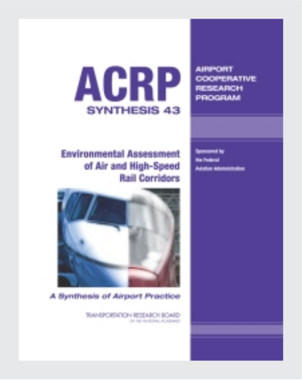

Environmental Assessment of Air and High-Speed Rail Corridors

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AUTHORS

Chester, Mikhail; and Smirti Ryerson, Megan

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP SYNTHESIS 43

Environmental Assessment of Air and High-Speed Rail Corridors

A Synthesis of Airport Practice

Consultants
Mikhail Chester
Arizona State University
Tempe, Arizona
and
Megan Smirti Ryerson
University of Pennsylvania
Philadelphia, Pennsylvania

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FOREWORD

Airport administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the airport industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire airport community, the Airport Cooperative Research Program authorized the Transportation Research Board to undertake a continuing project. This project, ACRP Project 11-03, “Synthesis of Information Related to Airport Practices,” searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an ACRP report series, *Synthesis of Airport Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Gail R. Staba
Senior Program Officer
Transportation
Research Board

There is significant experience and research on the competition and complementarity of air and high-speed rail (HSR) modes. In synthesizing the body of literature, reviewers focused on government-driven environmental comparisons and academic literature. Both government environmental reviews and academic studies have provided valuable insight into comparative assessments of air and HSR systems; however, institutional mechanisms coupled with methodological advances and tool development are needed to ensure that future long-distance transportation systems are deployed in ways that minimize impacts while improving mobility.

Mikhail Chester, Arizona State University, Tempe, and Megan Smirti Ryerson, University of Pennsylvania, Philadelphia, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

ENVIRONMENTAL ASSESSMENT OF AIR AND HIGH-SPEED RAIL CORRIDORS

SUMMARY

There is significant experience and research on the competition of air and high-speed rail (HSR) modes. The existing research covers areas including system structure (vehicle technology, cost, ridership, etc.) and environmental effects. The objective of the Environmental Assessment of Air and High-Speed Rail Corridors synthesis is to bring together research and other findings related to air and HSR environmental assessments and to understand where additional research can improve our ability to assess the environmental outcomes of these two systems. A literature review is the primary tool for collecting data for this synthesis of current practice.

The literature revealed that there are two approaches to categorizing air and HSR assessments: attributional and consequential. Attributional assessments look backward from some point in time and are used to allocate the environmental effects to passenger travel, a trip, or vehicle travel. Consequential assessments look forward as a result of a system change and can be used to determine the changes to the total regional environmental effects caused by a particular decision.

The air and HSR modes, although sometimes overlapping, are structured differently. The aviation system is structured as a system of nodes (i.e., airports) connected with aircraft operated by independent operators. The spatial scale of the nodes is vast, such that passengers can travel between nodes in a region or in two separate countries. Conversely, the HSR system is structured as a system of links, with the spatial scale being limited to a fixed regional area between major cities and the regions between. In contrast, aviation is not planned in corridors. Airports are planned to serve a region, and airlines connect this region to their hub airports and possibly some additional airports. That these two networks may have some overlapping portions yet serve different scales of network presents a complexity when defining the system structure for an environmental assessment. The result is *spatial incompatibility* between modes; rail service is planned in corridors, whereas air service is planned over a national and global network.

Spatial incompatibility across modes makes it difficult to compare environmental assessments. Most studies consider air and HSR to be “competitive corridors,” whereas a few view the broader aviation system network and HSR services to be complementary when nearby regions are linked with an airport. The fundamental differences in air and HSR environmental assessments impede the drawing of the analytical system boundary for environmental assessments; aviation is a system of nodes with the planning focused on airports, and rail is a series of nodes connected by links with the planning focused on specific corridors.

The synthesis focused on two types of literature: government-driven environmental impact assessments and academic. Government-driven environmental impact assessments are in the form of National Environmental Policy Act (NEPA) studies. However, considering the spatial incapability of the two modes, assessing if aviation meets the needs of an HSR project, and vice versa, is a highly complex process. As a result, few detailed modal assessments are found in EIS documents. Those that are present are consequential assessments that focus on a full range of effects to resources consistent with the NEPA process. Government-driven work provides an

important framework for assessing air and HSR environmental comparisons, yet the language of NEPA alternatives assessments can preclude a full, detailed analysis of modal alternatives.

Although there is a growing body of academic literature that seeks to reconcile spatial incompatibility, the academic literature is not bound by the same legal and institutional protocols of the environmental review process and therefore does not have to draw a constrained system boundary. Academic literature is free to compare any modes, regardless of whether they are implemented, programmed, or conceptual. The following is a sample of results from academic literature:

- The substitution of air by HSR was found to reduce NO_x, CO, hydrocarbon (HC), and PM_{10} emissions but increase SO_x by a factor of 12 owing to the sulfur content of primary fuels for electricity generation (Givoni 2007). Givoni's (2007) attributional assessment finds that between Paris and London there were significant reductions in criteria air pollutants (CAP) between air and HSR, respectively (18 to 0.4 g/seat HC, 126 to 2.2 g/seat CO, 71 to 18 g/seat NO_x, 2.9 to 35 g/seat SO_x, and 2.0 to 1.0 g/seat PM_{10}).
- A consequential assessment by Jamin et al. in 2004 found that substituting one-third of air travel for HSR in the relevant corridors increases SO_x emissions across the corridors from 100 to 2,000 tons and decreases NO_x (5,000 to 4,200 tons), HC (2,200 to 1,900 tons), and CO emissions (6,100 to 4,200 tons). This could be important when assessing human health and environmental impacts and would depend on where the emissions occur. Increases in sulfur emissions may result in acidification of soil and groundwater and occur from changes in operation and propulsion energy inputs and life-cycle effects (Chester and Horvath 2012).
- In 2002, the European Commission found that people are generally more annoyed by aircraft noise than rail noise, with highway noise falling between these two modes. In 2011, Eagan and Mazur noted that although this certainly has to do with acoustic factors, it also has to do with attitudes toward the noise source.
- Along with their spatial incompatibilities, air and HSR can have differing noise profiles. Aircraft noise is primarily a concern for near-airport operations because of the occurrence of low-altitude flight. Because HSR involves a system of links between stations, HSR noise may or may not occur predominantly at the nodes because of a combination of mitigation possibilities (FRA 2005a), the population density near tracks, and operation characteristics. In general, there is less impact expected near HSR stations than along the route.
- Air transport typically requires less land per passenger trip than does HSR transport (Rus 2011). Airport land-take occurs when the airport sees a need for capacity expansions, whereas land use impacts from HSR are dependent on the length of HSR line and the environment along the line, not the volume of traffic in the corridor.
- Furthermore, it is important that growth-inducing impacts on surrounding land be considered. Both air and HSR systems have the potential to create indirect land use impacts through new residential, commercial, and industrial activities near airports and train stations (Janic 2003).
- In 2007, Givoni's attributional assessment found that between London and Paris the CO_2 emissions from HSR travel were 7.2 kg/seat and from air travel 44 kg/seat.
- In 2003, Janic's attributional assessment estimated that the French HSR service (the TGV) emitted 4 g CO_2 per passenger-kilometer traveled (89% nuclear electricity), the German HSR service (the ICE) 28 g (50% coal electricity), and a competing flight between 100 and 150 g. These emissions combined with other damages (i.e., other air pollution, noise, land use, congestion, and accidents) are used to monetize the external costs of HSR and air travel, respectively, at Euros 0.002 to 0.01 and 0.02 to 0.08 per passenger-kilometer traveled in the United States and Europe.
- Chester and Horvath in 2012 included roughly 150 life-cycle components in the assessment of future long-distance travel in California and, by first using an attributional approach, found that although HSR is likely to produce lower greenhouse gas (GHG)

emissions per passenger-mile traveled, an average occupancy of 130 to 280 passengers is needed to compete with emerging aircraft and one of 80 to 180 passengers to compete with a 35-mpg sedan. Chester and Horvath then developed a consequential assessment to determine that, given future HSR adoption uncertainty, GHG payback will occur between 20 and 40 years, which includes emissions from construction and maintenance activities. The authors included modeling of emerging technologies, regional flight characteristics (instead of multiplying a per seat-mile factor across forecasted seat-miles), and uncertainty in mode shifting.

- Givoni (2007) computed the environmental benefits of mode substitution for air and HSR by estimating the aircraft, access/egress, aircraft journey, and HSR journey air pollution externalities per seat between London and Paris. He found that the external costs of travel on HSR are 0.52 Euros per seat and on air are 1.03 Euros. Janic (2003) monetized air emission externalities and estimated that the marginal costs of HSR travel generally are lower than those for air travel in Europe, but Janic did not assess the total costs of each system.

In investigating the role of air and HSR as competitors and complementary modes, understanding ridership is a crucial component. Several studies cite the importance of accurate ridership forecasts to understand the environmental outcomes of future long-distance transport systems. Some studies explore the sensitivity of environmental performance to ridership. Other studies focus on understanding the long-run per passenger-mile traveled footprint of passengers to understand the environmental intensity of service. Per-trip measures are common and valuable for eliminating the differences in trip distances to reach the same origin-destination pairs.

In an effort to produce unifying analytical boundaries and metrics for comparing air and HSR systems, the following assessments are used in academic literature: life-cycle assessment (LCA), impact assessment, and benefit-cost analysis. LCAs of air and HSR systems can include vehicles (manufacturing and maintenance), infrastructure (construction, operation, and maintenance), and energy production (primary fuel feedstock extraction, processing, and distribution) components. LCA results for a future California network that includes air and HSR show that (1) for air, life-cycle components can increase the mode's footprint by roughly 20%, and (2) for HSR, concrete and steel used in infrastructure construction may double the GHG footprint of the mode. Significant research and efforts have been made by the aviation industry and academics to understand the human health impacts of near-airport operations. Although GHG emission comparisons are critically important, it is also important that future studies consider other pollutants. By defining sustainability and environmental impacts broadly, opportunities will exist for understanding how the (1) reduction in one environmental concern may lead to a reduction in another, or (2) reduction in one environmental concern may lead to an increase in another; that is, an unintended trade-off. Finally, the development of an HSR cost model presents a unique set of challenges compared with the development of an aircraft cost model. Because HSR projects are built over various topographical landscapes, different technical solutions and levels of investment are needed. Although some studies have attempted to quantify the economic benefits of air travel, similar HSR benefits for a region are not well understood. Various studies in this area range from developing social welfare functions to assess transportation infrastructure investments, to developing a framework to justify HSR projects, to computing the environmental benefits of mode substitution for air and HSR.

Through the synthesis of the literature, major gaps in knowledge were found:

- Methodological frameworks and tools that assess future operating characteristics of long-distance transportation service have not been fully developed. Such frameworks and tools must address the two main components of the relationship between air and HSR: as competitors and as complementary modes.

- A framework and methodology are needed to analyze the impact to airline operations, and thus airport infrastructure use, of development of HSR. The same goes for the "no build" alternative: estimating the future of aviation flows in the absence of HSR infrastructure is necessary.
- By performing consequential assessments instead of attributional assessments, organizations will have information about the outcome of decisions that affect air and HSR systems. The consequential assessment will require an understanding of how up-front investments will lead to regional operating effects. Although NEPA in many ways requires a consequential assessment, the academic literature has for the most part avoided these quantifications, likely because of the complexities of accurate estimates.

In conclusion, environmental assessments of air and HSR systems have produced valuable knowledge but the creation of novel data analysis and methods will improve our understanding of future networks that house both modes. The large body of literature reviewed does not lead to a single cohesive conclusion relating air and HSR comparative environmental analysis. By establishing regional planning processes, drawing on previously established methods, and developing new tools and information for better understanding future processes, more comprehensive approaches can be developed to better understand the co-benefits of intelligent air and HSR planning.

CHAPTER ONE

INTRODUCTION

In accommodating surging intercity transportation demand during an era of unprecedented environmental concern, understanding the environmental trade-offs and co-benefits of air and high-speed rail (HSR) transportation is critical for producing high-quality information for decision makers. An analysis of the environmental impacts of air and HSR competition or complementary service in a region is only as strong as the uncertainty that is introduced by an analytical framework that does or does not (1) accurately account for the conditions under which future U.S. systems will operate, (2) model these conditions in a way that is true to actual operation, or (3) understand the potential future scenarios for air and HSR transportation. This is additionally complicated by institutional processes that preclude certain methodological approaches. Environmental assessments of these systems consider a comprehensive list of human health, ecosystem services, climate change, and resource depletion impacts from deploying different modes such that a broad suite of concerns are assessed simultaneously, leading to early identification of unintended trade-offs and the opportunity for cost-effective strategies that lead to environmental burden reduction. As the United States begins to ask questions about long-distance transportation futures, an integrated framework is desirable to guide transportation planning and investment decisions toward solutions that lead to sustainable travel.

In the following chapters, published literature on environmental assessments of air and HSR systems is synthesized. Academic publications and government studies are the focus of the synthesis, with nonprofit and private sector organizations discussed where relevant. In the literature, the focus is on government-driven environmental comparisons and academic literature. Government-driven environmental comparisons are in the form of National Environmental Policy Act (NEPA) studies. From these studies, the role of NEPA in environmental assessments and how the spatial incompatibilities of air and HSR systems and the scope of purpose and need statements complicate the full consideration of air and HSR as alternatives are explored. Academic studies are present in the literature focusing on one or a suite of pollutants. The literature synthesis finds many existing research studies that focus on criteria air pollutants, noise, land use, energy, and greenhouse gas (GHG) emissions, with the latter two being the focus of much of the academic work. Significant literature and methods provide a solid footing for deploying a consistent and comprehensive framework for air and HSR environmental assessment in the United States; this solid footing is not without gaps in the literature. These gaps are both procedural and analytical, such that they can be filled through research extensions, novel methods, or the appropriate tools or data. This document has been developed to identify these gaps and provide direction from the existing literature for how future environmental assessments of long-distance travel can be structured to provide the highest quality information for decision makers.

The literature synthesis categorizes air and HSR assessments into two approaches: attributional and consequential (Ekvall and Weidema 2004). Attributional approaches are designed to allocate the energy and environmental outcomes of air and HSR systems to passenger travel, a trip, or vehicle travel, considering average data over the long run of the system. Attributional assessments consider the system at a fixed point in time and evaluate backward in their allocation of effects. Consequential approaches, which the government environmental review process uses, are designed to assess the environmental impacts of decisions or changes to the long-distance transportation system and use marginal impacts in assessments. Consequential assessments are not for a given operational profile but rather for an operational profile that results from the decision to alter long-distance transportation service. Changes might include the implementation of an HSR system, new pricing policies for passengers, and a restriction of operations at a particularly busy airport, among others. As a result, consequential assessments involve assessing mode shifting and the interplay between multimodal travel (Givoni 2007; Chester and Horvath 2012; Behrens and Pels 2012), as well as mathematically determining the resulting environmental effects.

Both approaches have independent value. Attributional assessments are valuable for understanding the critical factors that in long-run average conditions lead to the greatest impacts for that mode. Consequential assessments are valuable for understanding how a policy or decision will affect long-distance travel and lead to corridor or regional environmental effects and how that may contribute to large-scale environmental goals. The following chapter addresses complexities in air and HSR environmental assessments and how they affect attributional and consequential assessments.

CHAPTER TWO

SPATIAL INCOMPATIBILITY

The scale and structure of the air and HSR systems and how they relate to the two systems' environmental assessment is of critical importance. The structure of the aviation system is fundamentally one of a system of nodes, or airports, connected with aircraft operated by independent operators. The spatial scale of the nodes is vast, such that vehicles and passengers can travel between nodes in a region or in two separate countries. In contrast, the structure of the HSR system is a system of links, with the spatial scale being limited to fixed regional and limited interregional market. This *spatial incompatibility*, where air and HSR networks may have some overlapping portions yet are serving a different scale of network, leads to complexity in defining the system structure for an environmental assessment. It leads to multiple scopes of environmental studies, with some studies considering air and HSR travel to be "competitive corridors" and others considering the broader aviation system network and that HSR can provide complementary service by linking nearby regions with an airport. In the following section the spatial attributes of air and HSR systems, spatial incompatibilities between the two, and the implications for assessments are explored.

CORRIDOR-BASED HIGH-SPEED RAIL SYSTEM

HSR systems are deployed around the globe. Japan's Shinkansen was the first HSR operating service; it went online in 1964, in time for the Summer Olympics held in Tokyo that year. The line now achieves speeds of 185 mph and connects 1,500 miles across the country. In Europe, Italy began service in 1978, connecting Rome and Florence; Spain, Germany, Belgium, Great Britain, and France now have lines with speeds as great as 150 mph. Although HSR in other countries is a mature mode of travel, there is limited HSR experience in the United States: specifically, the Acela. Federal statutes and policies have incentivized corridor-scale HSR planning in the United States. U.S. HSR national corridor planning began with the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), which called for the Office of the Secretary of Transportation to designate as many as five HSR corridors, with lines achieving speeds of at least 90 mph. Since then, six additional corridors have been designated; the most recent is the Northeast Corridor, added in March 2011 by Transportation Secretary Ray LaHood (FRA 2012a). The corridors are shown in Figure 1. Federal designation status is not an indication that the infrastructure for these corridors is funded or that the corridors are in a specific phase of project delivery; instead the designation status indicates that the corridors are national transportation priorities. Although ISTEA set the federal precedent for designating HSR corridors, the Passenger Rail Investment and Improvement Act of 2008 (PRIIA) established the first comprehensive legislative framework for planning, developing, and funding high-speed rail. PRIIA authorized several new federal grant programs for implementing new rail services or substantially improving existing services, which were consolidated by FRA into the High-Speed Intercity Passenger Rail (HSIPR) program. The American Recovery and Reinvestment Act of 2009 jump-started the HSIPR program with the largest-ever U.S. investment in HSR, appropriating $8 billion for "projects that support the development of intercity high speed rail service" (FRA 2009a). An additional $2.1 billion was provided in the fiscal year 2010 appropriations. The HSIPR program is a discretionary, competitive funding program, in which states apply for federal funding and FRA selects projects based on the evaluation and selection criteria defined in PRIIA.

The term "high-speed rail" has been used to describe many different types of rail systems; however, the FRA has adopted formal definitions based on speed (FRA 2010). The FRA's National Rail Plan identifies three tiers of rail travel. Core express corridors (Tier 1) connect large urban areas as much as 500 miles apart with lines at speeds between 125 and 250 mph on dedicated electrified passenger track. Regional corridors (Tier 2) connect midsize urban areas and have lines with 90- to 125-mph service on a mix of dedicated and shared track. Emerging or feeder routes (Tier 3) connect to the core or regional corridors and have lines with speeds as high as 90 mph; Tier 3 routes give remote areas access to the national rail system.

NODE-BASED AVIATION SYSTEM

In contrast to the rail corridor framework, aviation system infrastructure is node-based. The physical infrastructure is located at airports and not along the links; although air traffic management technologies facilitate trajectories between airports, the physicality of rail links is not present in the aviation system, so aviation system planning is rooted in airport development. The movement toward NextGen and performance-based management procedures will affect aviation's environmental footprint; however, systemwide envi-

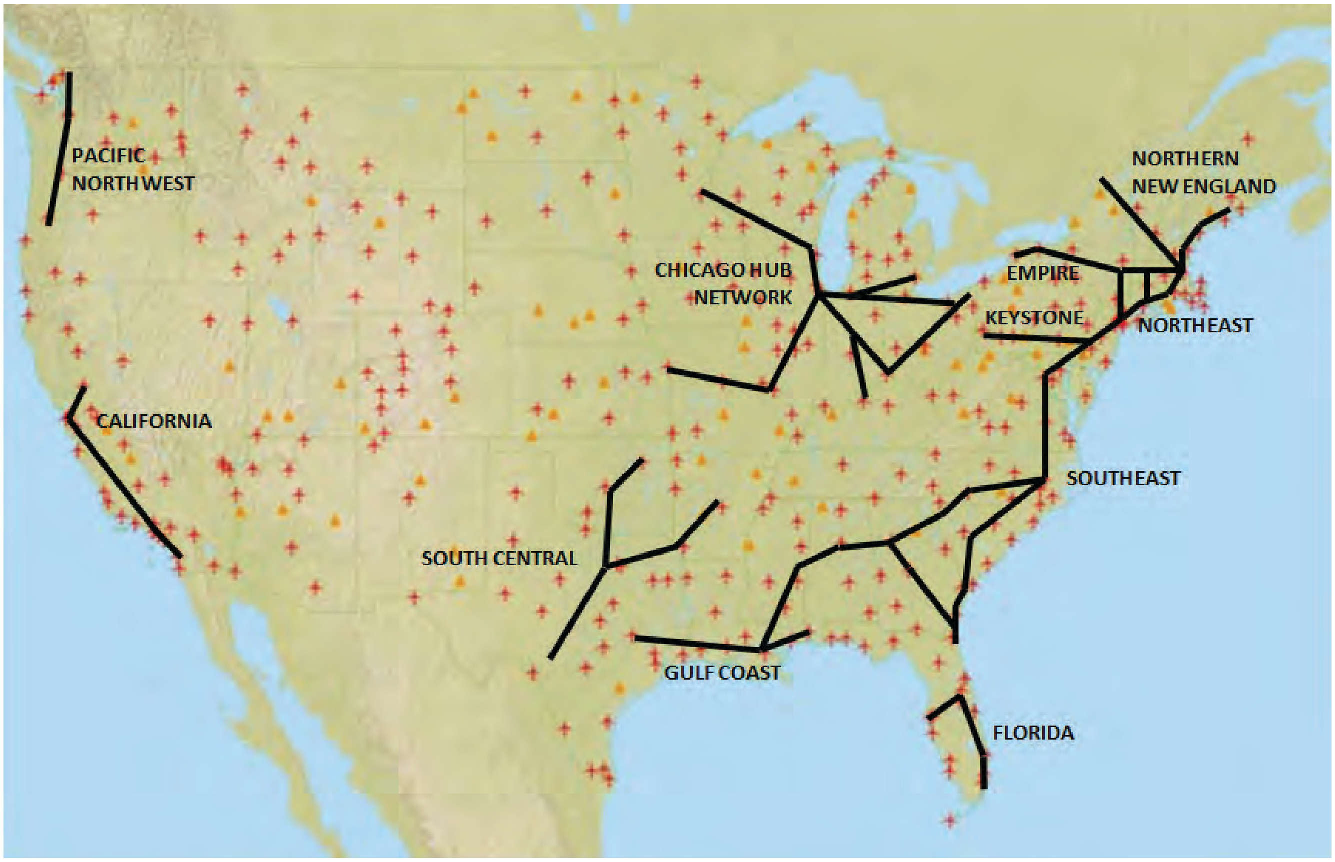

FIGURE 1 NPIAS commercial service airports with HSR corridors (adapted from FRA 2012a and FAA 2010). ✈ : primary airports; ▲ : commercial service airports.

ronmental outcomes are governed somewhat by airport infrastructure. Figure 1 shows the U.S. airports eligible for federal Airport Improvement Program funding (FAA 2010). Although airport funding is different globally, the concept of airports as nodes and HSR as a system of links persists globally.

SPATIAL INCOMPATIBILITY, COMPETITION, AND COMPLEMENTARITY

Consider Figure 1, which shows the designated HSR corridors in the United States overlaid on the National Plan of Integrated Airport Systems (NPIAS) commercial service airports map. HSR designations are termed “corridors” because that is the way they are planned: rail track between major cities and the regions between. Corridor planning has occurred for areas such as California, connecting the Bay Area with Los Angeles (and beyond), and the Northeast, linking Boston, New York, Philadelphia, and Washington, D.C. Aviation, in contrast, is not planned in corridors. Airports are planned to serve a region, and airlines connect this region (depending on many factors, including demand) to their hub airports and possibly some additional airports for point-to-point (PTP) service. The result is *spatial incompatibility* between modes; rail service is planned in corridors, whereas air service is planned over a national and global network. Assessing the region that rail travel affects generally is a more straightforward process than is doing so for aviation travel. When considering intercity passenger flows, they are either:

- PTP, such that air and HSR are competitors, or
- From an origin city to a transfer city, or hub city (point-to-hub or PTH), and then on to a distant destination city.

Although both air and HSR systems serve an overlapping market, the scope of the air system is spatially different from that of the HSR. There is an overlapping portion: the PTP and PTH travel. However, PTH passengers traverse the common corridor and then must take the air mode to travel to a distant city. HSR systems can play two roles from the perspective of air systems: they can be competitors, fighting for passenger traffic over a corridor (PTP), or they can be complementary modes, with HSR feeding passengers from the surrounding region to the airport for long-haul flights (PTH). The impact of system change on the operational profile of HSR and air travel will depend on how the air and HSR systems interact: as competitors and as complementary modes.

Consider the example of the California Corridor and HSR service connecting San Francisco and Los Angeles. Airlines focused on the origin-destination market of Northern to

Southern California may find HSR to be a competitor, whereas airlines operating a hub network out of San Francisco International Airport or Los Angeles International Airport might use HSR as a feeder mode. This feeder mode could compete with existing short-haul connecting service, yet also expand the catchment area of the airport, and possibly effectively serve small markets that are less desirable to serve by air. (A complete discussion of global experiences in competition and complementarity is forthcoming in Airport Cooperative Research Program 3-23: Integrating Aviation and Passenger Rail Planning.)

This spatial incompatibility across modes creates a difficulty in defining the scope for comparative environmental assessments. For purposes of environmental assessments, it is necessary to scope the system down to a comparative common corridor. The literature has largely focused on air and rail as competitors over PTP service; Charles River Associates (2000) found the potential for complementarity to be insignificant. However, transportation has evolved greatly since this finding, and Coogan et al. (Airport Cooperative Research Program 2009), among others, propose that environmental assessments be based on an underlying operational profile that is estimated with the consideration that HSR systems provide feeder service to airports, as well as competitive PTP service.

Methodologies to evaluate the environmental benefits of HSR as a feeder mode to air travel have challenges. National Airspace System (NAS) capacity could be improved if some of these destinations reduced flight frequency, and one must account for the emissions from reduced flights and also from reduced congestion. However, the amount of congestion imposed by a short-haul feeder flight must be carefully estimated because it has been found that in certain cases short-haul flights have a high probability of being cancelled if there is capacity shortfall at the airport (Xiong and Hansen 2009). In addition, defining when HSR is a competitor and when it is a complementary mode is not clear-cut. If HSR is defined as a competitor when air does not reduce frequency and a complementary mode when air does reduce short-haul frequency because of redundancy, then under a competition approach, HSR would not significantly alleviate national-level congestion or emissions. The reduction of frequency, and how much, is a critical question. Airline seat capacity is lumpy, such that a few passengers switching to HSR may have no impact on airline seat capacity. The reduction of service could lead to improved airspace capacity, regional mobility, and emissions reductions because short-haul flights generally are on relatively inefficient aircraft [see Ryerson and Hansen (2010) and Ryerson (2010) for a full discussion]. Neglecting to consider the larger logistics problem of trip chaining discounts the potential benefits to the aviation system and regional mobility through the development of HSR.

The issue of spatial incompatibility is present for the majority, if not all, of HSR corridors. Hub connections comprise a large proportion of traffic at many airports that are also important nodes in the proposed HSR network in the United States. For example, for six cities that are located along designated HSR corridors, connecting traffic is 50% or greater: George Bush Intercontinental in Houston (IAH), Dallas/Fort Worth International (DFW), Chicago O'Hare International (ORD), Hartsfield–Jackson Atlanta International (ATL), Charlotte Douglas International (CLT), and Cincinnati/Northern Kentucky International (CVG) airports (FAA 2010). The result of this discussion is that the geographic scope of environmental assessments is generally limited to the geographic scope of HSR. However, air cannot be limited by such geography: an aircraft that is serving a redundant market may have 50% or more passengers who are using the aviation system for its network and not origin-destination travel.

SPATIAL INCOMPATIBILITY IMPLICATIONS

The fundamental difference in air and HSR environmental assessments is that because aviation is a system of nodes with the planning focused on airports and rail is a series of nodes connected by links with the planning focused on specific corridors, the drawing of the analytical system boundary for environmental assessments is impeded. In the following chapters this incompatibility is explored, including how it complicates environmental assessments through the determination of factors such as ridership, metrics, and others. In addition, the synthesis of government-driven and academic literature leads to a clear dichotomy of the literature. Government-driven work notes the role HSR can play as a feeder and as a competitor; however, owing to other complications to be explored, few detailed assessments have been performed. Although there is a growing body of academic literature that seeks to reconcile this spatial incompatibility [see Janic (2003); van Wee et al. (2003); Chester and Horvath (2012)], the academic literature is not bound by the same legal and institutional protocols of the environmental review process and thus does not have to draw a constrained system boundary. No overarching framework exists for joining the complementary results.

CHAPTER THREE

MODELING COMPLEXITY

RIDERSHIP

In investigating the role of air and HSR systems as competitors and complementary modes, understanding ridership is a crucial component. Several studies cite the importance of accurate ridership forecasts to understand the environmental outcomes of future long-distance transport systems (Burgess 2011; Wang and Sanders 2011; Behrens and Pels 2012; Chester and Horvath 2012). Studies also explore the sensitivity of environmental performance to ridership (Ryerson 2010; Sonnenberg 2010; Burgess 2011; Chester and Horvath 2012). Induced demand is cited as a critical input for understanding future HSR performance (Lynch 1990; Hensher 1997; Cheng 2010; Hsu et al. 2010; Ryerson 2010; Åkerman 2011; Burgess 2011; Carroll and Walton 2011). In circumventing the need for ridership forecasts, ridership has been considered parametrically (Ryerson 2010; Chester and Horvath 2012) or through assumptions. Chester and Horvath (2012) evaluate the regional environmental effects of varying levels of mode shifting to HSR. They start by setting the California High-Speed Rail Authority's adoption forecast as an upper bound (assuming it is aggressive) and compute the environmental effects at incremental decreases, showing the outcome at a range of lower HSR adoption levels. Jamin et al. (2004) consider 10 U.S. high-speed rail corridors that exhibit redundancy with 220 airport pairs. Under the assumption that rail would capture one-third of the aviation market by 2030, Jamin et al. calculate that overall GHG emissions would decrease by one million tons per year because of the mode shift. However, this assumption may be a large overestimation of the potential of mode shift: International Civil Aviation Organization found that in Europe there is a maximum of 10% potential passenger shift from air to other modes (Intergovernmental Panel on Climate Change 1999). Furthermore, Jamin et al. (2004) find that the emissions of sulfur oxides (SO_x) increased by 10% as the result of a mode shift to rail because of the use of coal for electricity, highlighting the trade-offs between pollutants.

Ridership forecasts are not always available to assist with environmental comparisons of future long-distance travel. Those that are available face the challenges of predicting ridership; this is well addressed by Skamris and Flyvbjerg (1997) and Brownstone et al. (2010). The number of riders a new system will attract and how competing modal operators (such as airlines) will respond to a new system are subject to modeling uncertainties. For this reason, environmental comparisons that assess emissions per passenger or trip will be only as good as the ridership models that form the basis for the analysis. Organizations looking to evaluate air and HSR systems in a government review process have taken on this challenge in different ways, with some making coarse estimations of ridership changes (for example, the Chicago HSR Draft Environmental Impact Statement). Morgan et al. (TTI 2009) performed a demand analysis of the possible HSR corridors in Texas and developed a ranking methodology for the potential HSR corridors based on demand, population density, and capacity on existing modes. The California HSR model does consider mode shifting and induced demand from air and auto travel to HSR (Cambridge Systematics 2008); however, this forecast recently has been challenged (Brownstone et al. 2010). Work is currently under way at the FRA to develop flexible HSR ridership models that can be used by a region to consider HSR operations and costs.

Assessing complementarity in comparative environmental models and ridership models is not a simple proposition. For example, HSR was not explicitly modeled as a feeder mode for air in the California HSR ridership model, partially owing to the challenge of developing one modeling tool to capture both competition and complementary (discussion forthcoming in ACRP 3-23). In addition, complementarity is generally not modeled because of a research finding that HSR has little potential as a feeder mode for air. A study by Charles River Associates (2000) found that the potential diversion of connecting air travelers to HSR was less than 1% of ridership and revenue potential. As discussed in ACRP 3-23, this study was based on stated preference data. However, those surveyed would not have been exposed to high-quality transit to airports in California. Since 2000, airport connections by means of transit have increased tremendously in California (e.g., Bay Area Rapid Transit to San Francisco International Airport and the express Fly Away Bus service from downtown Los Angeles to Los Angeles International Airport). These changes and the intensification of interest surrounding comparative environmental studies likely make this an important time to revisit the complementary role of HSR and the environmental impact of this role.

The Northeast corridor's Amtrak Acela service provides valuable information for U.S. HSR planners. There is experience with both competition and complementarity. The clear competition in the mode shares for the Northeast corridor can be seen in Figure 2 (where rail is both Acela and conventional

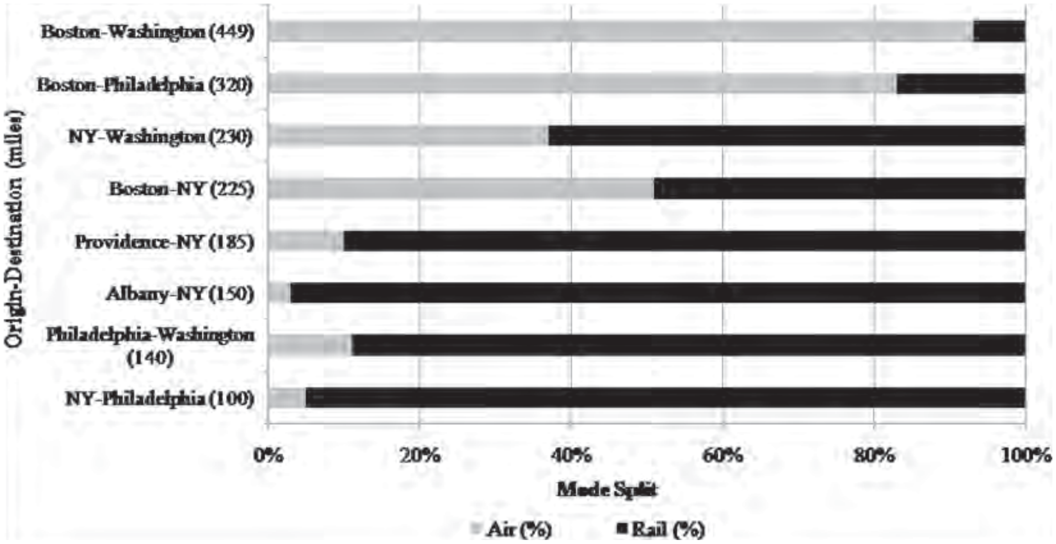

FIGURE 2 Mode share (and miles by driving) for certain Northeast corridor city pair markets.

rail) (ACRP 2009). Figure 2 shows the rail and air mode shares on the Northeast Corridor but only as a percentage of the total air and rail market share (auto excluded). Rail dominates in the corridors of less than 300 miles, and air dominates for the corridors of more than 300 miles. Embedded in these results is some experience with complementarity. United Airlines has a code share relationship with Amtrak at Newark Liberty International Airport. According to Negroni (2012), 24,000 people a year use this service, with the overwhelming majority coming from Philadelphia (a 79-mile journey).

Similar results were found in a study for the European Union by Steer Davies Gleave (2006) comparing HSR and aviation ridership. In the study, eight routes with both air and HSR travel options were considered with the objective "to understand the main factors driving the market share of rail operators, classic airlines and low cost airlines on each route." Although it is not an environmental impact study, it does address issues of market share and ridership using historic data reported by air and rail operators. As shown in Figure 3, the travel time on HSR is a strong determinant of rail market share when compared with air transport. For intercity transport travel times of less than 3 to 4 hours, the rail market share is consistently higher than 50%. This highlights the strong potential for intermodal competition and complementarity in short- to medium-haul intercity transportation corridors. The Steer Davies Gleave study was then used in Eurocontrol's Challenges of Growth report in 2008 (Eurocontrol 2008). The report demonstrates that there is a recognized contribution from HSR to alleviate airspace needs, further underscoring the role of complementarity. Furthermore, Patterson and Perl (1999) found that the ini-

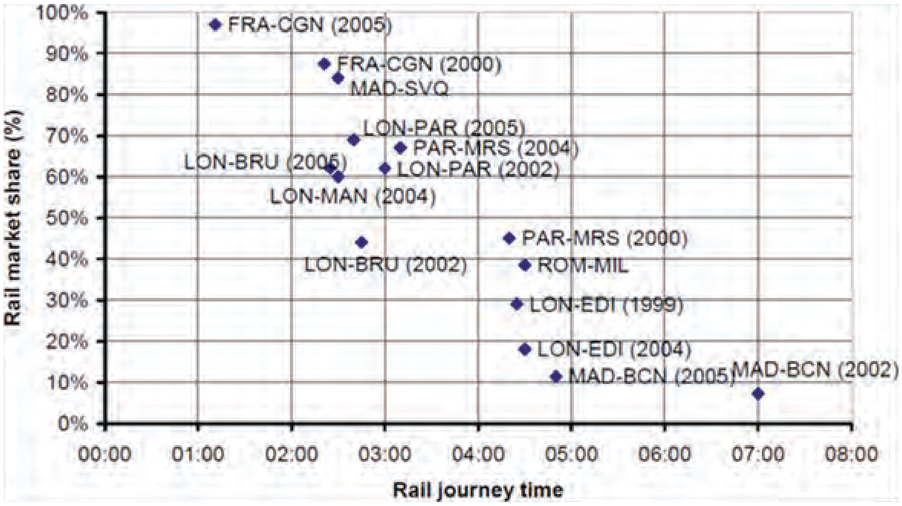

FIGURE 3 Rail market share (compared with air) against rail travel time for select European intercity transportation corridors. (Source: Steer Davies Gleave 2006.)

tial operation of the French TGV in 1981 produced drops in air passenger traffic at several major airports in France. This was dubbed the "TGV effect," and Patterson and Perl (1999) discuss how at a journey time of less than 3 hours, significant shifts in the market will occur toward HSR, which is reflected in the French experience.

Academic literature tends to develop comparative analyses at a commensurate spatial scale because it ignores the role of local and regional decision makers to evaluate air and HSR travel at a macro level. Academic literature often compares the modes at corridor, regional, or even country scale, ignoring the differences in system operators; that is, at macro scales air travel includes airports, airlines, and air traffic control, whereas HSR travel often consists of a single operator. These differing decision-making layers make government environmental review that spans multiple stakeholder interests challenging. For example, efforts have been made to estimate environmental effects when air and HSR systems are configured as complementary services. Janic (2003) proposes three configurations: (1) HSR partially replacing air on spokes; (2) HSR completely replacing air on spokes providing feeder services; and (3) air used exclusively for spokes with HSR connecting airports. For each of the three cases, regions in Europe that have been configured for complementary service are identified [i.e., (1) Frankfurt, (2) Paris to Rome, and (3) Paris Charles De Gaulle airport to Lyons Satolas airport]. However, an environmental assessment of these three cases is not performed. Hsu et al. (2010) discuss the possibility of increasing corridor air and HSR travel when complementary service is offered, yet no study identified contrasts the environmental outcomes when competing versus complementary service is offered. California corridor HSR market share was investigated, based on data from Eurostar, for the conditions in which air is best substituted by an HSR system (Behrens and Pels 2012). The authors found that travel time and frequency are the major decision criteria for business trips, and for leisure trips, price is the most significant factor and travel time is not a major contributor. Zanin et al. (2012) find that in Spain, corridors with HSR have lower GHG footprints than do corridors without HSR, and understanding the regional interactions of transportation modes is critical for understanding countrywide effects of transportation configurations.

METRICS

Energy and environmental measures for air and HSR tend to be normalized per trip, vehicle-mile, or passenger-mile; however, comparing across studies remains a challenge because of the different operating characteristics and goals of worldwide long-distance transportation systems. Although temporal and geographic (e.g., track alignment, electricity mixes, market demand, etc.) differences are often masked in normalized results, additional challenges remain when comparing the footprint of different train technologies and operating conditions. For understanding the impacts of air or HSR systems on regional emissions inventories, energy, emissions, and noise results are often presented per vehicle-mile traveled. Many studies focus on understanding the long-run per passenger-mile traveled footprint of passengers to understand the environmental intensity of service. Per-trip measures are common and valuable for eliminating the differences in trip distances to reach the same origin-destination pairs. Regardless, current air and HSR transportation systems that offer lower emissions might appear attractive from an environmental standpoint, but if such a system is unable to attract passengers, it will produce negative environmental benefits: a train or an aircraft with no payload does all harm and no good. Without ridership forecasts for corridors, environmental assessments will focus on vehicle-mile, passenger-mile, or trip comparisons of air and HSR travel, likely by assuming some ridership range or average ridership.

FORECASTING TECHNICAL AND BEHAVIORAL CHANGES

The analysis of future air and HSR travel sometimes includes projections of energy use, vehicle technologies, and mode shifting, and forecasting is constrained by limited information for emerging vehicle technologies and ridership outcomes for corridor alignments. The environmental impacts of air and HSR systems will be influenced by future electricity mixes (Jamin et al. 2004; Åkerman 2011; Chester and Horvath 2010, 2012), emerging vehicle technologies (Janic 2003; Jamin et al. 2004; Givoni 2007; Scott 2011; Chester and Horvath 2012), and mode shifting (van Wee et al. 2003; Chester and Horvath 2012). Advanced vehicle technologies coupled with cleaner electricity inputs have the potential to reduce both future air and HSR footprints (Chester and Horvath 2012). Cleaner electricity mixes will also improve local air quality (Jørgensen and Sorenson 1997). For HSR, optimizing operational characteristics such as acceleration, braking intensities, maximum speed, and distance between stations has been shown to reduce the energy footprint of trips (van Wee et al. 2003). New engine technologies are expected to significantly reduce aircraft fuel consumption (and corresponding GHG emissions) and NO_x emissions (Jamin et al. 2004). Optimal trip substitution distances have been computed to evaluate the GHG break-even points for air and HSR. For the Spanish AVE HSR lines, medium distance trips (i.e., fewer than 600 miles) were shown to produce a lower GHG footprint for HSR (Rus 2011; Tucker 2012). Emerging air and HSR systems have been contrasted with emerging automobiles (Kageson 2009; Chester and Horvath 2012). Higher economy gasoline and diesel automobiles, hybrid electric vehicles, and plug-in hybrid electric vehicles can significantly reduce the GHG footprints of on-road, long-distance passenger travel (Kageson 2009). The environmental trade-offs of future long-distance travel will be largely affected by mode shifts. For new systems such as HSR, deployment to short and dense corridors is expected to lead to the greatest environmental benefits for the region (Burgess 2011), and new analytical methods continue to be developed to determine the conditions under which this is true.

ENVIRONMENTAL INDICATORS

Environmental indicators are the measures by which human health, ecosystem services, climate change, resource depletion, and other impacts are assessed. They include those involved in a government environmental review process (see chapter four). A study may focus on a single indicator or a group of indicators. Studies that evaluate a broad suite of indicators often show that a reduction in one pollutant can lead to an increase in another. The indicators are fundamentally different in their *significance.* Indicators such as noise and criteria air pollutants have significance thresholds such that if an infrastructure project will result in pollutant levels above this threshold, the project might be altered. In contrast, GHG emissions do not have an established upper limit, and studies are generally accounting for the overall level of emissions without a threshold by which to compare.

DOOR-TO-DOOR ASSESSMENTS

Few studies consider door-to-door trips in the comparison of air and HSR systems but instead focus on the line haul section of trips, leaving a gap in the understanding of how the first and last mile contribute to environmental effects. The few HSR studies that exist have evaluated European conditions (Givoni 2007). Given the challenges of evaluating emerging HSR technologies deployed in the United States, most academic and government-driven studies identified consider only the competing legs of air and HSR travel. However, the process by which passengers access HSR stations, in particular, remains unclear. Although airport access behavior has been evaluated (Airport Cooperative Research Program 2009), no equivalent studies were identified for U.S. HSR systems. The environmental effects of access to and egress from airports and HSR stations may have non-negligible effects in the total footprint of the long-distance transportation system.

The two common analytical system boundaries that are used in the literature are door-to-door and line haul. The synthesis of door-to-door environmental assessments will include research that compares the long-distance air and HSR vehicle or passenger trip and information about how passengers access/egress airports or train stations. Research that falls under the line-haul category will compare only the long-distance air and HSR vehicle or passenger trip and exclude door-to-door access/egress. The overwhelming majority of the literature falls in the line-haul category, with very few studies drawing the system boundary around the door-to-door category.

LIFE-CYCLE ASSESSMENT

Life-cycle assessment (LCA), a framework for assessing cradle-to-grave effects, is used for assessing the comprehensive footprints of air and HSR travel beyond vehicle propulsion. The discussion of new HSR systems and existing air systems created a demand for comprehensive environmental assessment frameworks to understand how upfront construction or sunk environmental costs could be included in the long-run benefits and costs of different modes. LCA is needed for determining the time until payback. LCA studies include all or a subset of vehicle, infrastructure, and energy production components, in addition to propulsion effects. LCAs are expected to use an analytical system boundary that is larger than those required by governmental environmental review processes.

ADVOCACY DOCUMENTS

The studies considering GHG and energy in an air and HSR corridor comparison are overwhelmingly from the academic and advocacy communities. Regarding the advocacy community, HSR is largely characterized and marketed by rail advocates as an environmental improvement when compared with alternative modes such as personal vehicles and air transport. Rail advocacy groups maintain emphasis on CO_2 emissions reduction (American Public Transportation Association 2012). However, maintaining an emphasis on CO_2 reductions may ignore increases in other pollutants. For example, Chester and Horvath (2012) and Givoni (2007) show how decreases in one pollutant may lead to increases in another. Air advocates maintain that the majority of GHG emissions occur from very long-haul air trips, for which there is no viable alternative to aircraft; as such, they call for air traffic management and airframe improvements (European Regions Airline Association 2011). Such a statement disregards the fact that short-haul flights tend to be the most inefficient from the perspective of fuel consumption per passenger and that HSR has the potential to alleviate delay, which is a significant contributor to fuel inefficiency (Ryerson and Hansen 2010; Ryerson et al. 2011). In the literature synthesis, advocacy documents are not synthesized because of concerns about modal bias.

CHAPTER FOUR

NATIONAL ENVIRONMENTAL POLICY ACT PROCESS

In the following section, government-driven environmental comparisons from National Environmental Policy Act (NEPA) studies are explored. The role of NEPA in environmental assessments is explored and how the spatial incompatibilities of air and HSR systems and the scope of purpose and need statements complicate the full consideration of air and HSR travel as alternatives. As a result, few detailed modal assessments are found in Environmental Impact Statement (EIS) documents. Those that are present are consequential assessments that focus on a full range of pollutants consistent with the NEPA process.

NATIONAL ENVIRONMENTAL POLICY ACT OVERVIEW

The keystone piece of environmental assessment legislation is NEPA, which became law on January 1, 1970. This national policy, which is supplemented by case law, mandates environmental review of all proposed major federal actions significantly affecting the quality of the human environment. This chapter provides context for NEPA procedural analysis by highlighting the key components of the NEPA environmental review process, relevant case law, and resulting federal agency NEPA guidance documents. This will facilitate a synthesis of environmental review documents for airport and HSR systems to provide insight into the role of the environmental review process in performing environmental assessments of the two modes.

In general, the NEPA process investigates the extent of the environmental impacts of the proposed federal action and evaluates the environmental impacts of feasible and prudent alternatives to the proposed action. When environmental impacts are deemed to be potentially significant, an EIS is prepared in accordance with the NEPA process to document the extent of those impacts. Only alternatives that are deemed feasible and prudent move forward for full environmental impact review. There are cases for which federal actions do not necessitate an EIS. If impacts of the proposed project are not deemed to be significant, the NEPA process may culminate in a categorical exclusion or finding of no significant impact, and no further environmental review is required. If impacts are unknown, an environmental assessment will be prepared to determine whether the proposed project requires the in-depth review of an EIS. Because of the larger scope and detail of environmental review, we focus on EIS documents rather than categorical exclusion, finding of no significant impact, or environmental assessment documentation to illustrate how HSR and aviation alternatives are historically considered.

All EISs must include a discussion of the purpose and need for the action, a description of the proposed action and alternatives to the proposed action, analysis of the affected environment and environmental consequences, and mitigation measures. The alternatives to the proposed action may include alignment alternatives or modal options but must satisfy the objectives presented in the purpose and need statement. In addition, an “EIS must be prepared early enough so that it can serve as an important contribution to the decision-making process rather than be used to rationalize or justify decisions already made” (Bass et al. 2001).

Four Purposes of an Environmental Impact Statement

Bass et al. (2001) explain four main purposes of an EIS. The first is to inform federal agencies of a proposed action’s potential environmental effects and disclose these potential effects to the public. Second, the EIS presents methods to mitigate the environmental problems caused by the proposed actions. This may include identifying mitigation measures and proposing project alternatives that will meet the original purpose and need of the proposed action. Third, the EIS serves as a procedural framework that allows persons who would be affected by the federal action to participate in the environmental review process leading to a decision. The fourth purpose is to be an information source on environmental resources used by state, local, and tribal government officials.

Three Types of Environmental Impact Statements

If the federal action necessitates an EIS, there are three general categories of EIS documents that can be prepared: project specific, programmatic, and legislative. Legislative is the least common; it pertains to legislation that is “developed by or with the significant cooperation and support of a federal agency, but does not include requests for appropriations” [40 (CFR) 1508.17]. The project-specific EIS is the most common type of review; it covers the environmental impacts of a single proposed action limited to the geographic area where the action is taking place. The programmatic EIS (PEIS) is slightly different in scope and focus when compared with the project-specific

EIS. The PEIS is structured to “address a broad federal action such as the adoption of a regulation, policy, plan, or program” and usually there are “no defined facilities or specific sites to be evaluated.” In *Kleppe v. Sierra Club*, the Supreme Court ruled that a PEIS “is required only when there is a proposed formal agency program” (Bass et al. 2001). PEISs also can be implemented as a tiered process, where broader policies and programs initially are evaluated by an EIS, which may be called Tier 1, and then supplemented with subsequent narrower EISs or environmental assessments, which may be called Tier 2. The Tier 2 documents reference the general discussions from the Tier 1 PEIS and concentrate solely on the issues specific to the action items in Tier 2 [40 (CFR) 1502.4(b), 1508.28].

Environmental Impact Statement Content

Preparation of an EIS includes certain key content and involves multiple agencies and the general public. Early in the process, the lead agency and cooperating agencies must be identified to determine agency roles and responsibilities. The EIS is prepared to document the anticipated environmental impacts of the proposed action as well as the environmental impacts of feasible alternatives to the proposed action. Multiple project alternatives are considered in the EIS, along with a “no action” alternative. However, the alternatives must prove to be feasible and prudent alternatives to undergo full environmental review. In the event that a considered project alternative is designated infeasible, and thus excluded from further environmental review, the EIS must explain why it is infeasible. In addition, the EIS must describe specific actions that will be taken to mitigate adverse environmental impacts and list the necessary permit requirements to implement the proposed project. As air and HSR environmental assessments are considered in the EIS process, it is important to remember that the comparison of modal alternatives may be different from the first premitigation result. A preferred alternative will be suggested at the end of the analysis based on the results of the environmental review.

The completed analysis is submitted for public review and commenting in the form of a draft EIS (DEIS). This allows the general public and public agencies the opportunity to comment on the alternatives and the content of the environmental analysis. Once the commenting period ends, a final EIS (FEIS) is prepared. The FEIS includes a “Response to Comments” section that addresses all substantive comments received. This is to document that all comments were reviewed and considered. The FEIS may be used in court in the event that the project is contested, so it is imperative that the proposed action in the FEIS has a clearly documented consideration of environmental impacts such that it has adequate justification for the preferred alternative. Once the FEIS is complete, a record of decision is prepared, which includes discussion of the preferred alternative, and the project can move forward for implementation.

Purpose and Need

The purpose and need statement in the EIS is intended to define the objectives to be achieved by the proposed project (purpose) and the overarching problems that motivated the project (need). The framing of the purpose and need statement is a primary factor in determining the feasibility of alternatives in an EIS. Bass et al. (2001) list key principles for developing a range of reasonable alternatives, one of which states “the range of alternatives must achieve the proposed action’s objectives as stated in the statement of purpose and need.” This principle is derived from the NEPA case law *Citizens Against Burlington, Inc. v. Busey* (Bass et al. 2001). Federal and state case law has further defined the expectations for determining scope in the purpose and need statement, particularly with respect to how narrow the purpose and need may be defined and restricted. For example, in 2010, the U.S. District Court in Florida upheld the purpose and need statement, which the plaintiff considered to be impermissive. This case, *Citizens for Smart Growth v. Peters,* resulted in the courts arguing in favor of the defendant, citing NEPA “does not require that agencies state the goals of the action in the broadest possible terms” nor does it “require that agencies disregard the needs and goals of the parties applying for the agency action. Rather, the agency should take into account the needs and goals of the parties involved in the application.” In this case, the metropolitan planning organization (MPO) had included a particular four-lane bridge project as part of the agency’s long-range planning, and the court found that “NEPA does not confer the power or responsibility for long range local planning on federal or state agencies. Rather, the relationship of FDOT and FHWA to the Martin County MPO should be one that is premised on the idea that the representatives of the community are best situated to make the decisions regarding transportation planning for their community, with FDOT and FHWA demonstrating the proper respect for the sovereignty of local authorities” (*Citizens for Smart Growth v. Peters* 2010).

Environmental Impact Categories and Significance Thresholds

The passage of NEPA resulted in the creation of the Council on Environmental Quality (CEQ) to administer NEPA. The CEQ issued regulations for implementing NEPA, which serves as the procedural provisions of NEPA in the Code of Federal Regulations (CFR 2012). All federal agencies legally must comply with the CEQ NEPA regulations. In addition, all federal agencies must legally comply with federal statutes passed by the legislature and executive orders from the executive office. These orders and statutes, such as the 1990 Clean Air Act Amendments, typically provide greater specificity of the resource impacts to be reviewed in the NEPA process.

The orders, statutes, and regulations set the legal precedent for environmental review, but each federal agency may publish its own procedural guidance pursuant to the unique needs of the agency-specific programs and operating procedures

(CFR 2012). For example, the U.S. Department of Transportation participates in delivering railway and airport infrastructure projects through the FRA and FAA. The FRA agency guidance is published as Notice 51 (FRA 2012a), with further elaboration available for the High-Speed Intercity Passenger Rail Program. FAA NEPA policy is published as Order 1050.1E with further elaboration in FAA Order 5050.4b (*Federal Register* 2006). These FRA and FAA guidance documents list the resource impact categories to be considered during a NEPA process environmental analysis. Although the language between agencies is different, the impacts addressed are the same for both agencies because they are subject to the same federal legislation. The difference in agency language further challenges the direct comparison of environmental impacts between modes. In an effort to visualize the differences, Table 1 is formatted such that agency impact categories are grouped under the effects defined in the original CEQ regulations. Agency impacts are listed only once and matched with the most appropriate CEQ effect.

A major component of an EIS is the determination of significant impacts by the proposed action and the alternatives to the proposed action. Significance of an impact is considered in terms of context and intensity, where context is evaluated with respect to "society as a whole (human, national), the affected region, the affected interests, and the locality" and intensity "refers to the severity of impact" (CFR 2012). An infrastructure project may have impacts in a specific resource category, but the "significance threshold" identifies the point at which the impact becomes significant. The "significance threshold" may be a quantifiable metric for measuring pollutants, a score to label severity, or more loose interpretations of terminology such as "adverse" or "extensive" (*Federal Register* 2006). FAA Order 1050.1E lists corresponding statutes, regulations, and oversight agencies for each impact category to assist in determining the significance of environmental impacts. However, the significance threshold is listed as "none established" for coastal resources, solid waste, and wild and scenic rivers (*Federal Register* 2006). FRA agency guidance at a similarly detailed level could not be located. One challenge to comparing significant impacts across modes is related to the interpretations of significance and methodologies used to measure significance, which can vary between modes. Another challenge is related to the idea that impacts are not ranked in importance. Even if impacts can be compared within the same category with a similar metric and methodology, there is no clear indication of which categories warrant more concern.

Federal legislation is not the only source for environmental impact analysis requirements and significance thresholds. States may have their own legislation for state activities. For example, the California Environmental Quality Act (CEQA) is statewide legislation with guidelines for implementation published in the California Code of Regulations regarding development of environmental impact reports (EIRs). Appendix G of CEQA Guidance includes an environmental checklist form that lists environmental factors to be evaluated in an EIR. This requires the lead agency to check which factors "would be potentially affected" by the project and serves as the basis for further analysis (CCR 2012). The environmental factors are also listed in Table 1. It is important to note that CEQA and NEPA both apply to federal actions taken in the state of California; therefore, the EIS may be combined with the EIR to provide one document that satisfies the relevant federal and state statutes. California public infrastructure projects must also consider Assembly Bill 32: Global Warming Solutions Act and its "scoping plan" goals, including Senate Bill 375, the Sustainable Communities and Climate Protection Act of 2008 (California Air Resources Board 2008). California's Assembly Bill 32 seeks to reduce statewide GHG emissions to 80% of 1990 levels by 2020 through a portfolio of improvements, including regional reductions, HSR deployment, and energy efficiency measures (California Air Resources Board 2008).

If an impact is deemed significant, there are multiple ways the issue can be addressed. NEPA does not prevent an agency from implementing a project with significant impacts. In rare occasions, the project may be halted. More commonly, the project will experience design modifications or incorporate mitigation measures in an attempt to offset the impact caused by the proposed action or project.

Mitigation

Significant environmental impacts in an EIS are further evaluated in the context of mitigation. Mitigation measures are actions that can be taken to minimize adverse environmental impacts, often perceived as a resolution to the environmental impacts caused by the project. The CEQ (CFR 2012) defines mitigation actions as those that achieve

(a) Avoiding the impact altogether by not taking a certain action or parts of an action;
(b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation;
(c) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;
(d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; or
(e) Compensating for the impact by replacing or providing substitute resources or environments.

Although mitigation measures must be discussed for all impacts, "even those that by themselves would not be considered significant," federal agencies are not required to implement mitigation measures identified in the EIS. Generally, agencies are legally held to implement only those recorded in the record of decision. This may vary at the state and local level as a result of other agency requirements beyond federal NEPA statutes. In *Robertson v. Methow Valley Citizens*, the

TABLE 1
ENVIRONMENTAL IMPACT CATEGORIES LISTED IN AGENCY GUIDANCE DOCUMENTS

Federal Regulations Under NEPA					
CEQ *(from 40 CFR, Sec. 1508.8)*	Ecological	Health	Economic and Social	Aesthetic, Historic, and Cultural	[Direct, Indirect, and Cumulative]
Federal Agency Guidance Under NEPA					
FAA *(from FAA Order 1050.1(e) Appendix A)*	▪ Air quality ▪ Coastal resources ▪ Fish, wildlife, and plants ▪ Floodplains ▪ Natural resources and energy supply ▪ Wetlands ▪ Wild and scenic rivers	▪ Hazardous materials, pollution prevention, and solid waste ▪ Water quality	▪ Compatible land use ▪ Farmlands ▪ Light emissions and visual impacts ▪ Noise ▪ Socioeconomic impacts, environmental justice, and children's environmental health and safety risks	▪ Department of Transportation Section 4(f) ▪ Historical, architectural, archeological, and cultural resources	▪ Construction impacts ▪ Secondary impacts
FRA *(from FRA Notice 51)*	▪ Air quality ▪ Coastal zone management ▪ Ecological systems ▪ Flood hazards and floodplain management ▪ Impacts on endangered species or wildlife ▪ Impacts on wetlands areas ▪ Use of energy resources ▪ Use of other natural resources, such as water, minerals, or timber	▪ Public health ▪ Public safety ▪ Solid waste disposal ▪ Water quality	▪ Environmental justice ▪ Impacts on the socioeconomic environment ▪ Impacts on transportation: of both passengers and freight; by all modes, including the bicycle and pedestrian modes; in local, regional, national, and international perspectives; and including impacts on traffic congestion ▪ Land use, existing and planned ▪ Noise and vibration ▪ Possible barriers to the elderly and handicapped	▪ Aesthetic and design quality impacts ▪ Locations of historic, archeological, architectural, or cultural significance ▪ Recreational opportunities ▪ Use of 4(f)-protected properties	▪ Construction period impacts
State of California Regulations Under CEQA					
CEQA *(from CEQA Guidelines Appendix G)*	▪ Agriculture and forestry resources, ▪ Air quality ▪ Biological resources ▪ Geology/Soils ▪ Mineral resources ▪ GHG emissions	▪ Hazards and hazardous materials ▪ Hydrology/ water quality	▪ Land use/Planning ▪ Noise ▪ Population/ Housing ▪ Public services ▪ Transportation/ Traffic ▪ Utilities/Service systems	▪ Aesthetics ▪ Cultural resources ▪ Recreation	▪ Mandatory findings of significance

Supreme Court held that, with respect to mitigation measures presented in the EIS, NEPA "does not require their adoption" (Bass et al. 2001). Mitigation measures can be placed in the record of decision such that they are legally required.

According to Bass et al. (2001), in practice there are those who argue that items included as mitigation measures in EISs do not actually meet the definitions provided by NEPA and CEQA. Such "paper mitigation" measures are not adequate (Bass et al. 2001). In addition, some studies have found that compensatory techniques are inadequate as environmental solutions as a result of factors such as poor implementation. Robb (2002), who specifically investigated compensatory wetland sites in Indiana, cites studies from 1985 to 2000 that found that U.S. federal agencies "often permitted a net loss of wetland area . . . , that the compensation was often not constructed . . . , and that, when constructed, the mitigation failed to compensate for what was lost." A more recent study of Chicago area wetlands by Bendor (2007) found that small developments were more likely to use off-site mitigation wetlands banking than were large developments, but "lack the scale economies necessary for feasible permittee responsible mitigation." These studies indicate that including mitigation practices in a comparative environmental assessment will be a challenge because mitigation measures may not directly equal the impacts they are mitigating.

Massachusetts v. Environmental Protection Agency, 2007

The 2007 Supreme Court case, *Massachusetts v. Environmental Protection Agency* (*MA v. EPA*), resulted in the classification of GHGs as criteria pollutants to be regulated by the EPA (*MA v. EPA* 2007). The case was filed by a "coalition of states and private plaintiffs" who argued that the EPA could not continue to defer judgment on whether the agency would regulate GHG emissions from tailpipes in the new automobile fleet of the United States. The EPA had previously "decided not to decide," refusing to take a stance on regulation of GHGs (Freeman and Vermeule 2007).

The Supreme Court decision addressed three key legal points: standing, statutory authority, and an agency's discretionary rule-making authority. The court determined that the plaintiffs had legal standing to move forward with the case. One basis for the standing determination was the finding that the state of Massachusetts, one of the plaintiffs in the case, had coastal property threatened by sea level changes believed to be caused by GHGs. The court also determined that the EPA had statutory authority to make the ruling; previously the EPA had argued that the definition of "pollutants" was ambiguous and their current statutory scheme focused on localized pollutant impacts, rather than global incremental pollutant impacts. The Supreme Court ruled that GHGs would fit within the "pollutant" definition. Finally, the court established constraints on the agency's rule-making authority. Although prior case law had acknowledged the federal agency's "discretion to set priorities and allocate resources," the Supreme Court ruled that the EPA's denials of rule-making petitions are reviewable documents, therefore the agency must be able to firmly justify its decision-making priorities if there is further decision deferment, and denials may be made "only on technocratic and scientific grounds, not political ones" (Freeman and Vermeule 2007).

The rulings left the EPA with the responsibility to make an endangerment finding and conclude, once and for all, whether GHGs endanger public health and welfare. Ultimately, in December 2009, the EPA made a positive endangerment finding for GHG emission from new motor vehicles (Meltz 2012). Regulatory implementation of the court case findings is ongoing. After the initial court case ruling, but before the positive endangerment finding, Freeman and Vermeule (2007) noted the existing lawsuits from previous years that alleged "federal agency violations of NEPA's environmental impact disclosure requirements because of a failure to consider greenhouse gas impacts for proposed federal projects." This issue was of significance at the time of the ruling because *MA v. EPA* did not specifically address NEPA. Complications were expected to follow given the lack of "established protocols for how to assess the environmental impacts of greenhouse gases, which may be emitted (or reduced) depending on the nature of the proposed development project" (Freeman and Vermeule 2007). In a Congressional brief prepared by the Congressional Research Service, federal agency actions since the ruling are documented to the summer of 2012. Most of these actions pertain to regulations for tailpipe emissions and stationary sources of pollutants. Notably, the CEQ issued draft guidance in February 2010 to address "ways in which Federal agencies can improve their consideration of [GHG] emissions and climate change in their evaluation of proposals for Federal actions under [NEPA]" (CEQ 2010).

In addition, the FAA issued FAA Order 1050.1E, Change 1, Guidance Memo #3. This document includes conversion factors to obtain the difference in CO_2 for a project and guidance on which sources to include when evaluating different types of airport development or operation actions. For airport actions, the FAA continues to evaluate GHGs in a way that is consistent with "the current approach and EPA guidance with regard to local air quality evaluations." This refers to the local mixing height, which does not account for the duration of the flight (FAA 2012b).

> For airport actions, the GHG evaluation should include the same emissions sources that would typically be included in the air quality analysis. The maximum altitude for any analyses for an airport NEPA action would be the landing take-off cycle emissions up to the local mixing height, which is consistent with the current approach and EPA guidance with regard to local air quality evaluations. For non-aircraft emissions, GHG emissions should be determined from projections of fuel burn and converted to CO_2e.

When evaluating criteria pollutants, emissions that occur above 3,000 feet, the local mixing height, are considered to be beyond the purview of the airport (Schrooten et al. 2006; Yang et al. 2007). The inclusion of GHG emissions may necessitate a new paradigm as their impact occurs regardless of the location of their emission. One such paradigm is presented in the *Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories*, a state-of-the-art in airport GHG inventorying (Kim et al. 2009). The Guidebook suggests that GHGs from an entire flight should be estimated and attributed to a set of emissions owners, including the airport, the airlines, and the traveling public. The allocation of GHGs as such is reminiscent of the analytical system boundary drawn around air and HSR corridors for comparison. When passenger trips are considered, door-to-door and line-haul trips are considered; when aircraft operations are considered, airport-based operations and the en-route portion are considered. Although such a classification does not, in essence, preclude an environmental comparison, it does introduce complications. Environmental comparisons are initiated by an organization with an inherent scope; as a result, comparisons likely are driven by the needs of an organization with jurisdiction over particular pollutants, which likely influences the organization's actions.

CHALLENGES TO ENVIRONMENTAL IMPACT STATEMENT MODAL ALTERNATIVES ASSESSMENTS

There are few alternatives assessments that compare air and HSR corridors in government environmental review documents. Multimodal alternative assessments are within the purview of the NEPA process, yet the framing of purpose and need statements for intercity transport seems to reduce opportunities for comparative assessments of air and HSR. Because airport projects require specific airport capacity improvements as related to the NAS, the purpose and need statements are framed to address mobility at the national level. In contrast to the airport EIS documents, the HSR EIS purpose and needs statements focus on specific regional mobility issues, generally with the intent to enhance and expand reliable passenger mobility options. Consequently, the purpose and need statement is framed according to the service region of the proposed segment of HSR corridor. In essence, it becomes a matter of scope of the intended service area. There is a conflicting focus of regional and national mobility, where air "purpose and need" tends to focus on national airspace needs and rail "purpose and need" tends to focus on regional mobility in a specific corridor. See Table 1 for excerpts from examples of air and HSR purpose and need statements. In the following sections, we identify how the framing of the project objectives and scope of service can limit a full comparative environmental assessment of other modes. We find that in general, when the need is based on national issues, a regional response is rejected and vice versa.

High-Speed Rail Alternative Consideration Within Aviation Environmental Impact Statement

Aviation project EISs are reviewed to evaluate how HSR is considered as an alternative to proposed aviation infrastructure. EIS documents for capacity-enhancing airport infrastructure are more likely to consider HSR because capacity enhancements are driven by the need to accommodate additional passengers, which could be carried by another mode. The focus is on FEISs that support records of decision publicly listed on the FAA website dating to 1996 (FAA 2012a). From these, airport runway development FEISs at airports located along a federally designated HSR corridor are chosen (see Table 2).

In determining potential alternative modes for the aviation capacity enhancements, there is no strict definition for feasibility, leaving financial and time constraints as acceptable reasons to reject possible modal alternatives from the alternatives assessment. This often precludes full comparative environmental assessments of air and HSR in an airport EIS. Legislative allocation of transportation funding historically is mode specific because the collection of taxes into the aviation and highway trust funds are mode-specific "user fees." HSR lacks a trust fund and fluidity of funds; as a result, an airport EIS can reject HSR project alternatives as infeasible based on lack of funding support. As demonstrated by the American Recovery and Reinvestment Act HSR funding allocations, political will can elevate discussion of a previously underfunded mode.

Aviation FEIS documents do not consider enhancements for a specific airport corridor, which is best explained by the node-based planning approach to airport infrastructure improvements and legal constraints. In aviation, airports that accept public funds from the FAA agree to conditions of grant assurances such that all aircraft that can safely land at that airport must be accommodated with no discrimination (USC 2012). Airports have little to no influence on the airlines that operate at their airport, how often the airlines operate, and what type of aircraft they use for each operation. Consequently, aviation improvements focus on capacity and delay, not on serving specific destinations or individual corridors. The airport EIS purpose and need statements listed in Table 2 focus on specific capacity enhancements that are intended to reduce delay in the NAS, address the gap between good and bad weather capacity, or increase safety.

The first example is the Chicago O'Hare International Airport Modernization 2005 FEIS (FAA 2005b). This airport is located in the Chicago Hub Network HSR corridor. The FEIS makes note of Congress' goals for HSR corridor development and acknowledges, " . . . new HSR service could theoretically reduce aviation demand at O'Hare" but provides multiple reasons to exclude HSR from alternatives assessment (see pages 3 to 18 of the Chicago O'Hare International Airport Modernization 2005 FEIS). At the time of the

TABLE 2
EXCERPTS FROM EIS PURPOSE AND NEED STATEMENTS

Airport EIS (EIS/year)	Purpose and Need Excerpt
Chicago O'Hare, ORD (FEIS 2005)	"Address the projected needs of the Chicago region by reducing delays at O'Hare, and thereby enhancing capacity of the NAS. Ensure that existing and future terminal facilities and supporting infrastructure (access, landside, and related ancillary facilities) can efficiently accommodate airport users" (FAA 2005b).
Washington Dulles, IAD (FEIS 2005)	"The purpose of the project, from the Federal perspective, is to support the development of IAD such that it will safely accommodate the projected future aviation activity demand levels, without that aviation activity incurring unacceptable levels of aircraft operational delay, thereby causing resultant delays throughout the National Airspace System" (FAA 2005c).
Ft. Lauderdale, FLL (FEIS 2008)	"The purpose of the proposed action is to provide sufficient capacity for existing and forecast demand at FLL with an acceptable level of delay" (FAA 2008).
Philadelphia, PHL (FEIS 2010)	"The purpose of the Capacity Enhancement Program is to enhance airport capacity in order to accommodate current and future aviation demand in the Philadelphia Metropolitan Area during all weather conditions" (FAA 2012b).
HSR EIS (EIS/year)	Purpose and Need Excerpt
Chicago HSR (DEIS 2012)	"The purpose of the proposed Chicago to St. Louis HSR Corridor Program is to enhance the passenger transportation network in the Chicago to St. Louis HSR Corridor by improving high speed passenger rail service, resulting in a more balanced use of different corridor travel options by diverting trips made by automobile and air to rail" (FRA 2012b).
Florida HSR (FEIS 2005)	"The purpose of FHSR is to enhance intercity passenger mobility in Florida by expanding passenger transportation capacity and providing an alternative to highway and air travel" (FRA 2005b).
California HSR (FEIS 2005)	"The purpose of the proposed High Speed Train system is to provide a reliable mode of travel, which links the major metropolitan areas of the state, and delivers predictable and consistent travel times. A further objective is to provide an interface with commercial airports, mass transit and the highway network and relieve capacity constraints of the existing transportation system as increases in intercity travel demand in California occur, in a manner sensitive to and protective of California's unique natural resources" (FRA 2005c).

FEIS, there was no federal funding for the implementation of Chicago HSR that would "significantly reduce total passenger demand at O'Hare." Although there was a published FEIS in 2004 for HSR corridor improvements from St. Louis to Chicago, it is asserted in the airport EIS that the HSR line represents a "relatively small share of the total passenger demand" (FAA 2005b). In addition, it is stated that the time horizon over which improvements are needed at O'Hare is shorter than the time required for developing, financing, and constructing HSR. Therefore, the EIS did not include HSR as an alternative because "it does not appear reasonable to rely on this alternative to meet the purpose and need criterion of accommodating forecast aviation demand."

The next two examples occur along the Northeast Corridor for HSR, which was federally designated in 2011. They include the 2005 EIS for Washington Dulles International Airport (IAD) (FAA 2005c) and the 2010 FEIS for the Philadelphia International Airport (PHL) (FAA 2010). Neither airport EIS performed a detailed environmental assessment of HSR as an alternative mode, citing insufficient capacity issues. For IAD, the preparers explain "the proposed project objectives relate to capacity enhancement measures to accommodate existing and future aviation activity. Therefore, other modes of transportation were eliminated because they do not provide the same service as aviation and would not affect IAD's ability to safely and efficiently accommodate existing and future levels of aviation activity" (FAA 2005c). The PHL FEIS did not consider HSR as an alternative because the preparers "found that the rail alternatives did not reduce demand sufficient to match capacity and did not enhance capacity under all weather conditions. Therefore, this alternative did not progress to the full-scale alternatives analysis" (FAA 2010).

The fourth example is the Fort Lauderdale–Hollywood International Airport (FLL) 2008 FEIS (FAA 2008). This airport is located along the Florida HSR Corridor. The FLL

FEIS was developed during the early 2000s, when Florida voters first supported state funding for HSR in the form of a constitutional amendment. By 2004, the amendment was repealed by voters and funding for the Tampa Orlando segment was vetoed by the governor (Anderson 2011). FLL FEIS states that HSR is not a feasible alternative to new runways at FLL. It is noted in the purpose and needs section that for a modal alternative to be viable, it must be fiscally constrained; it is possibly for this reason that the FLL FEIS states that "while HSR may be potentially feasible at some undeterminable point in the future and continues to be deliberated in the State of Florida, public support for this type of public transportation service seems to no longer exist" (FAA 2008). A second opportunity for HSR funding came with the passage of the American Recovery and Reinvestment Act of 2009 but was too late for consideration in the FLL FEIS; a subsequent Florida governor ultimately denied funding for this corridor in 2011 (Anderson 2011).

Aviation Alternative Consideration Within High-Speed Rail Environmental Impact Statement

This section reviews how aviation is considered in HSR EISs prepared in the United States. First, projects that support ASCE technical definitions of HSR in the United States are considered. The ASCE (2010) describes intercity high speed passenger rail as having characteristics of "top speeds of at least 150 mph on dedicated, access controlled rights-of-way with grade separated crossings." Florida and California are the only corridors to have completed EISs with planned speeds in excess of 125 mph (Cambridge Systematics 2008). As such, these are chosen for further discussion in the synthesis. In addition, the Chicago HSR is reviewed; the Chicago HSR does not have speeds in excess of 125 mph but is currently in the NEPA process, and major system improvements are funded through American Recovery and Reinvestment Act of 2009 legislation. The three studies considered are among the well-developed planning efforts.

The 2003 DEIS for the Chicago, Illinois, to St. Louis, Missouri, HSR Corridor Program follows a tiered environmental process, as suggested in the FRA's guidance for NEPA compliance (FRA 2009a). Tier 1 chooses an alternative by considering "broad, corridor-level issues and alternatives," and Tier 2 addresses the "individual component projects" of the selected Tier 1 alternative (FRA 2009b). Although the Tier 1 DEIS intends to review broad, corridor issues, the DEIS's mode-specific project objective precludes other modes from alternatives selection, even if they can contribute to improved corridor mobility. Therefore, the discussion of aviation occurs in the no-build alternative, which consists of planned "intercity highway and aviation services and facilities in the Chicago to St. Louis corridor" along with committed HSR track improvements from 2004 (FRA 2012b).

California and Florida are two states that used different types of EISs for their proposed HSR projects. The different types of EISs affected the way different modal alternatives were considered for the projects. The California HSR EIS is an example of a tiered process, where the overall alignment for the state of California is evaluated in the first tier and sectional corridors are evaluated as multiple second tier EISs. This contrasts with the Florida HSR, which did not evaluate with a tiered approach. Instead, the project was phased into smaller segments, resulting in individual project EISs for each segment but lacking a PEIS for the overall Florida HSR line. Although there is a PEIS available for the Southeast HSR corridor, the PEIS does not address the Florida extension, presumably because Florida was added to the Southeast corridor after development for the PEIS had begun. The California HSR Tier 1 EIS reviews alternative modes as feasible alternatives with complete environmental review. The length of the entire planned corridor has trips that can be completed via aircraft. In contrast, Florida's project EISs reviewed smaller segments, which have fewer, if any, aviation alternatives. However, if Florida's HSR line were reviewed in its entirety, there may have been a case to consider aviation as an alternative, although it may have been found to be an infeasible alternative for other reasons.

During the time of the 2005 FEIS development, the Florida High Speed Rail Authority was acting under a constitutional amendment and the Florida High Speed Rail Authority Act of 2001 (which has since been overturned) (Anderson 2011). The Act charged the Florida High Speed Rail Authority with "planning, administering, and implementing a HSR system in Florida," specifying the initial HSR segment must serve Tampa and Orlando, with future service to Miami (FRA 2005b). The Florida HSR FEIS analysis that was completed in 2005 focuses on the Orlando–Tampa segment (FRA 2005b). Tampa and Orlando are separated by 84 miles on the Interstate system and lack direct commercial airline service; as a result, it is reasonable to omit air travel for this specific segment. However, the total Florida HSR corridor is proposed to serve travelers from Orlando to Miami, which is 230 miles of highway travel distance, and Tampa to Miami, which is 280 miles of highway travel distance. In the case of Florida, a fragmented HSR corridor analysis precludes consideration of the competitive and complementary nature of other modes, particularly in terms of ridership and environmental impacts. There was insufficient funding to continue HSR development in Florida, so it is not clear how additional segments of the corridor would be divided and assessed in the NEPA process.

The California HSR project, planned to extend from Sacramento to San Diego, continues to gain momentum with the passage of California Senate Bill 1029 in July 2012. This legislation appropriated funding for the first phase of HSR construction. As work is expected to continue, California HSR may be the first federally designated corridor to be constructed and operate at speeds in excess of 200 mph. This project's 2005 EIS is unique because it includes expansion of highway and aviation modes as alternatives to the proposed

HSR project (FRA 2005c). The no-action alternative represents the state's highway, air, and conventional rail system as it would be "after implementation of programs or projects that are currently in regional transportation plans and have identified funds for implementation by 2020." The "modal alternative" includes a combination of potentially feasible capacity enhancements to both highway and aviation infrastructure beyond that which is already planned in the no-action alternative. This primarily includes additional through lanes, passenger terminal gates, and runways that would be required to meet the projected intercity travel needs in 2020. As such, this is a consequential assessment because the impact of the implementation of HSR on the related intercity transportation systems of air and rail are incorporated into the assessment. The modal alternative was found to increase energy usage, increase suburban sprawl, and be less safe and reliable than the proposed HSR. For these reasons and others, the modal alternative was rejected in favor of HSR (FRA 2005c).

Currently, HSR is present in the United States in the form of the Acela, which serves the Northeast Corridor (NEC). The most recent PEIS for the NEC was in 1978. In 2012, a PEIS began: the NEC FUTURE—Passenger Rail Corridor Investment Plan (PRCIP). This document will consider rail services and corridor improvements going forward for the NEC. Because it is a PEIS, such that the corridors are not broken down into smaller pieces, it is likely to include air as an alternative mode (Amtrak 2012).

NATIONAL ENVIRONMENTAL POLICY ACT CONCLUSIONS

What does this mean for comparative environmental assessments of air and HSR in the context of NEPA? A seminal work in the legal field on the future of NEPA by Karkkainen (2002) discusses that perhaps some environmental challenges are too complex to fit in the framework of NEPA:

> NEPA's demand for comprehensive evaluation of environmental impacts, alternatives, and mitigation measures prior to an agency decision might have seemed straightforward and unproblematic at the time of its enactment. But we have subsequently learned that environmental impact assessment—and environmental management in general—are much more daunting challenges than they originally appeared. Environmental problems are complex, interrelated, and often only partially understood. The more we learn, the more we come to appreciate the complexities and recognize the gaps and uncertainties in our present knowledge—and the more the EIS production process comes to resemble a quagmire.

For the NEPA process to play a role in producing detailed air and HSR environmental assessments, the modes must be considered true modal alternatives, but understanding if the modes are truly alternatives is a highly complex issue that may be outside the scope of NEPA. Although NEPA processes are inherently consequential, such that they consider the change in impacts as a result of a system change, the quality of a consequential analysis depends on a detailed understanding of mode shifts related to competition and complementarity and airline and HSR operator behavior. An HSR system might meet the purpose and need of an air project by alleviating airspace congestion; this will be known only if detailed modeling regarding passenger demand and airline response can be performed. The estimation of this entire process is a highly complex endeavor (Airport Cooperative Research Program 2013). Guidance related to the bounds of a NEPA process as it relates to air and HSR environmental assessments has yet to be provided.

The NEPA process has immense value, particularly because it is rooted in law. The NEPA process performs assessments that are consequential, such that the impact of an investment or system change is evaluated. This provides key insight into the decision-making process because the impact of a decision or system change is evaluated. The NEPA process provides information on comparative environmental assessments before a project commences and before formal decisions are made, informing the decision-making process. Opportunities exist for environmental assessments outside of the NEPA process, most notably at the master planning or Interstate agency level (for example, the Oregon–Washington Bi-State Commission or the I-95 Corridor Coalition). These studies could provide great insight into environmental comparisons by allowing modes that are not fiscally constrained to be compared. However, such studies will not have the legal backing of a NEPA process and thus may have less impact than would a NEPA document.

CHAPTER FIVE

LOCAL AND REGIONAL IMPACTS

Local and regional impacts of air and HSR systems typically assess criteria air pollutants (CAP), noise, and land use. These impacts produce externalities on the local populations that may use the air and HSR systems, which is different than GHG externalities, which are possibly far from the regional systems.

CRITERIA AIR POLLUTANTS

Air quality effects are assessed by evaluating changes in CAP and precursor emissions and often include SO_x, NO_x, PM_{10}, $PM_{2.5}$, CO, and VOCs (or some subset thereof). CAPs cause direct human health and ecosystem service impacts and are regulated by the 1970 Clean Air Act and 1990 Amendments. Several studies consider CAPs to evaluate the trade-offs between airport and electricity generation effects. Some studies consider aircraft propulsion or HSR electricity generation emissions exclusively, whereas others include life-cycle effects. The inclusion of a broad suite of CAP emissions (often in addition to GHG emissions) can reveal unintended trade-offs. The substitution of air travel by HSR travel was found to reduce NO_x, CO, hydrocarbon (HC), and PM_{10} emissions but increase SO_2 by a factor of 12 owing to the sulfur content of primary fuels for electricity generation (Givoni 2007). Givoni's (2007) attributional assessment found that between Paris and London there were significant reductions in CAP between air and HSR systems (18 HC grams/seat air to 0.4 HSR, 126 to 2.2 CO, 71 to 18 NO_x, 2.9 to 35 SO_x, and 2.0 to 1.0 PM_{10}). Jamin et al.'s (2004) consequential assessment found that substituting one-third of air travel for HSR in the relevant corridors increases SO_x emissions across the corridors from 100 to 2,000 tons and decreases NO_x (5,000 to 4,200 tons), HC (2,200 to 1,900 tons), and CO emissions (6,100 to 4,200 tons). This could be important when assessing human health and environmental impacts and would depend on where the emissions occur. Increases in sulfur emissions may result in acidification of soil and groundwater and occur from changes in operation and propulsion energy inputs and also life-cycle effects (Chester and Horvath 2012). Some European studies monetize the local air pollution externalities (Janic 2003; Givoni 2007). Studies that assess CAPs rarely evaluate their human health and ecosystem service impacts. Chester and Horvath (2012) connect these emissions to human health respiratory, acidification, eutrophication, and photochemical smog formation impact potentials. Although significant research has been done to understand the impacts of aircraft, only one study identified in the United States assesses the impacts of HSR mode shifts (Chester and Horvath 2012). The study found that the time until environmental payback can vary significantly with the uncertainty in future ridership, which is affected primarily by the number of trip takers shifting from automobiles.

NOISE

Noise trade-offs are often considered for each mode to quantify the externalities of additional aircraft operations or how new rail lines will affect neighborhoods. There are studies that evaluate noise trade-offs of competing air and HSR travel (Janic 2003; Eagan and Mazur 2011), as well as studies that compare air, conventional rail, and automobile travel (European Commission 2002; Miedema 2007). The European Commission (2002) found that people generally are more annoyed by aircraft noise than rail noise, with highway noise falling between these two modes. Eagan and Mazur (2011) note that although this certainly has to do with acoustic factors, it also has to do with attitudes toward the noise source.

In the United States, the FAA has the authority to regulate noise at airports. This differs from the FRA, which typically performs noise mitigation based on an EIS and community concern. A key metric in noise evaluation, and thus in modal comparison, is annoyance and the day-night sound level, the 24-hour average sound level at an airport. Regarding annoyance, human annoyance response varies based on the degree of previous noise exposure, the degree of the incremental increases in exposure, and whether the source of noise is intermittent or constant. Although conventional rail noise generally is considered to generate less annoyance than air noise (European Commission 2002; Miedema 2007), rail noise is found to be largely correlated with train speed, and it is anticipated that annoyance associated with HSR noise will be higher than that with rail noise (Campos and de Rus 2009; Eagan and Mazur 2011). However, HSR can mitigate noise with low-to-the-ground sound walls because the noise is generated mainly from wheel-rail interaction similar to that of conventional rail (FRA 2005a). However, the impact of mitigation on annoyance is not clear. Noise exposure can translate into different levels of annoyance because nonacoustic factors, such as whether the source of the noise is visible and whether fear is associated with the source, also contribute to annoyance (Stallen 1999). In addition, “new noise” can generate more annoyance than existing noise of the same level, and noise in wealthy areas (“rich noise”) can be perceived as more onerous (Hansen et al. 2013). In addition, new noise is a complex topic for HSR. HSR will be a completely new source of noise that is also present among existing sources of transportation noise. This type of new noise is very different in perception compared with that of additional flights to an airport, which may not constitute new noise (Egan and Mazur 2011). Hansen et al. (2013) argue that airport noise impact is more a psychosocial phenomenon than an acoustic one, given that the receiver of sound may think or believe that sound is noise through the influence of others; the same may be true for HSR. Eagan and Mazur (2011) argue that this suggests that air and HSR systems may need different criteria that may not be based on high annoyance at DNL 65. Overall, the FAA has a long history of considering noise exposure relative to annoyance; if and when HSR is implemented across the United States, the FRA likely will amass a similar history.

Along with their spatial incompatibilities, air and HSR systems can have differing noise profiles. Aircraft noise is primarily a concern for near-airport operations because of the occurrence of low-altitude flight. Because HSR involves a system of links between stations, HSR noise may or may not occur predominantly at the nodes owing to a combination of mitigation possibilities (FRA 2005a), the population density near tracks, and operation characteristics. Areas of concern for HSR noise can vary based on characteristics of the operating plan and the corridor, and there are many contributing factors affecting whether a system may have more noise impact near nodes or more along the route. In general, there is less impact expected near stations than along the route. Some of the reasons for this are lower train speeds as trains approach and depart stations and less noise-sensitive land use near stations, particularly for stations located in urban areas, where there may be more commercial or industrial land use. Higher ambient noise levels at stations located in more urban areas can also result in less impact near stations because ambient noise levels determine the criteria for noise impact in rail assessments. However, noise impacts could be greater near stations if the train route goes through low population areas and has greater population density near stations; this may result in similarities with air, despite different values of population exposed (Janic 2003). Population density also affects where cost-effective mitigation might occur along a train route. Even with potential similarities in noise profiles for air and HSR systems, similar noise profiles do not immediately translate into a simple comparison methodology because of the psychosocial phenomena addressed by Hansen et al. (2013).

LAND USE

Land use impacts are commonly considered to assess the procurement efforts needed to deploy new air and HSR systems and typically are assessed in a consequential approach. Land uses, including farmland, forests, and wetlands, are common environmental metrics considered. The construction, operation, and maintenance of air and HSR systems requires land and can contribute to barrier effects (Kageson 2009; Rus 2011). Barrier effect occurs when linear infrastructure, such as road or rail lines, cuts through natural resource areas causing disturbance to animal migratory paths and ecosystems (Ree et al. 2007). Given the different infrastructure configurations of air and HSR systems, land use impacts manifest differently. Although HSR lines must be located between population centers, airport land size is largely governed by the volume of air traffic (Rus 2011). Air transport typically requires less land per passenger trip than does HSR (Rus 2011). Airport land-take occurs when the airport sees a need for capacity expansions, whereas land use impacts from HSR are dependent on the length of the HSR line and the environment along the line, not the volume of traffic in the corridor (Janic 2003). HSR must acquire land for the potential upper bound of use; the leveling of these capital and expansion land uses is not accounted for in the literature. Furthermore, it is important that growth-inducing impacts on surrounding land should be considered. Both air and HSR systems have the potential to create indirect land use impacts through new residential, commercial, and industrial activities near airports and train stations. Airports can create demand on nearby land for new industries that provide passenger and freight support infrastructure for airline operations. Although similar effects can occur with HSR, there is a stronger emphasis on understanding the planned growth of residential and commercial activities near stations (Nuworsoo and Deakin 2009).

CHAPTER SIX

GREENHOUSE GAS EMISSIONS

Starting in the 1990s, academic research began emerging comparing air and HSR environmental effects. Initially, the studies focused on European systems, and in the past 5 to 10 years there has been an emergence of research focusing on U.S. corridors. A summary of this literature is shown in Appendix A. Although most European studies identified evaluate long-distance travel in Spain, France, Germany, and Italy (Campos and de Rus 2009; Albalate and Bel 2012), literature was identified for nearly every country with an HSR system. In the United States, research is focused on the five corridors that have made the most progress toward deploying HSR systems: California, Florida, Texas, the Midwest, and the Northeast (Lynch 1990; Ryerson 2010; Burgess 2011; Carroll and Walton 2011; Chester and Horvath 2012; Tucker 2012). The trade-offs in energy consumption and GHG emissions are typically considered by evaluating changes in petroleum consumption and power plant effects from different levels of mode switching (Kosinksi et al. 2010). In general, study goals are to evaluate the environmental changes that occur from substituting air and automobile travel for new HSR travel.

Many studies develop GHG assessments comparing existing and future air and HSR travel, and there are a few that stand out for their comprehensiveness and novel approaches. Although many of the studies shown in Appendix A focus on HSR, those presented in this synthesis have significant air travel analyses as either a business-as-usual future or a future where air travel has made advances in reducing its environmental footprint and is a competing or complementary service to HSR. Jamin et al. (2004) estimate the GHG and other air emissions effects of aviation emission abatement policies in the United States and include substitution of some short-distance air travel with HSR. Both Givoni (2007) and Janic (2003) develop comprehensive assessments that include GHG emissions in addition to other impacts and monetize the results. Givoni (2007) produces a door-to-door assessment of air and HSR travel between London and Paris and normalizes GHG and CAP emissions to their monetary external costs. Givoni's (2007) attributional assessment finds that between London and Paris the CO_2 emissions (kilograms per seat) from HSR travel are 7.2 and from air travel are 44. Janic's (2003) attributional assessment estimates that the French TGV emits 4 g CO_2 per passenger-kilometer traveled (89% nuclear electricity), the German ICE 28 g (50% coal electricity), and a competing flight between 100 and 150 g. These emissions combined with other damages (i.e., other air pollution, noise, land use, congestion, and accidents) are used to monetize the external costs of HSR and air travel, respectively, at ¢0.002 to 0.01 and ¢0.02 to 0.08 per passenger-kilometer traveled in the United States and Europe. Chester and Horvath (2012) include roughly 150 life-cycle components in the assessment of future long-distance travel in California, and by first using an attributional approach, they find that although HSR is likely to produce lower GHG emissions per passenger-mile traveled, an average occupancy of 130 to 280 passengers is needed to compete with emerging aircraft and one of 80 to 180 passengers to compete with a 35-mpg sedan. They then develop a consequential assessment to determine that given future HSR adoption uncertainty, GHG payback will occur between 20 and 40 years; that payback includes emissions from construction and maintenance activities. Chester and Horvath also include modeling of emerging technologies, regional flight characteristics (instead of multiplying a per seat-mile factor across forecasted seat-miles), and uncertainty in mode shifting. Several common approaches are used to assess large-scale GHG emission changes in regions. Most comparative studies are designed to assess the GHG emission changes that result from shifting away from air to HSR. Consequently, many comparative studies are structured as deviations from the status quo (i.e., air travel) and focus on the critical factors that will drive the success of HSR deployment in a region.

The time-based GHG impacts from the initial construction of air and HSR infrastructure are another important factor considered by long-distance transportation researchers (Kageson 2009; Chang and Kendall 2011). Time-based radiative forcing assessment methods have been developed as consequential assessments to account for the upfront global warming potential from initial construction of new systems. Radiative forcing is an imbalance in the earth system between incoming and outgoing radiation. GHGs allow shortwave light radiation to enter the earth's atmosphere but restrict the exit of long-wave heat radiation, resulting in an accumulation of energy that leads to climate change. GHGs vary in their radiative efficiency, which determines their ability to accumulate heat. Per unit of mass, N_2O traps the most heat, followed by CH_4 and then CO_2. A GHG will continue to cause radiative forcing and trap heat in the earth system as long as it remains in the atmosphere (U.S. Department of Energy, March 26, 2011: http://carboncycle2.lbl.gov/resources/experts-corner/fossil-fuel-combusion-heat-vs-greenhouse-gas-heat.html).

Chang and Kendall (2011) apply cumulative radiative forcing methods used by the Intergovernmental Panel on Climate Change to normalize the warming potential that occurs over the long run of California's HSR system. They show that the global warming potential payback of HSR, which is highly sensitive to ridership, takes longer when cumulative radiative forcing methods are used, rather than straight GHG accounting.

CHAPTER SEVEN

UNIFYING FRAMEWORKS

LCA, impact assessment, and benefit-cost analysis are sometimes used to produce unifying analytical boundaries and metrics for comparing air and HSR systems. These frameworks produce common footings by which the net social costs of long-distance transportation services can be assessed.

LIFE-CYCLE ASSESSMENT

Most environmental assessments focus on vehicle operation and propulsion; however, there has been a recent emergence of studies that quantify the life-cycle effects by including vehicle, infrastructure, and energy production components. Environmental LCA approaches have been used for U.S. transportation systems assessment since the mid-1990s (Lave et al. 1995; MacLean and Lave 1998) and recently have been applied to air and HSR systems for environmental comparisons (Network Rail 2009; Chester and Horvath 2010, 2012). LCAs of air and HSR systems can include vehicles (manufacturing and maintenance), infrastructure (construction, operation, and maintenance), and energy production (primary fuel feedstock extraction, processing, and distribution) components. LCA studies tend to capture either all components (Chester and Horvath 2010, 2012) or strictly infrastructure construction effects (Chang and Kendall 2011), in addition to vehicle operation and propulsion. There are several LCA studies that focus exclusively on the construction impacts of HSR (Thiebault 2010; Åkerman 2011; Chang and Kendall 2011), whereas other studies consider only vehicle operation and propulsion (Givoni 2007; Scott 2011). LCA results for California's air and HSR systems show that (1) for air, life-cycle components can increase the mode's footprint by roughly 20%, and (2) for HSR, concrete and steel used in infrastructure construction may double the GHG footprint of the mode (Chester and Horvath 2012). In Figure 4, life-cycle GHG emissions (per passenger-mile traveled) for long-distance modes in the California corridor from Chester and Horvath (2012) are shown. The life-cycle results contrast operation (gray) and propulsion (light green) GHG emissions against vehicle (manufacturing and maintenance), infrastructure (construction, operation, and maintenance), and feedstock energy (raw primary fuel extraction, processing, and distribution). Emissions from infrastructure construction may be offset by reductions in automobile manufacturing, roadway construction, and airport construction in the long run (Åkerman 2011). Wang and Sanders (2011) use economic input-output LCA methods to estimate that Florida HSR construction will have significantly lower energy and GHG effects than that of California because of heavy engineering requirements in California, particularly in structure work.

Sustainability trade-offs between future air and HSR systems should connect environmental perturbations with their human health, ecosystem services, resource depletion and climate change impacts where possible. Over the past half century, significant research and efforts have been made by the aviation industry and academics to understand the human health impacts of near-airport operations (Bastress 1973; Westerdahl et al. 2008; Hu et al. 2009). As questions emerge about the trade-offs of air and HSR systems, it will be important to define "sustainability" in its broadest sense (instead of strictly GHG emissions) to understand environmental benefits or unintended trade-offs. Although GHG emission comparisons are critically important, it is also important that future studies consider other air emissions (in particular CAP emissions) as well as the environmental concerns identified by NEPA. By defining sustainability broadly, opportunities will exist for understanding how the reduction in one environmental concern may lead to a reduction in another, or reduction in one environmental concern may lead to an increase in another (i.e., an unintended trade-off). By identifying unintended trade-offs early in the planning process, more opportunities will exist for implementing mitigation strategies. The summary of studies shown in Table A1 reveals a heavy interest in energy and GHG analysis, and only one comparative study was identified that connects air emissions to human health and ecosystem services impacts (Chester and Horvath 2012); that study evaluates GHG emissions and the potential for human health respiratory impact, acidification, eutrophication, and photochemical smog formation trade-offs in future long-distance travel in California. Existing research can aid in classifying the many sustainability impacts that can be considered beyond the standard NEPA criteria considered in EIRs and EISs. Few studies have attempted to quantify the human health, ecosystem services, and resource depletion impacts outside of GHG effects. Although not all impacts will be relevant or of interest to different stakeholders, it is critical to understand the interrelation of pollutants. The quantification of pollutant trade-offs is valuable; however, ultimately a more rigorous understanding is needed of the impacts these pollutants cause with their release in particular geographic areas.

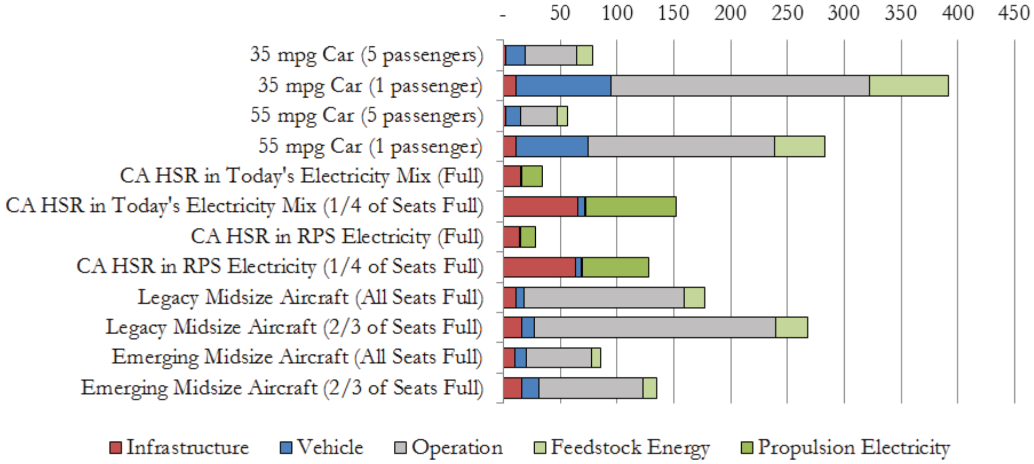

FIGURE 4 Life-cycle GHG emissions per passenger-mile traveled. (Source: Chester and Horvath 2012.) Emissions to impacts (*note*: RPS electricity is the U.S. regulatory Renewable Portfolio Standard that requires the increased production of energy from renewable energy sources, such as wind, solar, biomass, and geothermal).

Impact assessment practitioners in LCA have identified and categorized broad suites of human health, ecosystem quality, climate change, and resource depletion concerns, and air and HSR system decision makers can use this research to aid in the environmental assessment of their systems. Table 3 shows the categorization of pollutants into midpoint categories that are then aggregated to damage categories. For example, several midpoint categories produce human health impacts and Jolliet et al. (2003) advocate that these midpoint categories can be joined after impacts are normalized to disability adjusted life-years to obtain a comprehensive assessment of human health impacts.

Life-cycle impact assessment methods generally focus on physical pollutants and do not include characterization methods for many of the NEPA criteria. However, the methods developed provide a framework upon which air and HSR environmental assessment practitioners can begin joining the many indicators that are of interest for future decisions.

BENEFIT-COST ANALYSES

Defining an HSR cost model presents a unique set of challenges compared with the aircraft cost model development. Currently there are no HSR systems in the United States from which to collect cost and operating statistics. Although there are many HSR systems across the world, publicly available data are limited and not available in a consistent format. For example, many HSR operators present their operating statistics in annual reports, yet these statistics may be aggregated with conventional rail operations. Campos and de Rus (2009), in a comprehensive study of HSR system costs and HSR modeling techniques, note the challenge of comparing (and therefore modeling) costs across HSR systems. Because HSR projects are built over various topographical landscapes, different technical solutions and levels of investment are needed. This is unlike the air mode, for which one can model aircraft costs with some level of consistency. Although some studies have attempted to quantify the economic benefits

TABLE 3
MIDPOINT AND DAMAGE CATEGORIES FOR ENVIRONMENTAL ASSESSMENT PRACTITIONERS

	Midpoint Category	Damage Category
Pollutants	Human toxicity	Human health
	Respiratory (inorganics)	Human health
	Ionizing radiation	Human health
	Ozone layer depletion	Human health
	Photochemical oxidation (respiratory organics)	Human health/Ecosystem quality
	Aquatic ecotoxicity	Ecosystem quality
	Terrestrial ecotoxicity	Ecosystem quality
	Terrestrial acidification/Nutrification	Ecosystem quality
	Aquatic acidification	Ecosystem quality
	Aquatic eutrophication	Ecosystem quality
	Land occupation	Ecosystem quality
	Global warming	Climate change
	Non-renewable energy	Resource depletion
	Mineral extraction	Resource depletion

Adapted from Jolliet et al. 2003.

of air travel, similar HSR benefits to a region are not clear. The costs of U.S. HSR systems have been of interest as regions attempt to understand the investments and operating commitments that will be needed to maintain service; however, the economic benefits of that service are not well understood.

Benefit-cost analyses of air and HSR systems sometimes include monetization of environmental impacts (Levinson et al. 1997; Janic 2003; Givoni 2007; Adler et al. 2010; Rus 2011) (see Figure 5). Adler et al. (2010) develop social welfare functions that include environmental externalities to assess transportation infrastructure investments and their effects on transportation equilibriums. They find that the European Union should include HSR development in future long-distance transportation investment to maximize social welfare. Rus (2011) develops a framework that includes monetized externalities to evaluate the conditions under which investment in HSR projects are justified. Givoni (2007) computes the environmental benefits of mode substitution for air and HSR by estimating the aircraft, access/egress, aircraft journey, and HSR journey air pollution externalities per seat between London and Paris. Givoni finds that the external costs of travel on HSR are 0.52 Euros per seat and on air are 1.03 Euros per seat. Janic (2003) monetizes air emission externalities and evaluates that the marginal costs of HSR travel are generally lower than those of air travel in Europe but does not assess the total costs of each system.

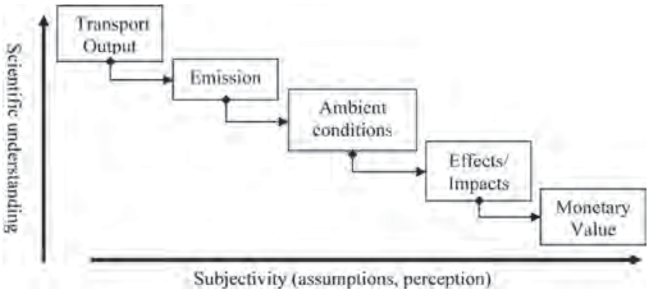

FIGURE 5 Givoni (2007) outlines the steps leading to the monetization of environmental impacts. At each stage, additional uncertainty is introduced, decreasing the level of scientific understanding and increasing subjectivity.

CHAPTER EIGHT

CONCLUSIONS

There is significant experience and research on the competition and complementarity of air and high-speed rail (HSR) modes. The existing research covers areas including system structure (vehicle technology, cost, ridership, etc.) and environmental effects. The objective of this synthesis is to bring together research and other findings related to air and HSR environmental assessments. A literature review is the primary tool for collecting data for this synthesis of current practice.

The literature revealed that there are two approaches to categorizing air and HSR assessments: attributional and consequential. Attributional assessments look backward from some point in time and are used to allocate the environmental effects to passenger travel, a trip, or vehicle travel. Consequential assessments look forward as a result of a system change and can be used to determine the changes to the total regional environmental effects caused by a particular decision.

The air and HSR modes, although sometimes overlapping, are fundamentally structured differently. The aviation system is structured as a system of nodes (i.e., airports) connected with aircraft operated by independent operators. The spatial scale of the nodes is vast, such that passengers can travel between nodes in a region or in two separate countries. In contrast, the HSR system is structured as a system of links, with the spatial scale being limited to a fixed regional area and one operator providing both the rail infrastructure and locomotive services. HSR is planned in designations termed *corridors:* rail track between major cities and the regions between. In contrast, aviation is not planned in corridors. Airports are planned to serve a region, and airlines connect this region to their hub airports and possibly some additional airports. That these two networks may have some overlapping portions yet serve different scales of network presents a complexity when defining the system structure for an environmental assessment. The result is *spatial incompatibility* between modes; rail service is planned in corridors, whereas air service is planned over a national and global network.

Spatial incompatibility across modes makes it difficult to compare environmental assessments. Some studies consider air and HSR to be “competitive corridors,” whereas others view the broader aviation system network and HSR services to be complementary when nearby regions are linked with an airport. The fundamental differences in air and HSR environmental assessments impede the drawing of the analytical system boundary for environmental assessments; aviation is a system of nodes with the planning focused on airports, and rail is a series of nodes connected by links with the planning focused on specific corridors.

The focus when synthesizing the literature was on two types of literature: government-driven environmental impact assessments and academic literature. Government-driven environmental impact assessments are in the form of National Environmental Policy Act (NEPA) studies. In general, the NEPA process investigates and reports the extent of the environmental impacts of the proposed federal action and further evaluates the environmental impacts of feasible and prudent alternatives to the proposed action. When environmental impacts are deemed to be potentially significant, an Environmental Impact Statement (EIS) is prepared in accordance with the NEPA process to document the extent of the environmental impacts. Alternatives that are deemed feasible and prudent move forward for full environmental impact review.

For an alternative mode to be fully assessed in an environmental review process, it must meet the purpose and need. The Purpose and Need Statement in the EIS is intended to define the objectives to be achieved by the proposed project (purpose) and the overarching problems that motivated the project (need). The framing of the purpose and need is a primary factor in determining the feasibility of alternatives in an EIS. All EISs must include a discussion of the purpose and need for the action, a description of the proposed action and alternatives to the proposed action, analysis of the affected environment and environmental consequences, and mitigation measures. However, considering the spatial incompatibility of the two modes, assessing if HSR meets the needs of an aviation project, and vice versa, is a highly complex process. As a result, few detailed modal assessments are found in EIS documents.

Government-driven work provides an important framework for assessing air and HSR environmental comparisons, yet the language of NEPA alternative assessments can preclude a full, detailed analysis of modal alternatives. Government-driven work also notes the role HSR can play as a feeder and as a competitor; however, owing to other complications to be explored, few detailed assessments have been performed.

Although there is a growing body of academic literature that seeks to reconcile spatial incompatibility, the academic literature is not bound by the same legal and institutional protocols of the environmental review process and therefore does not have to draw a constrained system boundary. Academic literature is free to compare any modes, regardless of whether they are implemented, programmed, or conceptual. The following is a sample of results from academic literature:

- The substitution of air by HSR was found to reduce NO_x, CO, hydrocarbon (HC), and PM_{10} emissions but increase SO_2 by a factor of 12 owing to the sulfur content of primary fuels for electricity generation (Givoni 2007). Givoni's (2007) attributional assessment found that between Paris and London there were significant reductions in criteria air pollutants (CAP) between air and HSR, respectively (18 to 0.4 g/seat HC, 126 to 2.2 g/seat CO, 71 to 18 g/seat NO_x, 2.9 to 35 g/seat SO_x, and 2.0 to 1.0 g/seat PM_{10}).
- In 2004, a consequential assessment by Jamin et al. found that substituting one-third of air travel for HSR in the relevant corridors increased SO_x emissions across the corridors from 100 to 2,000 tons and decreased NO_x (5,000 to 4,200 tons), HC (2,200 to 1,900 tons), and CO emissions (6,100 to 4,200 tons). This could be important when assessing human health and environmental impacts and would depend on where the emissions occur. Increases in sulfur emissions may result in acidification of soil and groundwater and occur from changes in operation and propulsion energy inputs and also life-cycle effects (Chester and Horvath 2012). The study found that the time until environmental payback can vary significantly with the uncertainty in future ridership, which is primarily affected by the number of trip takers shifting from automobiles.
- The European Commission (2002) found that people are generally more annoyed by aircraft noise than rail noise, with highway noise falling between these two modes. Eagan and Mazur (2011) noted that although this certainly has to do with acoustic factors, it also has to do with attitudes toward the noise source.
- Along with their spatial incompatibilities, air and HSR can have differing noise profiles. Aircraft noise is primarily a concern for near-airport operations because of the occurrence of low-altitude flight. Because HSR involves a system of links between stations, HSR noise may or may not occur predominantly at the nodes because of a combination of mitigation possibilities (FRA 2005a), the population density near tracks, and operation characteristics. In general, there is less impact expected near stations than along the route.
- Air transport typically requires less land per passenger trip than does HSR transport (Rus 2011). Airport landtake occurs when the airport sees a need for capacity expansions, whereas land use impacts from HSR are dependent on the length of HSR line and the environment along the line, not the volume of traffic in the corridor (Janic 2003). Furthermore, it is important that growth-inducing impacts on surrounding land be considered. Both air and HSR systems have the potential to create indirect land use impacts through new residential, commercial, and industrial activities near airports and train stations.
- Givoni's (2007) attributional assessment found that between London and Paris the CO_2 emissions from HSR travel are 7.2 kg/seat and from air travel are 44 kg/seat.
- Janic's (2003) attributional assessment estimated that the French HSR service (the TGV) emits 4 g CO_2 per passenger-kilometer traveled (89% nuclear electricity), the German HSR service (the ICE) 28 g (50% coal electricity), and a competing flight between 100 and 150 g. These emissions combined with other damages (i.e., other air pollution, noise, land use, congestion, and accidents) are used to monetize the external costs of HSR and air travel, respectively, at Euros 0.002 to 0.01 and 0.02 to 0.08 per passenger-kilometer traveled in the United States and Europe.
- Chester and Horvath (2012) included roughly 150 life-cycle components in their assessment of future long-distance travel in California and, by first using an attributional approach, found that although HSR is likely to produce lower GHG emissions per passenger-mile traveled, an average occupancy of 130 to 280 passengers is needed to compete with emerging aircraft and one of 80 to 180 passengers to compete with a 35-mpg sedan. Chester and Horvath then developed a consequential assessment to determine that, given future HSR adoption uncertainty, greenhouse gas (GHG) payback will occur between 20 and 40 years, which includes emissions from construction and maintenance activities. They included modeling of emerging technologies, regional flight characteristics (instead of multiplying a per seat-mile factor across forecasted seat-miles), and uncertainty in mode shifting.
- Givoni (2007) computed the environmental benefits of mode substitution for air and HSR by estimating the aircraft, access/egress, aircraft journey, and HSR journey air pollution externalities per seat between London and Paris. He found that the external costs of travel on HSR are 0.52 Euros per seat and on air are 1.03 Euros per seat. Janic (2003) monetized air emission externalities and estimated that the marginal costs of HSR travel generally are lower than those for air travel in Europe, but Janic did not assess the total costs of each system.

In investigating the role of air and HSR as competitors and complementary modes, understanding ridership is a crucial component. Several studies cite the importance of accurate ridership forecasts to understand the environmental outcomes of future long-distance transport systems. Some studies explore the sensitivity of environmental performance to ridership. Other studies focus on understanding the long-run per passenger-mile traveled footprint of passengers to understand the environmental intensity of service. Per-trip measures are common and valuable for eliminating the differences in trip distances to reach the same origin-destination pairs. Regardless, current air and HSR transportation systems that offer lower emissions might appear attractive from an environmental standpoint, but if such a system is unable to attract passengers, it will produce negative environmental benefits: a train or an aircraft with no payload does all harm and no good.

In an effort to produce unifying analytical boundaries and metrics for comparing air and HSR systems, the following assessments are used in academic literature: life-cycle assessment (LCA), impact assessment, benefit-cost analysis, and GHG assessment. LCAs of air and HSR systems can include vehicles (manufacturing and maintenance), infrastructure (construction, operation, and maintenance), and energy production (primary fuel feedstock extraction, processing, and distribution) components. LCA results for California's air and HSR systems show that (1) for air, life-cycle components can increase the mode's footprint by roughly 20%, and (2) for HSR, concrete and steel used in infrastructure construction may double the GHG footprint of the mode. Significant research and efforts have been made by the aviation industry and academics to understand the human health impacts of near-airport operations. Although GHG emission comparisons are critically important, it is also important that future studies consider other air emissions, as well as the environmental concerns identified by NEPA. By defining sustainability broadly, opportunities will exist for understanding how the (1) reduction in one environmental concern may lead to a reduction in another, or (2) reduction in one environmental concern may lead to an increase in another; that is, an unintended trade-off. Finally, defining an HSR cost model presents a unique set of challenges compared with the aircraft cost model development. Because HSR projects are built over various topographical landscapes, different technical solutions and levels of investment are needed. Although some studies have attempted to quantify the economic benefits of air travel, similar HSR benefits for a region have not been rigorously studied. Various studies in this area range from developing social welfare functions to assess transportation infrastructure investments, to developing a framework to justify HSR projects, to computing the environmental benefits of mode substitution for air and HSR.

Through the synthesis of the literature, major gaps in knowledge were found:

- Methodological frameworks and tools that assess future operating characteristics of long-distance transportation service have not been fully developed. Such frameworks and tools would need to address the two main components of the relationship between air and HSR: as competitors and as complementary modes.
- A framework and methodology are needed to analyze the impact to airline operations, and thus airport infrastructure use, of development of HSR. The same goes for the "no build" alternative: estimating the future of aviation flows in the absence of HSR infrastructure is necessary.
- By performing consequential assessments instead of attributional assessments, organizations incentivize practitioners to use comprehensive assessment frameworks. The consequential assessment would require an understanding of how up-front investments lead to regional operating effects. Although NEPA in many ways requires an assessment of impacts, the academic literature has for the most part avoided these quantifications, likely because of the complexities of accurate estimates.

In conclusion, environmental assessments of air and HSR systems have produced valuable knowledge for reducing human health, ecosystem services, and resource depletion impacts. However, gaps still exist. If these gaps can be closed, decision makers would have more information on which to base their decisions. By establishing regional planning processes, drawing on previously established methods, and developing new tools and information for better understanding future processes, more comprehensive approaches can be developed to better understand the benefits of intelligent air and HSR planning.

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APPENDIX A

Literature Survey

The academic studies in Table A1 were reviewed for this synthesis. For each study, Table A1 shows the geographic region assessed and the relevant environmental indicators that were quantified.

TABLE A1
AIR AND HSR ENVIRONMENTAL INDICATORS LITERATURE SURVEY

Study	Geographic Region(s)	Environmental Indicators				
Energy and GHGs		Energy	GHGs	CAP	Land Use	Noise
Burgess (2011)	United States United States (California, Northeast, Midwest)	✓	✓			
Carroll and Walton (2011)	United States (Texas)	✓	✓		✓	
Center for Clean Air Policy and Center for Neighborhood Technology (2006)	United States		✓			
Chester and Horvath (2010)	United States (California)	✓	✓	✓		
Chester and Horvath (2012)	United States (California)	✓	✓	✓		
Eagan and Mazur (2011)	United States (Northeast)					✓
Givoni (2007)	France, United Kingdom		✓	✓		✓
Greene and Wegener (1997)	Europe					✓
Jamin et al. (2004)	United States		✓	✓		
Janic (2003)	Europe	✓	✓		✓	✓
Janic (2011)	Europe		✓		✓	✓
Kageson (2009)	Sweden		✓			
Kosinksi et al. (2010)	United States		✓			
Lynch (1990)	United States (Florida)	✓	✓	✓		
Smith (2003)	Global	✓	✓			
Thiebault (2010)	United States (California and Florida)		✓	✓		
Tucker (2012)	United States (California)		✓			
Wang and Sanders (2011)	United States (California and Florida)	✓	✓			
Westin and Kageson (2012)	Europe		✓			
Zanin et al. (2012)	Spain		✓			

The Environmental Impact Statement literature reviewed for this synthesis is shown in Table A2. The literature is categorized by air and HSR projects.

TABLE A2
FEIS DOCUMENTS FOR CAPACITY-ENHANCING AIRPORT AND HSR PROJECTS

Airport with Capacity Enhancement Project	Year of FEIS Publication/ Record of Decision	Nearby HSR corridor	Final Environmental Impact Statement Title
Chicago O'Hare International Airport	2005	Chicago Hub	O'Hare Modernization Final Environmental Impact Statement
Philadelphia International Airport	2007/2010	Northeast and Keystone Corridors	New York/New Jersey/Philadelphia Metropolitan Area Airspace Redesign
Washington Dulles International Airport	2005	Southeast and Northeast	Final Environmental Impact Statement for New Runways, Terminal Facilities and Related Facilities at Washington Dulles International Airport
Fort Lauderdale-Hollywood International Airport	2008	Florida	FEIS for the Development and Expansion of Runway 9R/27L and Other Associated Airport Projects At Fort Lauderdale-Hollywood International Airport
HSR Corridor Project and Expected Top Speed	Year of FEIS Publication/ Record of Decision	Nearby Major Airport(s)	Final Environmental Impact Statement Title
Chicago Hub Network (80–110 mph)	2003/2001	O'Hare, Lambert–St. Louis International Airports	Final Environmental Impact Statement Chicago–St. Louis High Speed Rail Project
Florida (120–170 mph)	2005/2010	Tampa, Orlando, and Orlando Sanford International Airports	Final Environmental Impact Statement Florida High Speed Rail Tampa to Orlando
California (220+ mph)	2012 (Revised)/ 2005	Los Angeles, San Francisco, Sacramento, Oakland, and San Diego International Airports	California High Speed Train Project Environmental Impact Report/Environmental Impact Statement

Abbreviations used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation