Interaction of High-Speed Rail and Aviation

Exploring Air–Rail Connectivity

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U.S. airports face significant congestion problems, particularly in major metropolitan areas with continued population and economic growth. In addition to growth in air travel demand, frequent short-haul flights on routes of less than 500 mi contribute to airport congestion. The potential for high-speed rail (HSR) to substitute for aviation on these short-haul routes is well documented; however, there is a need to explore how rail can serve in a complementary mode to relieve congestion at airports by providing short-haul services in support of longer-haul airline services. The primary objective of this research project is to examine the role of cooperation between HSR and aviation to improve the aviation system planning process. This study addresses the following key questions: (*a*) How have airports, airlines, and rail operators cooperated to enable airport–HSR connectivity? (*b*) What are the service characteristics of airport–HSR connectivity? (*c*) What are the unique challenges associated with airport–HSR connectivity? (*d*) How has the demand for air transportation evolved in the presence of airport–HSR connectivity?

It is suggested that the expansion of high-speed rail (HSR) lines in Europe has resulted in substantial shifts in mode share away from aviation for intercity passenger transport in this region. These adjustments in travel behavior have significant implications for infrastructure investment decisions and the environmental footprint of the transportation sector. Airports and HSR require costly infrastructure that, once built, is typically used for long periods (*1*). Given the relationship between demand for aviation and HSR, increased understanding of the factors that shape intercity travel demand for these two modes is critical for long-range transportation system planning.

In the past decade, several studies have emerged that analyze the substitution of HSR for air transportation, particularly in Europe and Asia (*2, 3*). Most of these studies focus on mode choice between two major cities, using choice modeling methods to examine revealed preference or stated preference data. A few studies documenting air transportation and HSR in France, Spain, and Japan conclude that it is difficult for air transportation to compete effectively in short-haul markets of 500 km or less (*2, 4*). Comparative studies based on European HSR development have also examined historical market share and general trends in demand for air transportation and HSR.

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There is little existing documentation detailing the history of how airport, airline, and rail operator partnerships were formed to enable airport–HSR connectivity. In addition, although there is much speculation about how air–rail connectivity affects air traffic demand, there is little existing empirical analysis of systemwide air traffic trends where airport–HSR integration exists. This study increases the understanding of how airport–rail partnerships are formed, how they are implemented, and how they affect broader demand for aviation systems.

METHODOLOGY

This project used a multiple-case design methodology to examine aviation–rail cooperation in Europe. Data collection and analysis focused on the country as the primary unit of investigation, with a concentration on the country's major airport. Germany's Frankfurt on Main Airport (Frankfurt Airport) and France's Paris Charles de Gaulle (CDG) Airport were the main airports studied for this research because they include integrated HSR and passenger air service.

Three primary sources of data were used: (*a*) interviews with key stakeholders engaged in airport–rail partnerships, (*b*) archival data, and (*c*) statistical data on air traffic demand in Europe.

Interview data were gathered through telephone interviews with aviation industry experts and rail operators providing service to the airport of interest. Interviews explored the following issues:

- Relationships between airports, airlines, and rail operators;
- Services that are provided and may support air–rail connectivity (e.g., code sharing, bags checked through final destination, single security checkpoint);
- Other unique challenges associated with providing air–rail intercity connectivity; and
- The impact of policies at national, regional, and airport levels on supporting air–rail connectivity.

Historical industry data were collected and included reports and conference presentations, which documented the history of air–rail partnerships, key challenges associated with offering the integrated service, and evolution of transportation demand at each airport.

The primary quantitative data source used in this study is a publicly available database maintained by Eurostat, the statistical office of the European Union (EU). Eurostat's air transport statistical database was accessed in May and June 2011. Two primary metrics for air traffic available through Eurostat are total commercial flights and passengers carried for major airport pairs and airports. Total passengers carried includes all passengers who travel between two airports, including those who may be connecting to or from another flight. Eurostat data were collected to examine air traffic at the origin–destination (O-D) and airport level, including domestic, intra-EU, extra-EU, international (intra-EU + extra-EU), and total traffic.

GERMANY

Evolution of Air Transportation Demand in Germany

Airport congestion, particularly at major airports around the world, is often cited as a key reason for developing air–HSR connectivity (*5*). It has been suggested that if short-haul travel on corridors of 500 mi or less could be served effectively by HSR transportation, landing and takeoff slots at congested airports could be freed up for longer-haul domestic and international travel not effectively served by rail.

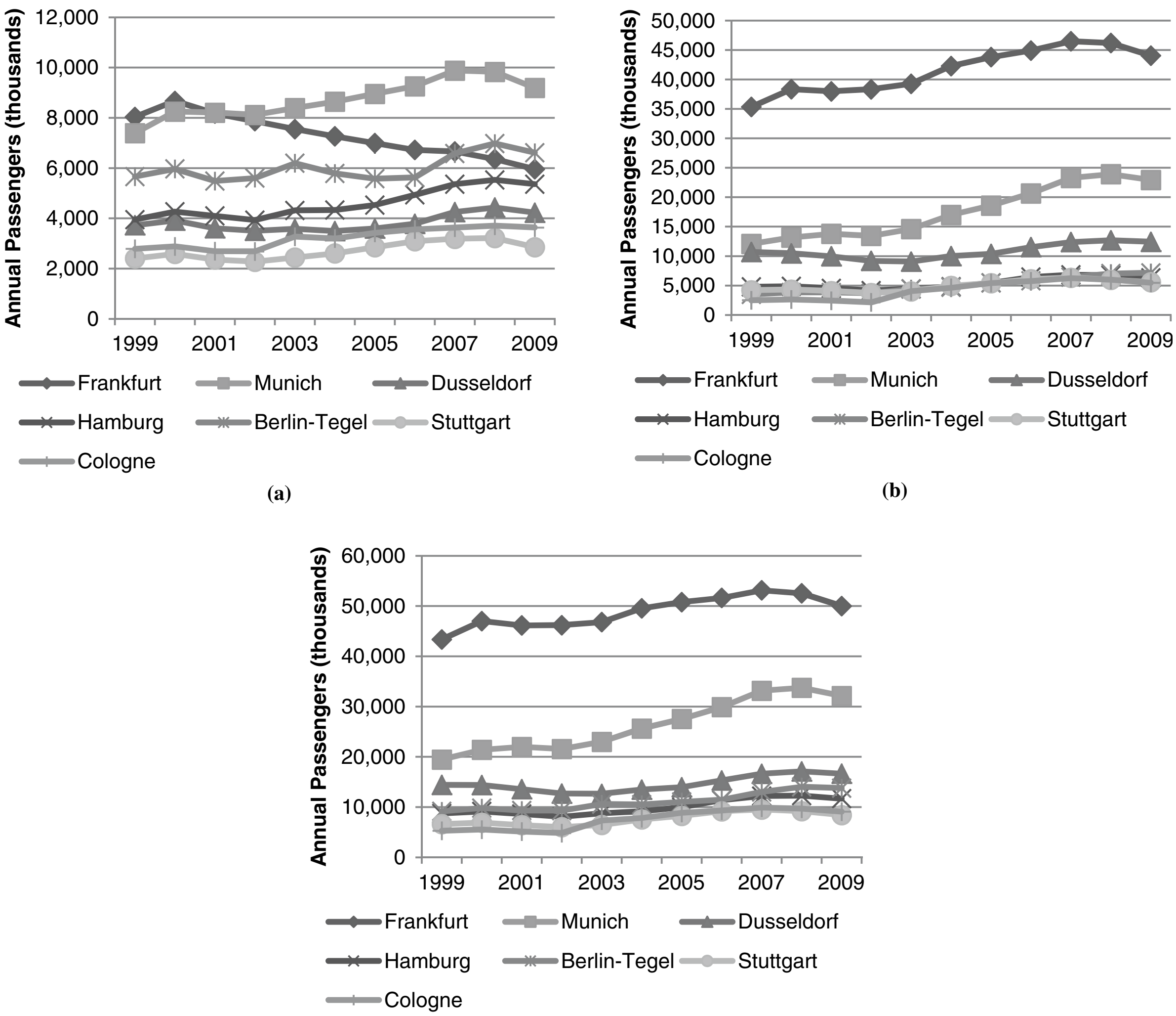
This section analyzes air traffic at the airport level in Germany and examines how passenger traffic has evolved for domestic, international, and total air traffic in the presence of air–rail connectivity (Figure 1). Table 1 summarizes the annual average change in traffic at the top seven German airports from 1999 through 2009.

Frankfurt Airport

As shown in Table 1 and Figure 1*a,* domestic travel declined significantly after the launch of HSR connectivity at Frankfurt Airport. Domestic air passenger traffic steadily increased at the Frankfurt Airport in the late 1900s through 2000, but began to decline starting in 2001, as travel was likely influenced by the economic downturn and the September 11, 2001, terrorist attacks. A decline in domestic and international traffic occurred at all major airports in Germany starting in 2001; however, all airports except Frankfurt experienced a recovery of growth in domestic air traffic in 2002 or 2003. Frankfurt Airport experienced an average annual change of −3% in domestic traffic between 1999 and 2009, while all other major German airports experienced an annual average change of +2%.

Total air traffic at Frankfurt Airport increased modestly during this time period, driven by a 2% growth in international passenger traffic (Figure 1*b* and *c*). Several changes occurred between 1999 and 2003 that improved access to Frankfurt Airport, including the following:

- Infrastructure improvement that enhanced access to Frankfurt Airport from the eastern part of Germany,



(c)

FIGURE 1 German airport domestic and international passenger traffic, 1999–2009: (*a*) domestic traffic, (*b*) international traffic, and (*c*) total traffic.

TABLE 1 Air Traffic at Seven Major Airports in Germany, 1999–2009

	Domestic Traffic		International Traffic		Total Traffic	
Airport	Average Annual Passengers	Average Annual Change (%)	Average Annual Passengers	Average Annual Change (%)	Average Annual Passengers	Average Annual Change (%)
Frankfurt	7,296,877	–0.03	41,537,512	0.02	48,834,389	0.01
Munich	8,738,587	0.02	17,581,311	0.07	26,319,899	0.05
Dusseldorf	3,829,775	0.01	10,797,182	0.02	14,626,957	0.02
Berlin Tegel	6,007,973	0.02	5,078,354	0.08	11,086,328	0.04
Hamburg	4,601,099	0.03	5,396,168	0.03	9,997,267	0.03
Stuttgart	2,716,573	0.02	4,967,827	0.03	7,684,400	0.05
Cologne–Bonn	3,225,936	0.03	4,295,495	0.11	7,521,431	0.07
Average		0.02		0.05		0.04

- A new long-distance train station at Frankfurt Airport that provided a direct connection from the south of Germany for the first time, and
- Launching of HSR lines to Cologne and Stuttgart.

The infrastructure improvements resulted in a significant increase in the catchment area of Frankfurt Airport. With the opening of the Frankfurt–Cologne and Frankfurt–Stuttgart HSR lines, Frankfurt Airport increased its catchment area by 10 million people who suddenly lived within 2 h of the airport. According to expert interviews and archived presentations from Fraport, the owner and manager of Frankfurt Airport, in 2008 more than half (53.2%) of the originating passengers who departed from Frankfurt Airport began their journey outside the Rhine Main–Hesse region where the airport is based.

The expansion of Frankfurt's catchment area has affected the ability of other major airports in Germany to compete with Frankfurt for international flights. Although it appears that Munich Airport's international traffic increased substantially from 1999 to 2009 compared with Frankfurt Airport (7% versus 2%), the increase in total volume is on a similar scale: 8.7 million more passengers at Frankfurt, and 10.9 million more international passengers at Munich. An interesting observation is the type of international traffic at these two airports: Munich's ratio of EU traffic to non-EU international traffic is 54:46, compared with Frankfurt's ratio of 65:35. Whereas Frankfurt Airport may be limited in terms of capacity, it has managed to support an increase in international passenger traffic and to maintain dominance in Germany as the major long-haul international airport serving the country.

Munich Airport

Munich Airport's domestic and international passenger traffic has grown substantially since 1999—by 2% and 7%, respectively. Rebuilt in 1992, the airport was established by Lufthansa as its second hub (after Frankfurt Airport). The new airport is located 28.5 km northeast of Munich, where there might be fewer capacity constraints in the future in terms of runway expansion. Munich Airport is linked to two branches of the S-Bahn, a rail system that runs through the city, providing service from the city center to the airport in 40 min.

The new Nuremburg–Munich HSR line was launched in 2006; however, it was not constructed with an alignment at Munich Airport. From the perspective of the rail operator, the natural rail path from Munich to other major cities in Germany lies to the northwest. Although there is no airport alignment, domestic traffic at Munich Airport declined fairly significantly, starting in 2006 when the HSR line opened. Since 2006, domestic flights have declined at an average of 3% per year, and international flights have grown by 1% per year.

The key differences between Munich and Frankfurt Airports are the lack of opportunity for HSR to provide feeder rail service for air passenger traffic and capacity constraints at the airport. In the case of highly constrained Frankfurt Airport, it appears that the HSR alignment reduced domestic passenger traffic, likely enabling growth in international traffic. At Munich Airport, O-D traffic has decreased, possibly providing more capacity for international flights.

Cologne–Bonn Airport

After the introduction of the AIRail service from Cologne and Stuttgart to Frankfurt, it became increasingly difficult for the Cologne–Bonn Airport to compete for international passenger traffic originating in Germany. Although Cologne–Bonn is a fairly populated region, it is served by both Cologne–Bonn and Dusseldorf Airports and, after the introduction of AIRail, also by Frankfurt Airport. Over the past decade, Cologne–Bonn Airport has redefined itself as a facility with several low-cost and charter airlines, primarily serving destinations in Europe. Its EU passenger traffic has increased substantially, growing at an average rate of 17% per year since 2003 when AIRail was launched.

History of Airport–Rail Connectivity in Germany

The first steps toward air–rail cooperation in Germany were motivated by the federal government in the 1970s. Through a coalition between the Social Democratic and Free Democratic parties, Lufthansa (the first German airline to become privatized) and DB Bahn (the German national railway) were pushed to work together to benefit the environment.

The first cooperative air–rail service offered by DB Bahn and Lufthansa was the Lufthansa Airport Express, which was in operation between 1982 and 1993. The route for an older DB Bahn train set was altered slightly to provide connecting air–rail service to Cologne, Bonn, Dusseldorf, and occasionally Dusseldorf Airport. However, this service was not competitive in terms of travel time, and passengers who used the service were mostly tourists who wanted to see the German countryside or passengers traveling to the Bonn main station.

The successor to the Airport Express was the Lufthansa InterCity Service. Hourly intercity trains provided connecting rail service to and from Frankfurt Airport and to Bonn and Cologne main stations. Connecting Lufthansa passengers received a coupon for the train and a meal. As rail and air transfer times became shorter, this service was discontinued and planning for the present AIRail began.

Overview of AIRail

AIRail, the current integrated HSR and air transportation service in Germany, was initiated in the late 1990s, building on previous cooperation between Lufthansa and DB Bahn. The following is a brief timeline and overview of AIRail service offerings:

- Frankfurt–Stuttgart launched March 1, 2001. Pilot AIRail service between Frankfurt and Stuttgart was launched. A German InterCity Express (ICE) line was diverted from Hamburg and Hanover to Frankfurt and Stuttgart, with a 2-h headway at Frankfurt.
- Frankfurt–Cologne launched August 1, 2002. AIRail service was launched between Frankfurt and Cologne, with a 2-h headway at Frankfurt.
- Next generation of AIRail launched May 2003. The second generation of AIRail service was launched for both the Frankfurt–Stuttgart and Frankfurt–Cologne routes, including new service integration features and hourly service for Frankfurt–Cologne.

Integration Logistics and Passenger Services

In the beginning, to offer the connecting ICE service, Lufthansa paid DB Bahn for every seat in a separate train car reserved for AIRail passengers. As on the services on a flight, every Lufthansa passenger received a full meal on the train. Integrated ticketing was available from the initiation of the AIRail product in 2001 and 2002.

In May 2003, a new generation of service was launched; this included improved service frequency, a mechanism for Lufthansa to purchase tickets from DB Bahn, and improved customer service. In May 2003, DB Bahn began using two ICE lines (of their seven ICE services between Frankfurt and Cologne) to provide hourly service to Frankfurt Airport and thus improved the connecting options for flights arriving from Frankfurt. During this time, DB Bahn also implemented a new fare system by building on revenue management strategies traditionally used in the airline industry. For the first time, rail travelers were encouraged to purchase tickets in advance and were assigned to a specific train. Rail fares—available for a 7-, 3-, or 1-day advance purchase—increased as the departure date became closer. Under this new fare system, the pricing for Lufthansa's AIRail seats was adjusted; travelers are now able to block a certain fixed number of seats, with the option of canceling seats up to 7 days in advance. Given that Lufthansa no longer purchases an entire rail car for AIRail passengers, AIRail and DB Bahn passengers can be seated in the same rail cars.

Baggage Handling and Security

In 2001, ICE trains were modified: 16 seats at the end of the train were removed so that a sealed baggage container could be wheeled onto the train. Bags were not screened in Stuttgart or Cologne train stations; upon entry to Frankfurt Airport's AIRail terminal, passengers and bags were required to go through security. Stuttgart Hauptbahnhof (Central Station) and Koln (Cologne) Hauptbahnhof were assigned International Air Transport Association codes ZWS and QKL, respectively.

For the second generation of AIRail, which began in 2003, 16 seats in a lounge at the back of the each train were reserved for luggage. This arrangement provided a capacity of 64 pieces of luggage (two per passenger), all of which could be loaded into the lounge in less than 4 min. Under both systems, passengers were able to check bags through to their final destinations.

Because of cost-cutting measures and because the service was not well utilized, checked-through baggage is no longer offered as part of AIRail. Passengers now transport their luggage and pass through customs on their own.

Challenges

It took several years for the AIRail product to gain market share, particularly for the Frankfurt–Stuttgart market. An initial challenge identified by the AIRail team before launching the service was the need to educate potential customers about the product. The target market included passengers from all over the world, with different languages, preferences, and perspectives on rail travel. The team focused on ensuring that significant information about the service was widely available to assure passengers that the integrated service was functional and that they and their bags would arrive at their final destination in a reliable manner.

A significant marketing effort was undertaken for outbound traffic (from Germany) as well. Travel agencies were invited to ride on the route for free, with mailings sent to every travel agency in Stuttgart. To give customers an incentive to use the service, Lufthansa also offered 1,000 frequent flyer miles for every leg on AIRail.

Another key challenge, from the perspective of the airline, was scheduling and computer reservation system positioning. This challenge affected mainly the Frankfurt–Stuttgart market and is described further in the analysis of travel demand.

Other Cooperation and Agreements

In addition to the more seamlessly integrated AIRail service described above, this subsection summarizes two other types of agreement that facilitate integrated air–rail service in Germany:

- Code shares: Rail&Fly. Starting in 1994, DB Bahn began selling rail coupons to airlines that might want to offer service to smaller destinations in Germany. For example, Cathay Pacific could issue rail coupons to passengers; when the coupons were collected on the train, DB Bahn processed them to charge the airlines for those passengers. Starting with American Airlines in 2004, airlines began to offer official code shares on DB trains.
- Interlining: Good for Train. DB Bahn has an interlining agreement with Lufthansa and EuroWings (now part of Lufthansa). In the case of flight cancellations, air tickets are valid for travel on the German rail system.

Impacts on Capacity and Passenger Traffic

The AIRail product is often highlighted as a primary success story of intermodal cooperation between HSR and aviation. In particular, the Frankfurt–Cologne corridor is notable because Lufthansa initially significantly reduced capacity on the route. The AIRail service can make the journey to provide connecting service between Cologne and Frankfurt Airport in approximately 60 min, whereas the Lufthansa flight took 40 to 50 min, plus typical airport access and wait times. When AIRail was first launched, Lufthansa cut their capacity from six daily flights to four (two of them with smaller aircraft). In 2009, they stopped offering flight service altogether. Thus, for Cologne–Frankfurt, capacity and passenger traffic between the two airports declined substantially (Figure 2*a*).

The impacts on aviation capacity and passenger traffic differ slightly for the Frankfurt–Stuttgart corridor (Figure 2*b*). Compared with Frankfurt–Cologne, capacity and passenger demand were not reduced nearly as significantly for the Frankfurt–Stuttgart corridor. However, both capacity and demand were reduced between 2003 and 2010 (when the current generation of AIRail was introduced for Frankfurt–Stuttgart) as follows:

- 39% reduction in passengers,
- 46% reduction in available seats, and
- 17% reduction in flights.

Although it is clear that aviation capacity and passenger traffic declined between Frankfurt and Stuttgart, this corridor is not considered to be as successful as the Frankfurt–Cologne corridor. The following subsection examines the key differences between these two similar, but remarkably different, intermodal connections at Frankfurt Airport.

Comparison of Cologne and Stuttgart Services

There are several differences between the Frankfurt–Cologne and Frankfurt–Stuttgart rail services, including primarily the train set technology and position within the German rail network structure, both of which affect passenger demand for this service.

Train Set Technology and Travel Times

The rail line between Stuttgart and Frankfurt uses ICE 1, the first series of German high-speed trains, while the line between Cologne and Frankfurt operates with a newer generation train, ICE 3. It was designed specifically for passenger rail and can reach speeds up to 300 km/h, whereas ICE 1 operates at a top speed of 250 km/h on the Frankfurt–Stuttgart corridor. Given the different rail technology, the travel time to Stuttgart is slower (74 min) than the travel time to Cologne (58 min).

The travel times appear to have had a significant effect on the popularity of the Cologne and Stuttgart AIRail services. Because the Cologne–Frankfurt travel time was competitive with flights, it was displayed on the first page of computer reservation systems used by travel agents and online search engines. However, the Stuttgart–Frankfurt travel time was not as competitive in terms of flight time and thus was often displayed on the second page, or several pages later, on computer reservation systems. Although for a business traveler with a final destination in downtown Stuttgart the AIRail service might offer a competitive true origin to true destination travel time, it would likely not be booked because of its placement in the computer reservation systems. This positioning was a key competitive advantage the Cologne–Frankfurt route held compared with Stuttgart–Frankfurt.

Network Structure and Frequency

The German rail network structure also has a significant impact on the different services that were possible for the two corridors. Before the AIRail service was launched, DB Bahn provided passenger rail service for the Hamburg–Switzerland and Hamburg–Stuttgart corridors, using the same ICE 1 train sets, with half the trains heading to Zurich, Switzerland, after stopping at Frankfurt and the other half heading to Stuttgart. As a result, the Stuttgart–Frankfurt corridor has a 2-h headway, whereas Cologne–Frankfurt has hourly service (as of 2003). This difference in service frequency is the second key reason why the Cologne–Frankfurt AIRail service was much more successful than Stuttgart–Frankfurt. The success of intermodal connectivity depends in part on whether the rail service arrives at a time to meet a bank of connecting flights at Frankfurt Airport. In the case of Cologne–Frankfurt, the transfer times for travelers were minimized because of the frequent connecting rail service, but that was not possible for Stuttgart–Frankfurt.

When AIRail was first launched, the rail timetables were not coordinated with Frankfurt's flight timetables. In 2007, the timetables for

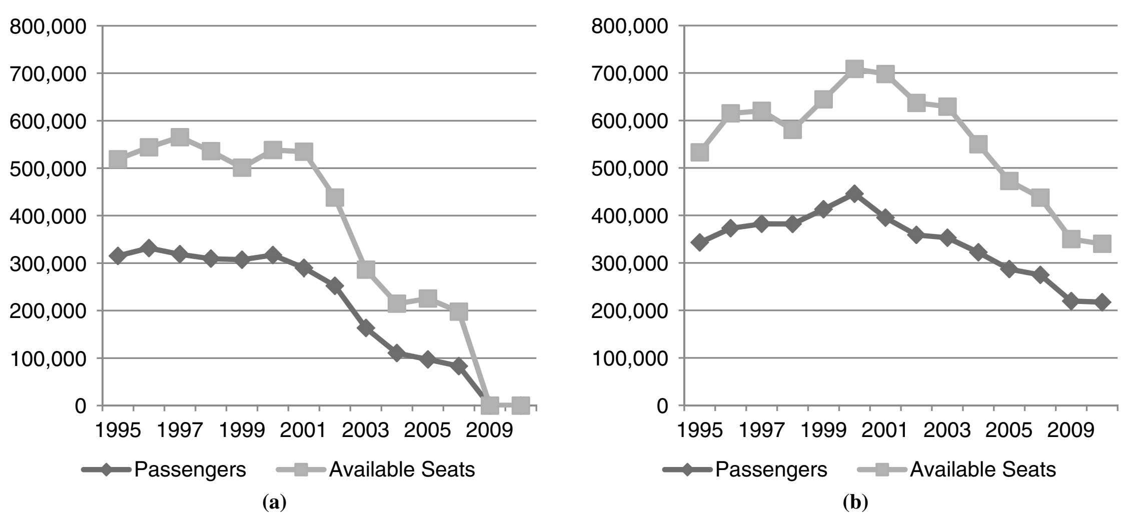


FIGURE 2 Air passenger capacity and traffic: (*a*) Frankfurt–Cologne and (*b*) Frankfurt–Stuttgart.

both Cologne–Frankfurt and Stuttgart–Frankfurt were optimized to provide shorter transfer times. However, there was little motivation for DB Bahn to significantly alter its timetables or network structure to provide hourly frequency between Stuttgart and Frankfurt. The Frankfurt–Stuttgart rail service typically used two train sets (offering 800 seats). From the perspective of the rail operator, there was no motivation to alter the network timetables to accommodate an average of 32 potential connecting passengers from Frankfurt airport, particularly because the Hamburg–Zurich and Hamburg–Stuttgart routes were already well utilized by regular O-D rail passengers.

Although both Cologne–Frankfurt and Stuttgart–Frankfurt can largely be considered successes in air–HSR connectivity, it is clear that there are challenges associated with designing intermodal transportation systems. In particular, the key stakeholders that provide transportation services (rail operators, airlines, and airport management) have different goals, perspectives, and constraints. In the case of airlines and rail operators in particular, once a complex network structure has been established to provide transportation services to passengers, it becomes increasingly difficult to design intermodal systems.

FRANCE

The French HSR, Train à Grande Vitesse (TGV) was established in the 1970s by what is now the Société Nationale des Chemins de Fer Français (SNCF), France's national state-owned rail company. TGV, the fourth commercial HSR service in the world, provides fairly extensive service between major cities in France. It is one of only two HSR systems in Europe with a direct airport connection at both Paris CDG and Lyon Saint Exupéry. This section examines general air traffic trends in France, the history of a partnership that has enabled air–rail connectivity, and detailed analysis of how this connection has affected demand.

Evolution of Air Traffic in France

Figure 3 presents an overview of passenger traffic for the six major airports in France. Paris Orly Airport (ORY) and CDG dominate the air traffic markets, with ORY serving as the main domestic hub, while CDG is the main international hub. Domestic traffic at ORY has declined since the late 1990s, falling an average of 3% per year since 2001. This reduction in traffic is likely due to network improvements that expanded rail service in France during that time (Figure 4). In June 2001, the LGV Méditerranée extended service to two of the more populated cities in France, Marseille and Montpellier, reducing travel times to 3 h and to 3 h 15 min, respectively (*6*). As shown in Figure 3, domestic traffic declined at Marseille Provence Airport after HSR service was introduced. To the east of Paris, the development of TGV Est in 2007 reduced travel times between Paris and Strasbourg from roughly 4 h to 2 h 20 min, resulting in a decline in O-D traffic, as described below.

A general analysis of airport-level air traffic trends indicates that the major airports where average domestic traffic has increased include primarily those cities not connected to Paris by HSR: Nice, Toulouse, Bordeaux, and Nantes. Contrary to what planners anticipated, Lyon Saint Exupéry also experienced an increase in domestic traffic, despite a HSR connection constructed at the airport. Experts have concluded that this air–rail connection failed to provide the type

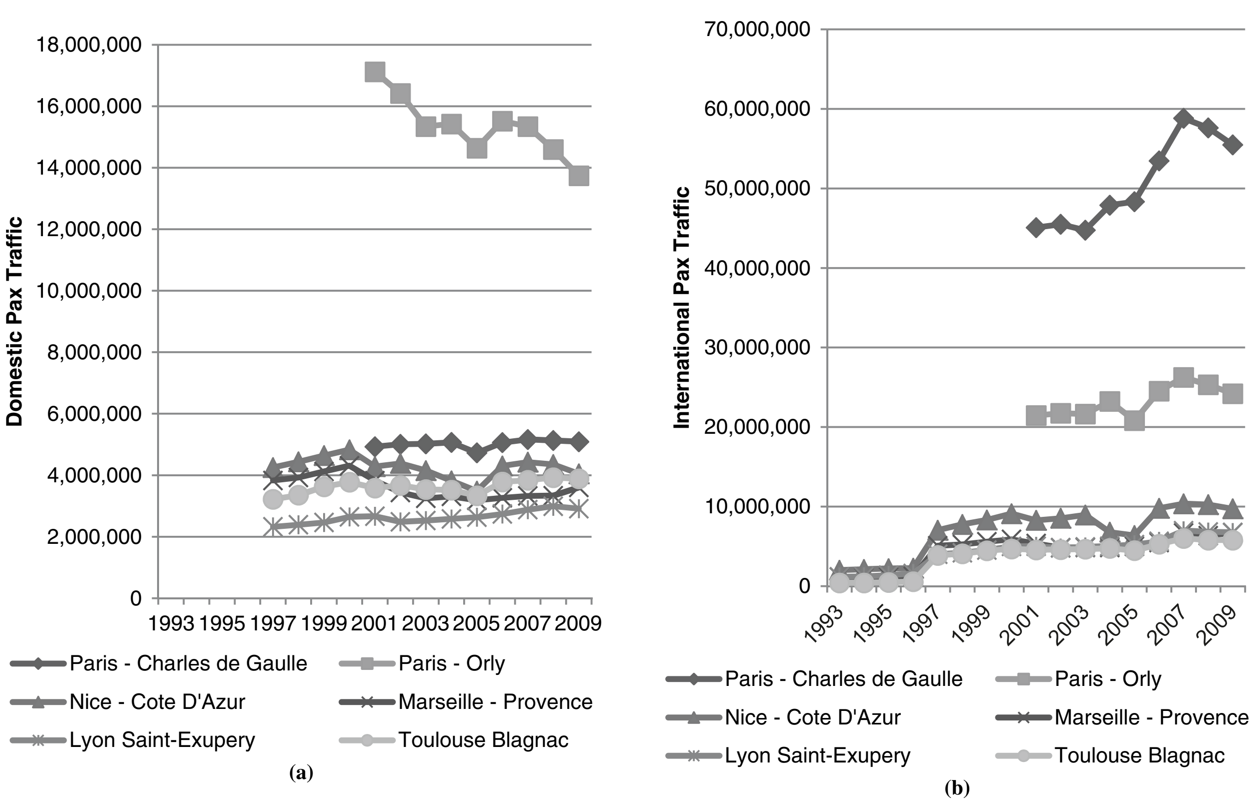


FIGURE 3 Passenger traffic at major airports in France: (*a*) domestic and (*b*) international.

FIGURE 4 Map of TGV lines. (Source: Wikipedia, July 2011.)

of air–rail connectivity that transportation planners envisioned, with only 0.05% of air passengers using rail-to-air ground access (*7*).

International traffic has grown fairly substantially at top French airports over the past decade, including primarily ORY (12% annual average growth since 2001) and Lyon Saint Exupéry (7% annual average growth). Given that ORY does not have a direct airport connection and that passengers do not appear to be using the air–rail connection at Lyon Saint Exupéry, it is hypothesized that the key reasons for this growth in international traffic include the entry of low-cost carriers and, in the case of ORY, increased capacity due to reduced domestic O-D demand. Two low-cost carriers have emerged to provide service in France and appear to have affected airport-level traffic: France Transavia began operations in 2007, with a hub at ORY, and Star Airlines started service in 1995, reorganizing as XL Airways France in 2006, with a hub at CDG. International air traffic increased substantially at those airports when these low-cost carriers entered the market (+21% at ORY), with primary growth in the intra-EU markets that are typically served by these carriers. However, the global economic downturn starting in 2008 appears to have resulted in a decline in traffic, an expected trend given that the low-cost carriers primarily serve leisure travelers with higher-income elasticity of demand.

Given the analysis of airport-level traffic trends in France and interviews with experts, it is concluded that HSR has likely influenced observed changes in passenger demand at the airport level. Most airports in cities that are connected to Paris with service of about 3 h or less have experienced a reduction in domestic O-D traffic. Over the same period, the entry of low-cost carriers and the availability of new landing slots at previously constrained airports has enabled the growth of international air traffic.

Overview of TGVair

The partnership between the French rail operator SNCF and various airlines started in 1996 with Air France. At the time, Air France hoped to reduce flights between Lille and Paris, which takes only 1 h by TGV. The airline company was interested in selling an integrated rail–air travel itinerary as a complete package to customers (e.g., Lille–Paris–New York City). The first version of integrated air–rail service took the form of a code-sharing agreement between SNCF and Air France.

Over time, other airlines were interested in providing connecting service to various destinations in France via Paris. However, there were only two options for foreign airlines to provide service to Lille: (*a*) to purchase expensive connections from Air France or (*b*) to arrange a code share with SNCF as well. Eventually, several airlines developed partnerships with SNCF, and the rail operator has expanded its TGVair agreement to include Air Austral, Air Caraibes, Air Madagascar, Air Tahiti Nui, Cathay Pacific, Corsairfly, Gulf Air, Middle East Airlines, Openskies, and Qatar Airways in addition to Air France.

Ticketing and Integration of Systems

Although it was not available from the start of the SNCF–Air France partnership, an integrated ticketing system was developed for routes out of CDG. The TGV now has a dispatch control system that is integrated with the systems of the TGVair partner airlines. This system enables SNCF to check passengers to their final destinations and view all their partner airlines' flights that provide connecting service.

Service Logistics

Baggage integration has been in place since 2001; however, luggage cannot be checked from the initial origin to the final destination. When passengers board domestic train services, they carry their own bags and then go through the security process when they arrive at the airport.

Impacts on Capacity and Traffic

Figure 5 presents an overview of traffic to and from CDG and ORY over the past decade. Passenger traffic at CDG has declined significantly only on the Paris–Strasbourg route, where TGV improved service from 4 h to 2 h 20 min in 2007. Capacity, as measured in annual flights, also significantly declined on this corridor. However, for all other routes to and from CDG, passenger traffic and capacity have remained relatively stable or increased. Two major routes, Paris–Nantes and Paris–Bordeaux, do not have competitive HSR alternatives; thus, it is reasonable for O-D traffic to increase steadily over this period. The other two routes, Paris–Lyon and Paris–Montpellier, experienced a relatively flat trend in passenger traffic, although there are competitive HSR alternatives that link these cities directly to CDG. In particular, the capacity on these routes has remained relatively stable, supporting research claims that airlines are likely to maintain a certain number of flights at their hub airports to maintain their network, even with the presence of fast and reliable HSR–air connectivity (*7*).

ORY's O-D traffic trends differ from those at CDG, which is likely explained by ORY's dominance as a short- and medium-haul airport, while CDG dominates as an international hub. Given the expansion of TGV service between Paris and France's major cities, passenger traffic from ORY experienced a fairly steady decline. In the case of ORY, where airlines are not as concerned about feeding connecting service to international flights and the competition is less fierce, trends in capacity follow trends in passenger demand quite closely, with reductions in the number of flights offered on several routes.

By comparing capacity and traffic trends at CDG and ORY, empirical data suggest that air–rail connectivity may not quite have the impact on O-D traffic reduction that transportation strategies strive to achieve. In the case of this multiairport city, the airport with the direct HSR link (CDG) experienced a reduction in passenger traffic but only a modest reduction in capacity, while ORY experienced a steady reduction in passenger traffic and slightly more reductions in capacity.

UNITED STATES

This paper concludes with a brief analysis of San Diego Airport, a major airport in California, where a true HSR linkage is being considered. Building on the two European cases, this paper comments on key lessons that are relevant for this U.S. airport and outlines the unique challenges that face air–rail transportation planning in the United States.

San Diego, California

Overview

San Diego International Airport, also referred to as Lindbergh Field, was the 28th largest airport in the United States in 2010, with continued passenger growth expected over the next 20 years. Aviation demand in Southern California, including San Diego, Tijuana, and five airports in the Los Angeles area, is projected to increase 50% between 2009 and 2030, from 48 to 80 million passenger enplanements (*8*). Although an extensive search was carried out to find a second airport for the San Diego region, an alternative was not identified. The regional planning agency, the San Diego Association of Governments, has endorsed linking the California HSR system to the airport, which could provide service starting in 2027 and potentially alleviate capacity constraints.

Characterizing Airport Demand

A key issue raised during interviews with experts about the San Diego case is the nature of San Diego Airport's demand and the purpose of the airport–rail linkage. In places where HSR connectivity has been highly utilized, it has often served to feed long-haul traffic at major international hub airports (Frankfurt and CDG). Although San Diego Airport is classified as an international airport, its market is almost entirely domestic. Only 1% of the 16,889,622 passenger enplanements in 2010 were traveling to or from international destinations (*9*). However, if the proposed airport–rail connection succeeded in providing improved access to a wider catchment area in Southern California, it could simply feed long-haul domestic traffic, possibly resulting in a net increase in flight traffic at Lindbergh Field.

A secondary purpose often cited as part of integrated aviation and HSR system planning is to alleviate O-D demand. The top domestic market at Lindbergh Field in 2010 was California's San Francisco Bay Area (San Francisco, San Jose, and Oakland). The journey times for the California HSR service to San Diego is projected to be 3 h 56 min from San Francisco, and 3 h 27 min from San Jose (*10*). To reduce O-D air passenger traffic on a route, most experts agree that HSR service should provide city-center-to-city-center journey times of 3 or 3.5 h or less. A key consideration for the San Diego case is whether the downtown alignment versus the airport alignment will provide a greater decrease in short-haul traffic, thereby alleviating congestion at San Diego Airport.

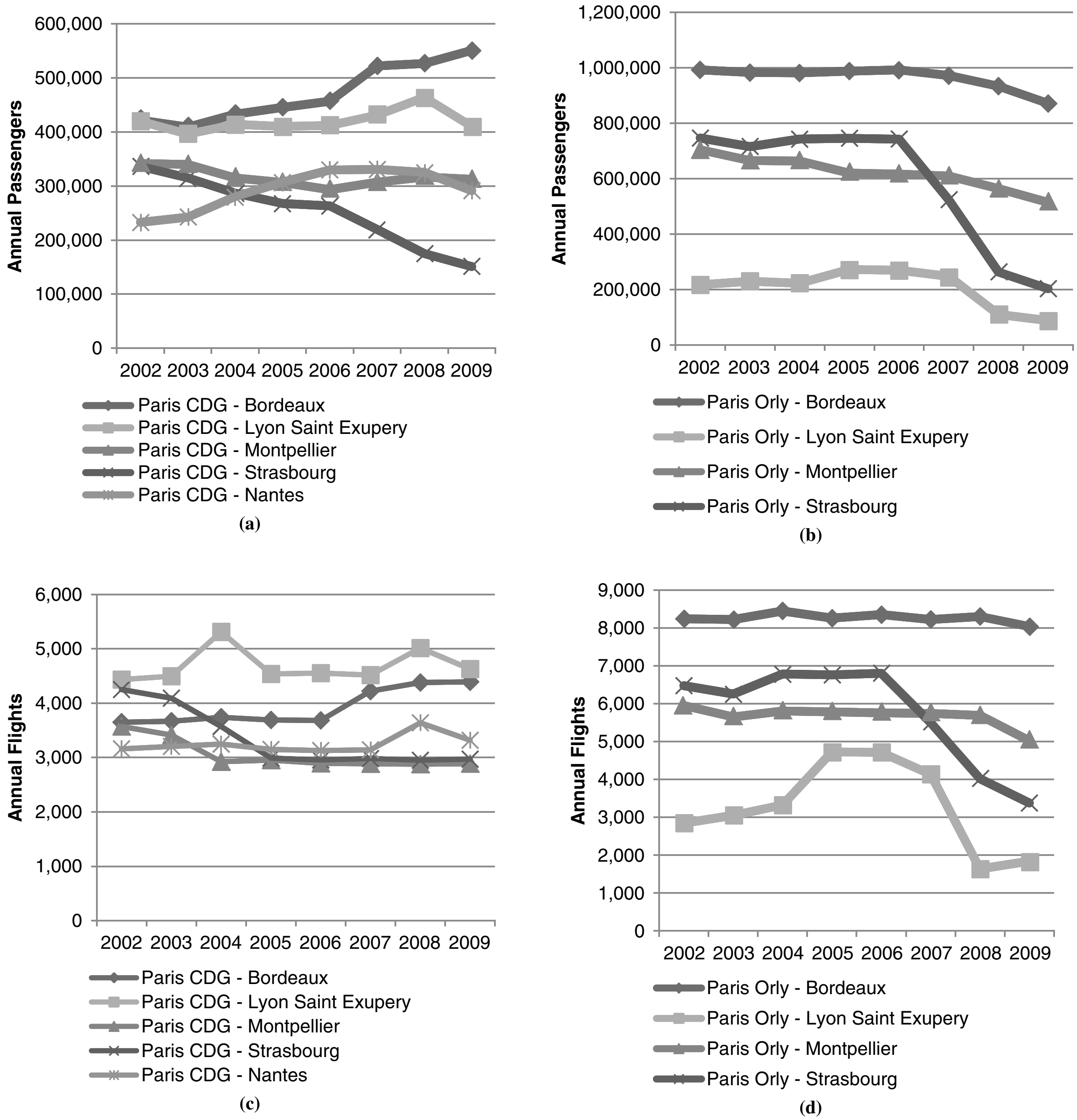


FIGURE 5 CDG and ORY air passenger capacity and traffic: (*a*) CDG annual passengers, (*b*) ORY annual passengers, (*c*) CDG O-D flights, and (*d*) ORY O-D flights.

Unique Challenges in the United States

Route Economics

The case of CDG highlights the importance of route economics and air traffic networks. Major airlines at CDG did not reduce their short-haul domestic flights entirely, even though the TGV provides fast, reliable service directly at the airport. Although passenger demand declined on many routes, carriers continued to maintain some level of scheduled service to feed their long-haul traffic, which is typically their most lucrative service. In the United States, the issue of network economics is even more complex, given the large number of legacy and low-cost carriers that provide both domestic and international long-haul service through hub airports. Although there are a number of airports where capacity constraints are likely to become more severe over the next 25 years (e.g., Chicago, Illinois; San Francisco; and the entire New York airport system), it is unclear whether HSR connectivity would provide a decrease in flights, given the complexity of competition among air carriers and network economics.

Financing and Rights-of-Way

For integrated airport and HSR to become feasible in the United States, it is necessary for HSR to become feasible. Two key issues set the U.S. case apart from the European cases considered in this study.

First, financing costly HSR infrastructure has proved to be a challenge, particularly in the United States, where the issue has become highly politicized. Second, passenger rail in the United States is largely subservient to freight railroads, where it operates over freight railroad rights-of-way. These two issues are intertwined and thus, for regions where existing infrastructure is utilized by both passenger rail and freight (e.g., the Northeast Corridor), decisions about proposed infrastructure improvements for passenger rail are particularly complex. Practically speaking, to consider HSR and airport integration at U.S. airports, it is important to recognize these two significant challenges facing the development of HSR in the United States.

CONCLUSIONS

Air–rail connectivity in Europe has influenced air traffic patterns in Germany and France; however, it is clear that many other factors shape demand. In the case of Frankfurt–Cologne, Frankfurt–Stuttgart, and corridors at ORY, O-D domestic traffic has been reduced as a result of the introduction of HSR. Additionally, the HSR lines appear to serve as successful feeders for international air traffic at Frankfurt Airport (particularly the Frankfurt–Cologne corridor) and at CDG.

Key factors that appear to contribute to a successful airport–HSR connection can be summarized as follows:

- Infrastructure. To provide feeder or transfer service between HSR and air transportation, the rail station should be located at the airport. If the HSR connection at the airport is constructed as a detour from the primary network patterns on the rail system, it is unlikely that the airport will be served with enough frequency.
- Schedule and frequency. Rail operators and airlines often have the same goal of optimizing their networks, but they are separate networks. Coordinating timetables to ensure that rail service meets banks of connecting flights is an important consideration.
- Market characteristics of the airport. In the two successful cases in this study, the primary airports with HSR links were the dominant international hubs of each country. For both CDG and Frankfurt International Airport, domestic traffic declined and international passenger traffic increased. Two key factors may have influenced this growth: partial alleviation of congestion at the airport by decreasing domestic flights and success of the HSR lines as feeder service for international flights.

A number of factors influence the evolution of air traffic, capacity, and demand at airports. In the case of Cologne–Bonn and Dusseldorf Airports, the HSR link to Frankfurt Airport ensured that Frankfurt would remain the dominant airport serving long-haul international destinations. During the past decade, since the introduction of AIRail service, Cologne–Bonn and Dusseldorf have reinvented themselves as airports that provide low-cost and charter service primarily to European and seasonal vacation destinations. Cologne–Bonn has been particularly successful, growing its international traffic by 11% per year since 1999.

From an environmental perspective, it is important to consider the complexity of intercity transportation networks potentially served by HSR and air transportation. HSR is likely to provide more competitive, reliable, and energy-efficient service for short-haul intercity routes. However, it may not be the only solution for reducing the carbon footprint of the transportation sector, given that a variety of complex factors affect the evolution of air traffic.

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