 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 (BTS, 2011). Based on the experiments, 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.

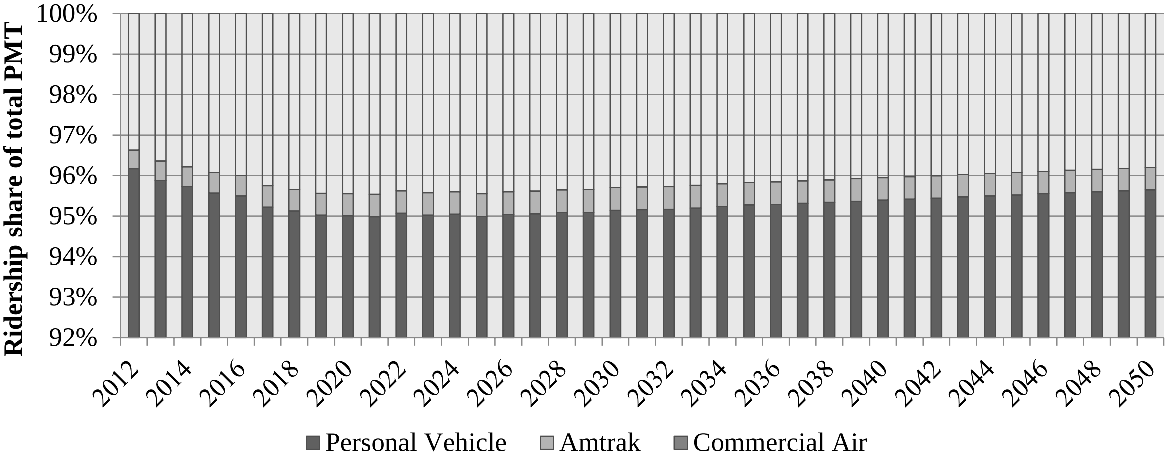

Figure 4.1 Ridership share of Midwest corridor intercity travel market (No HSR) (34.5 billion system-wide PMT in 2012 and 51.1 billion system-wide PMT in 2050)

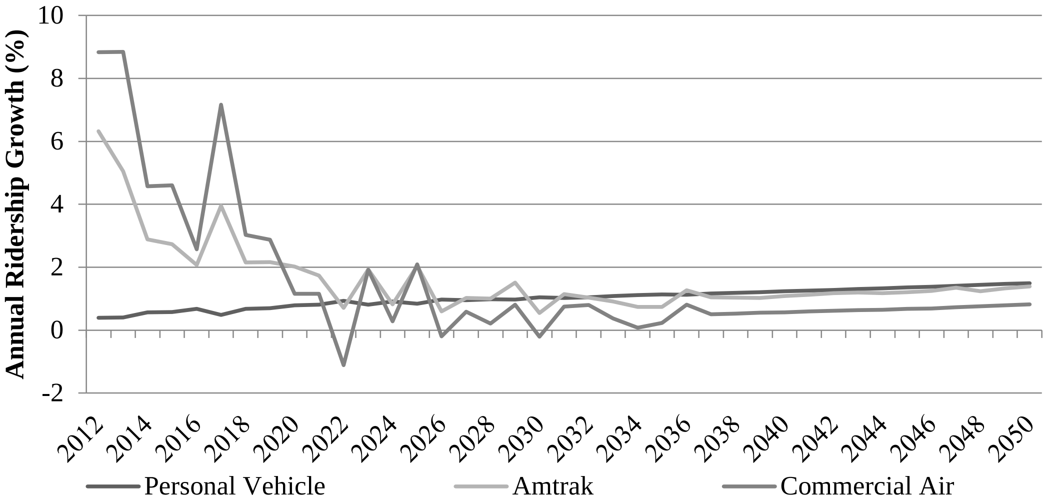

Figure 4.2 Modal ridership growth as a function of time (No HSR)

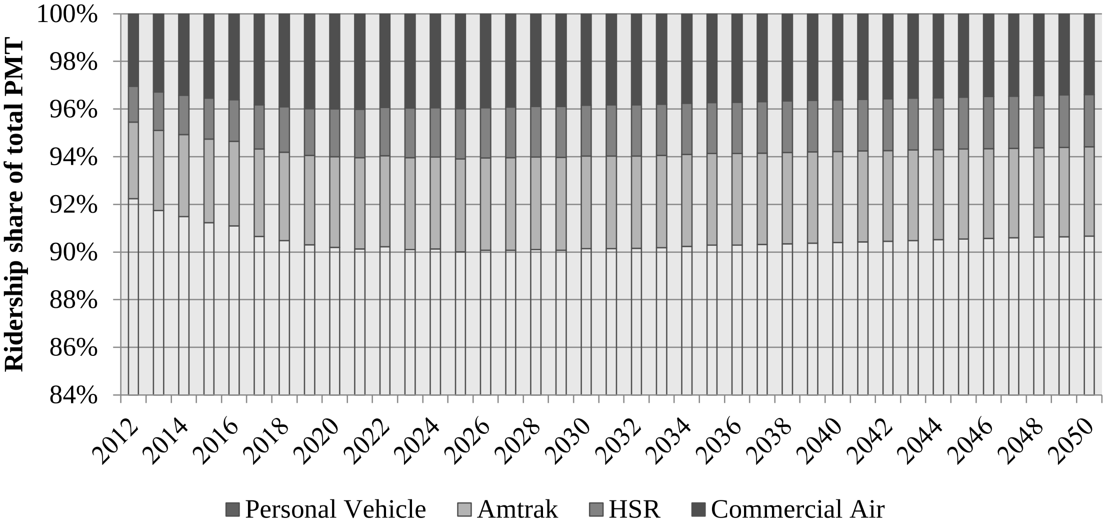

Figure 4.3 Ridership share of Midwest corridor intercity travel market for HSR (35.4 billion system-wide PMT in 2012 and 52.4 billion system-wide PMT in 2050)

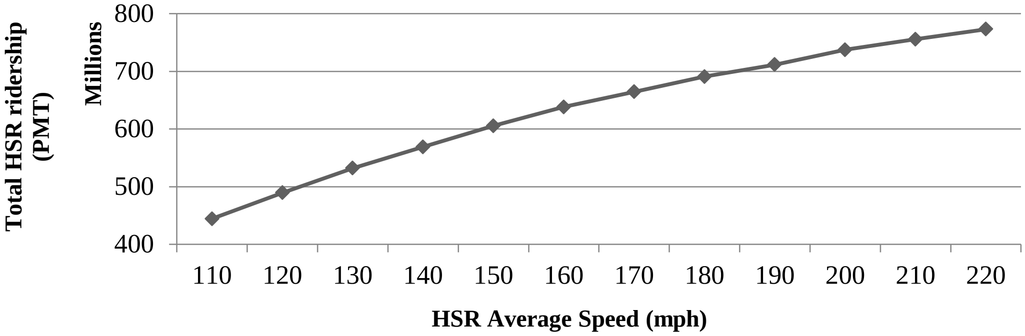

Figure 4.4 HSR ridership (PMT) as a function of HSR average speed in the year 2030

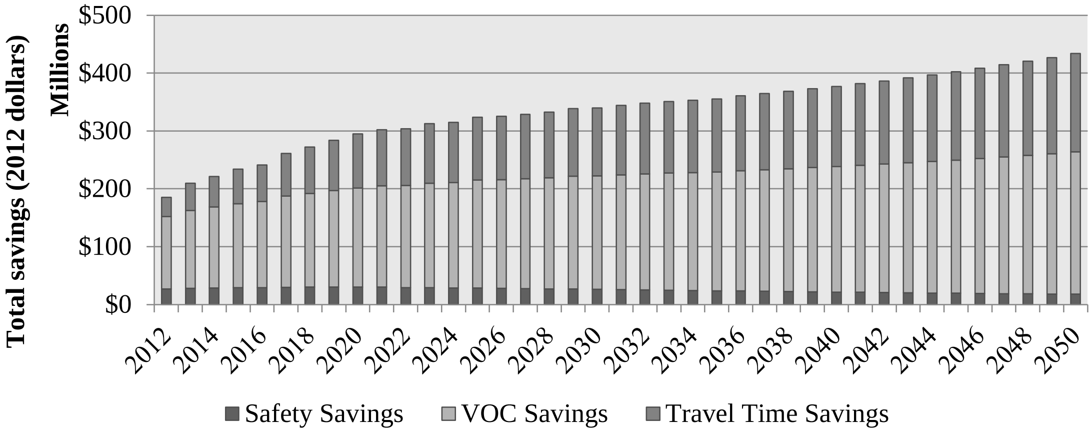

Figure 4.5 Annual monetized travel time savings, safety, and VOC savings from 2012 to 2050 for HSR compared to no-HSR case (2012 dollars)

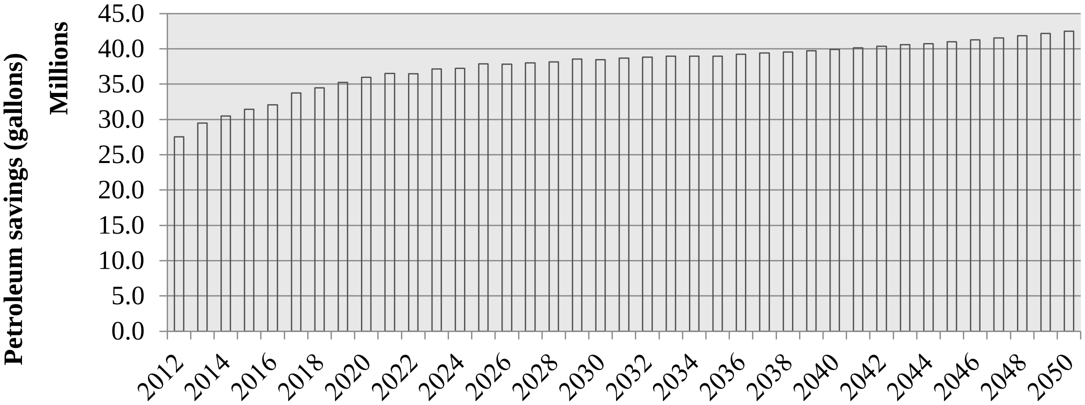

Figure 4.6 Petroleum consumption reduction from 2012 to 2050 for HSR compared to no-HSR case

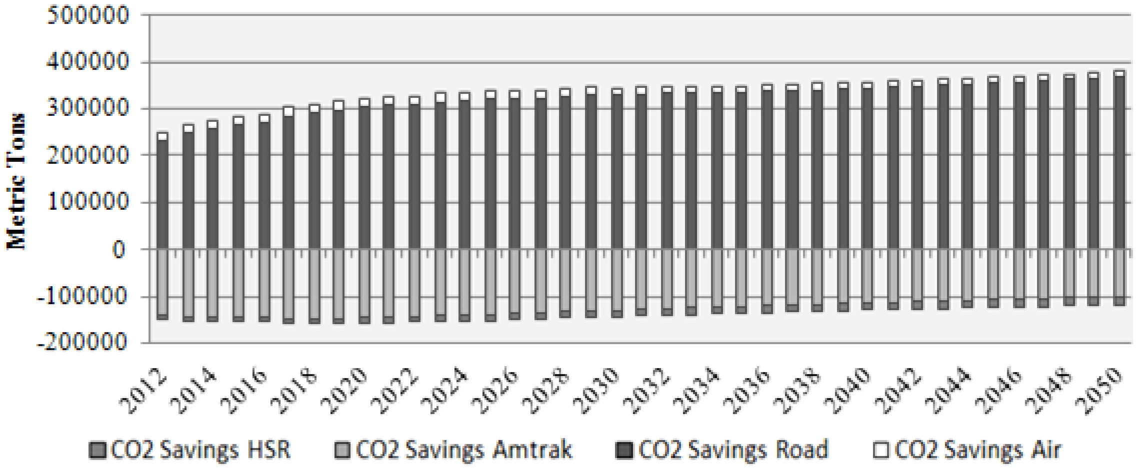

Figure 4.7 CO_2 savings from 2012 to 2050 for HSR compared to no-HSR case

CHAPTER 5. CONCLUSIONS

This chapter summarizes the research, highlights its contributions, and proposes directions for future research. Section 5.1 summarized the research and highlights significant results and contributions. Section 5.2 proposes possible future directions for this research.

5.1 Summary

Much of the current uncertainty and debate regarding the potential for HSR as a viable alternative in the multimodal transportation network is based on ridership. This study develops a systematic model (LUCIM) which provides robust predictions of long-term modal ridership shares due to sensitivities to economic, demographic, and technological trends. The model is validated against actual data at a systemwide level and reasonably captures ridership responses to evolving exogenous stimuli such as fuel prices. This provides planners and policymakers with a robust, systematic methodology for analyzing the viability of a proposed HSR network over the long term.

Furthermore, the approach adopted in this study 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 study 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.

Experimental results from the study scenarios show that if operational characteristics were improved to match that of air service in terms of frequency, comfort, etc., HSR has the potential to see ridership on the order of 50 to 60 million riders annually. MWHSRA predicted ridership of 35 and 44 million annually for 130 mph and 160 mph average speeds, respectively. The LUCIM-predicted 6% market share of intercity travel in the Midwest is a little lower than the 7-8% ridership shift predicted in the California HSR study (Cambridge Systematics, 2007). Considering the difference in underlying assumptions in the models, study areas, and the inherent error in prediction in the long-term, these results are surprisingly similar. The projected ridership is at a level high enough to warrant future research in HSR in the Midwest corridor. Furthermore, the results demonstrate that there will be a continual ridership shift to passenger train as fuel costs increase for the alternative modes in the long-run until there reaches a point when vehicle efficiency can offset these costs. This, along with the average HSR speed sensitivity analysis, shows the capabilities of the model with respect to important HSR design considerations (e.g., average speed, fare price, projections in exogenous variables).

Based on the experimental assumptions adopted from previous HSR ridership forecasts, 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. 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 CO_2 emissions in the United States. Since intercity trips account for only about 30% 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 intracity rather than intercity level.

5.2 Future research directions

While new and different scenarios are enabled by the flexibility of the LUCIM model used in this study, there remain some limitations and opportunity for improvement of the LUCIM methodology.

First, results shown here may warrant much deeper investigation into model (Table 2.1), especially with respect to introducing induced demand and congestion effects into LUCIM. Also, refining experimental assumptions (Table 2.2) by conducting region-specific mode choice surveys and adding LOS characteristics of a proposed HSR service in the Midwest corridor would more accurately estimate both ridership and provide a more complete picture of HSR as part of the intercity, multimodal transportation network.

Second, capital, maintenance, and operating cost factors may be added as they are specifically left out of this analysis. Additional costs and savings (e.g., non-CO_2 emissions and pollutants, noise) could be included without much modification within this framework. A complete cost-benefit analysis could be conducted by including these costs.

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.

The authors welcome comments and collaboration to further develop or apply the LUCIM model.

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