Promoting Connectivity at HSR Stations: Lessons from Germany and Spain

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Abstract

The study seeks to understand the requirements for high levels of connectivity and spatial and operational integration of HSR stations and extract lessons for seamless, and convenient integrated service in California HSR stations. It draws data from a review of the literature on the connectivity, intermodality, and spatial and operational integration of transit systems; a survey of 26 high-speed rail experts from six different European countries; and an in-depth look of the German and Spanish HSR systems and some of their stations, which are deemed as exemplary models of station connectivity. The study offers recommendations on how to enhance both the spatial and the operational connectivity of high-speed rail systems giving emphasis on four spatial zones: the station, the station neighborhood, the municipality, and the region.

Introduction

High-Speed Rail (HSR) can have transformative effects on cities and regions, altering the built environment of station-neighborhoods and affecting municipal economies. However, benefits from HSR systems have been unevenly distributed among cities (Vickerman 2007; Martinez and Givoni 2009*).* A number of studies have examined the economic and development impacts of HSR projects on station-cities finding differential impacts depending on the type of station-city (first- or second-tier) (Garmendia et al. 2012a), distance from other major cities on the network (Garmendia et al. 2012b), condition of the local economy and land market, and station location (central or peripheral) within a city (Ureña et al. 2012).

Most scholars agree on the importance of two factors for successful HSR development: connectivity of the station with other transportation modes and anticipatory planning (Van den Berg and Pol 1997; Meer et al. 2012). A Delphi survey found HSR experts emphasizing the need to "provide good connections with intra-urban transportation systems," "plan stations as intermodal nodes," and "develop good urban design station-area plans" (Loukaitou-Sideris et al. 2012:44). Similarly, Bertolini and Spit (1998: 31) have noted that "a railway station's essential feature appears to be its function as an intermodal interchange, rather than a place where trains arrive and depart. The railway station is to be seen as 'an urban exchange complex'… The railway system has to offer full connectivity in both the hard sense – the infrastructure – and the soft sense – the services… In the process the railway station turns into 'a place to be', not just a 'place to pass through.'" This underscores the importance of a station as both a transportation *node* and a vibrant *place*.

This study will seek to tease out the requirements for high levels of connectivity and spatial integration of HSR systems, with an eye towards outlining lessons for California, which has initiated planning for a $68-billion HSR project to connect its northern and southern parts. The study seeks to answer the following questions:

1. What are the challenges of connectivity and intermodality in the context of HSR systems and stations?

2. How are these challenges addressed in two successful systems—the ICE in Germany and ALVIA/ALTARIA in Spain?
3. What lessons can we learn that are relevant for the California context?

The study drew from the following date sources: 1) a review of the literature on connectivity and intermodality of railway systems; 2) a survey of 26 HSR experts from six European countries; and 3) a close examination of the German and Spanish HSR systems and some of their exemplary stations. In the following sections, we review the literature on the connectivity, intermodality, and spatial integration of transit systems; report on surveys with HSR experts; examine in-depth the connectivity elements of German and Spanish HSR systems, and conclude with some lessons for California.

Spatial and Operational Connectivity of Stations

Spatial connectivity denotes the spatial integration of a station with its surroundings, and can be achieved through good urban design. *Operational connectivity* denotes high station accessibility from different points of origin, and is achieved through frequent HSR services, operational integration of the HSR system with other transportation modes (including walking and cycling), and high levels of intermodality (convenient and seamless transfer between travel modes). Good spatial and operational connectivity enhance the node qualities of a station, while good spatial connectivity also contributes to its place quality (Bertolini 2009). Both are crucial to attracting passengers by making transit travel more convenient and increasing travelers' mobility benefits (GAO 2013). At the same time, poor connectivity may negatively affect transit ridership (MTC 2005).

One of HSR's biggest advantages over air travel is that it can offer passengers a one-seat ride into the center of cities, eliminating time-consuming airport transfers and wait times, and providing opportunities for intermodal transfers at these locales. However, this is highly dependent on its integration with existing intercity and commuter/regional transit systems. This requires careful pre-planning, operational coordination between modes, and station infrastructures that effectively accommodate smooth modal transitions (Nash 2003).

Research on connectivity and ridership has mostly analyzed transit service and urban form characteristics separately. Dill and Schlossberg (2013) sought to synthesize these disparate approaches and examine their combined influence on transit ridership at the transit stop/station level. They found that while transit service plays the most important role in predicting transit ridership, characteristics of the built environment, such as the nearby presence of bicycle paths, also matter. When good transit services and a good physical infrastructure co-exist, connectivity improves and ridership increases. This emphasizes the importance of the built environment as a major factor in improving transit's connectivity. Similarly, Mbata et al. (2008) emphasize that a station-area design that connects to different transportation modes, including walking and cycling, will result in higher rates of ridership.

Improving HSR connectivity requires careful attention to a wide range of physical/infrastructural (e.g. station design, connection between different platforms) and operational factors (e.g. line integration and scheduling, fare and information systems, integration of different transportation systems). We are discussing both below.

Spatial Connectivity

Only a miniscule part of the HSR literature discusses physical and urban design interventions that can improve spatial connectivity. Loukaitou-Sideris (2013) identifies four spatial zones that must be considered for ensuring good connectivity and access to HSR stations: 1) the station itself; 2) the station-district, generally defined as about half-mile radius around the station; 3) the municipality at large; and 4) the broader region. Good urban design enhances the station's spatial connectivity in the first two zones; while good multimodal services improve the connectivity of the station with the municipality and region at large. Spatial connectivity is enhanced when adjacent parking lots and bus stops are in close proximity to station entrances, and the connections between ticketing areas, train platforms and other station facilities are direct, short, and legible for passengers. At the station-neighborhood, a major urban design challenge is the bridging of "the barrier effect," the gap between the station and its neighborhood, created by the bulky railway infrastructure and parking facilities. Appropriate design interventions depend on the guideway type (elevated, surface, or tunnel), and the width of the right-of-way is wider and more challenging to bridge when the HSR operates on its own dedicated track) (Loukaitou-Sideris 2013).

Operational Connectivity

Operational connectivity is enhanced by high levels of intermodality and the seamless integration and time-coordination of different travel modes. A particularly interesting integration is between HSR and air travel. Givoni and Banister (2006) suggest that policy makers consider the two modes as part of one transport network, rather than separate and competing entities. Defining integration as "aircraft and high-speed railway services provided as one complete journey with a fast and seamless transfer between the modes" (388), they recommend that railway stations minimize the distance of transfers and link to multiple destinations with services at a relatively high frequency.

Developing the HSR station in close proximity to retail and tourist attractions requires its integration with walking and biking. Pan et al. (2010) examine the challenges and opportunities for improving the bicycle-rail connectivity based on surveys of railway passengers in Shanghai. They recommend the provision of additional bicycle parking spaces and a bicycle rental system for improving the bicycle-rail connection and utilizing the bicycle more fully as an efficient supplemental mode for rail transportation in China.

Regarding efficient time-coordination of different modes, the Swiss example of "clockface scheduling" is "the most streamlined delivery of public transport and Europe's best practice for bus, tram, and railway interchange" (Green and Hall 2009:46). All Swiss trains are programmed to arrive at the interchange stations of all major cities at exactly the same time, at 00 and 30 minutes pass the hour. Inter-city trains arrive every 30 minutes, regional trains and buses connecting to the station arrive every 15 minutes, while local trams and buses arrive every 7.5 minutes.

Clever (1997) examines the concept of Integrated Time Transfer (ITT), utilized in Europe as a way to improve public transportation services. Under ITT, trains, buses, boats, and other means of local and long-distance public transportation not only operate on a fixed-interval schedule, but also connect with each other in ways that minimize transfer times. The advantages of ITT include reduction of transfer times, more frequent services, better spatial coverage, and more profit for operators, while a possible disadvantage is longer headways.

Noting that building infrastructure to support connectivity can be expensive and time-intensive, some scholars also note the importance of good signage, real-time information about the schedules of connecting modes, information kiosks, and ticketing practices that enable passengers to purchase combined transport services (GAO 2013; Sauter-Servaes and Nash 2009). Effective internet-based platforms such as the multi-modal route advisory system (MRASD) developed by Chiu et al. (2005) have enabled travelers to link with multiple transit modes, taxis and shuttles in identifying the shortest, fastest or cheapest multimodal connections.

Overall, the literature demonstrates that both spatial and operational connectivity are important for HSR services and can provide a wide range of mobility benefits for travelers and increase ridership.

Expert Survey

To complement the findings of the literature on issues of connectivity and integration of HSR stations, we surveyed 26 HSR experts from Europe. Respondents had positions at universities or think-tanks, had conducted research and had significant publications on HSR development and evaluation. The survey asked experts about the importance of HSR connectivity and their recommendations for enhancing such connectivity. They were also asked to pinpoint exemplary HSR stations in Germany and Spain for further study.

There was an overall consensus among the experts of the critical importance of HSR connectivity and network integration. As reasoned:

> "You must consider the new HSR lines as part of a multimodal system, and ensure interdependencies among the rail lines. A good transportation system is a system that ensures high connectivity" (Richer interview).

> "The HSR's integration with the rest of the transport network is probably one of the most, if not the most, important element in its planning" (Ghivoni interview).

> "Maximum connectivity is reached if users experience the HSR service as much as possible as one door-to-door system" (Bertolini interview).

An important topic that emerged from the survey was the trade-offs of having stations in central versus peripheral city locations. In Spain, new HSR stations have often been located peripherally, at a distance from city centers in small and intermediate cities, while they are centrally located in large cities. In contrast, Germany has integrated all its HSR connections into pre-existing stations in central urban areas. As explained:

> "There are two scenarios: The first is that of stations in the city center. It is easier to integrate different services and modes of transportation there. Be careful though because it requires a lot of work to adapt to different modes in the station area. Capital works are cumbersome and complex. The second scenario is of stations on the outskirts of cities. Here it is essential to organize the transportation of passengers to the city center" (Berion interview).

> "Integrating an HSR station in a densely built district hinders access by car, because of the congestion of the urban street system, but allows access by walking or cycling" (Facchinetti-Mannone interview).

Respondents noted that if a HSR station is at a peripheral location, away from conventional railway services, then a dense network of intercity buses should connect it to different parts of the metropolitan area. This is the case in Valence, France – a new station built exclusively for the HSR-- that is served daily by 74 bus connections. In Besançon, a specific rail link was built to connect the new HSR station to the conventional rail network. In Reims, the new HSR station is integrated into the urban transport network through the building of a new tramway service (Facchinetti-Mannone interview).

In terms of *spatial connectivity*, one expert referred to the "need for continuity between the station and its neighborhood, and easy recognition of the access path to the city and other interconnected transport networks" and recommended to "design the space of the station as an urban open avenue/space, permeable and equipped with functions and activities that integrate it to the surrounding urban fabric" (Pucci interview). Another respondent noted that, "the best integration results from an intelligent placement of the public transit network and from avoiding an over-abundance of parking at multimodal stations" (Richer interview).

Some respondents emphasized the importance of station planning, design, and programming for enhancing the place qualities of HSR stations for both travelers and non-travelers:

> "Plan functions and activities which express mix, flexibility and versatility of the spaces to ensure the presence of different populations and different practices not only related to the trip or for temporal use" (Pucci interview).

> "It is important to bring new services into the stations to make them attractive. Such services may include retail, restaurant, and even cultural activities" (Aveline interview).

Others referred to the importance of allowing visual connections, physical proximity and short walking distances from the HSR platform to other transport modes, including conventional rail (Bonnafous interview, Garmendia interview). There was a lack of consensus, however, as to the desirability of shared or separate station platforms between HSR and conventional trains. Some believed that shared platforms are preferable because they maximize interconnectivity (Bertolini interview), while others recommended against them because they "necessitate waiting at the platform for one service to depart and the next to arrive" (Ghivoni interview). Most respondents, however, qualified their response on the basis of particular contexts. Thus, the number of trains that arrive or depart from a station should influence the number of required platforms. As explained: "In Dutch stations there are only a small number of high-speed trains, and separate platforms seem a waste of space, but this is different in Brussels Midi where there are many more high-speed trains" (Trip interview). The type of station (intermediate or terminal) also plays a role: "Separate platforms are essential at intermediate stations where high-speed trains pass through at high velocities. At endpoints they are helpful and convenient, but not essential to ensure efficient service" (Ahlfeldt interview). Whether platforms should be separate or shared depends on whether trains have similar or different dwell times (Hall interview).

Respondents also referred to the importance of information panels and good wayfinding signage for achieving good connectivity. As mentioned, "Signage is important and especially indicating on the ticket in advance from what platform the next train will depart" (Ghivoni interview). Much of this information can become more available in the future via real-time smart phone apps.

Respondents also noted the significance of *operational connectivity,* coordination and seamless connection between the HSR and other travel modes, and the goal of "complementarity rather than competition among the different modes" (Klein interview). Some noted that integration and coordination should extend to the ticketing of different transportation modes, as already happens in Germany. As recommended: "Have one ticket for the entire journey even when it involves a plane, a train and a coach" (Ghivoni interview).

Some respondents also emphasized the importance of institutional coordination among the managers of HSR and other transportation services (Berion interview). One expert suggested the creation of "an overall transport authority for multimodal functions" (Campos interview), and another suggested "terminal managers with coordination responsibilities over different operators, spaces and services" (Monzón interview).

Overall, the survey respondents underlined the importance of what was referred to as "triple integration" -- spatial, operational and institutional" (Monzón interview).

Connectivity in German and Spanish Stations

The survey of experts indicated the German and Spanish HSR systems and, in particular some of their stations, as good examples of HSR connectivity. Germany's ICE was inaugurated in 1991, while the Spanish AVE started operation between Madrid and Seville in 1992. Both systems integrate node and place qualities at many of their stations. Additionally, and similar to California's intentions, they both have extensive HSR networks operating on tracks shared between high-speed and conventional trains. To be sure, European cities have generally a more compact, dense, walkable, and bicycle-friendly urban form and higher levels of intermodality than California's car-oriented cities, whose residents have higher rates of automobile ownership and travel more automobile miles per capita. Nevertheless, the European HSR experience can provide some lessons for California.

In Germany, we visited six case-study stations (Berlin Central, Berlin South Cross, Hannover Main, Kassel Wilhelmshöhe, Leipzig Main, and Erfurt Main), interviewed station managers, and used publicly available information on new HSR corridors and station construction projects. In Spain, we interviewed representatives of the HSR operator RENFE and station managers of the six case study stations (Madrid Puerta de Atocha, Barcelona sants, Zaragoza Delicias, Málaga Maria-Zambrano, Córdoba Central, and Lleida Pirineus). The Spanish station owner ADIF provided us with relevant data. We also consulted European and national transport ministry websites. In what follows, we synthesize our findings per system.

Germany

Optimization of connectivity and intermodality lies at the heart of Germany's transit system. HSR operations were designed to blend seamlessly intro pre-existing rail operations, and corridors are not exclusive to high-speed passenger rail operations under the ICE label. The overall slower top speeds of the system are outweighed by its good overall connectivity, still allowing for impressive door-to-door connections. Depending on location, route and time of day, ICE trains operate at half-hour, hour or two-hour intervals. With the exception of the newly built ICE station at Frankfurt Airport, major stations across the country are all located at city centers.

Relying mostly on upgrading existing routes to higher speeds, Germany has built comparatively few new HSR corridors or completely new HSR stations. Instead, German Railways (DB) remodeled and adapted many historic stations to better accommodate HSR services. All German cities of over one million inhabitants, namely Berlin, Hamburg, Cologne and Munich, have more than one HSR station, and Germany's largest metro area, the Rhein-Ruhr agglomeration of 10 million people, features more than 15 HSR stations.

Where new HSR lines were constructed, DB promoted the re-purposing of secondary rail stations along the new routes into new, well-linked HSR nodes (e.g. Berlin South Cross and Kassel Wilhelmshöhe). Historic inner-city rail stations (e.g. Berlin Central Station, Hanover, Leipzig, Erfurt), meanwhile, underwent vast transformations into multi-modal hubs with amplified commercial and retail functions. The related planning processes integrated national, regional and local redevelopment efforts.

The German approach of privileging modal connectivity at the station level over achieving top speeds at the corridor level was optimally suited to the country's polycentric settlement pattern. To compete with other travel modes, DB had to re-invent itself as a one-stop mobility provider offering integrated and price-competitive ticketing that also interlinks with DB-owned car- and bike-sharing programs. This is how Germany achieves high inter-modality at its HSR stations:

- With the exception of Limburg, Germany's 150+ ICE stations are *never* exclusive to HSR but are also served by regional and/or local rail.
- Station remodeling has sought to promote smooth passenger flows within the stations, via barrier-free access and/or high-capacity elevators and escalators.
- Stations provide quick access to other travel modes and pedestrian connections to surrounding neighborhoods. Several stations (e.g. Berlin Central Station, Berlin South Cross, Erfurt) achieve short pedestrian connections by layering tracks atop each other.
- There is good HSR connectivity with local metro and tram systems.
- Most stations provide direct and convenient connections to nearby airports.
- DB uses standardized easy-to-read signs for in-station wayfinding. Wayfinding often extends into the station-adjacent neighborhoods.
- All major stations have good availability of bicycle parking and bike-sharing programs.
- All major stations offer car rental services and provide short- and longer-term parking near the station. Due to the availability of strong transit networks, German cities do not typically promote park- or kiss-and-ride at inner city stations the way U.S. cities do, with the exception of Berlin South Cross station, which has a strong car-orientation.
- All major stations offer a variety of passenger services, including those commonly found in airports (first-class and business lounges, boarding areas, information kiosks, travel agencies, free WiFi).
- DB cooperates rather than competes with Lufthansa, Germany's national airline. Special AIRail HSR trains take passengers to Frankfurt Airport from several German cities, featuring airport-like check-in and airline boarding passes as tickets.

- DB has perfected integrated ticketing, offering easy online, early booking discounts. Its DB Navigator app lets smartphone users check time tables, receive real time information on arrivals, and book tickets.

Spain

Spain has a combination of systems, from pure HSR systems (the so-called AVE that rolls along new HSR infrastructure at 185-205 mph), to blended HSR services called ALVIA and ALTARIA (that in certain segments roll along new HSR infrastructure and at other segments along the conventional infrastructure at 175 mph), to short distance commuting HSR services called AVANT, (that only roll on new HSR infrastructure but with slower 150 mph trains). Spain's HSR trains can share tracks with conventional rail by changing gauge at certain locations, slowing down but not having to stop. This system allows HSR trains to typically travel at higher speeds than the German ICE trains. One serious drawback is the limited number of changeover location that makes the network less flexible.

In the Spanish cases, intermodality is achieved through:

- Good station location with easy access to other travel modes and good pedestrian connections. Such location is either at the city center or at a secondary center, linked to the core via frequent and direct bus lines.
- Smooth passenger flows within the stations and proximity of HSR station platforms with the platforms of conventional rail services.
- Location of a central bus terminal inside the station, or directly adjacent to it.
- For cities with a metro system, a location of a metro stop inside the station.
- Direct connection to the city airport through a "fly-away" bus, metro line, or both.
- Availability of bicycle parking, and bike-sharing programs at the station.
- Availability of park- and kiss-and-ride lots. However, the high level of station intermodality decreases the need for large amounts of parking.
- Good information panels within the station and standardized, easy-to-read signs for way-finding
- Availability of passenger services inside the station, more often seen at airports (first-class lounges, boarding areas, information kiosks, travel agencies, car rental facilities).
- Integration of ticketing services.

Many Spanish HSR stations serve not only as transportation nodes for travel but also as social destinations and vibrant places in the city, incorporating retail stores, cafes, restaurants, and sometimes hotels, museums, and gardens. In some stations, good architecture – either through the preservation and expansion of significant historic buildings (such as in Madrid Atocha and Lleida Pirineus) or the building of a new structure (such as in Zaragoza–Delicias)-- aims to reclaim or create an architectural landmark in the city. Such stations serve both as routes for seamless travel and as places for other urban activities.

Lessons for California

The ways that the studied German and Spanish examples achieved connectivity at the four zones indicated as important in the literature-- the station, station-neighborhood, municipality, and broader region -- provides some lessons for California.

At the *station level,* attention was given to both the aesthetics and functionality of the station building. In some cases, historic buildings were renovated and expanded (e.g. Madrid's Puerta de Atocha Station, Lleida Pirineus Station, Leipzig Main Station). In other cases, significant new buildings were built (e.g. Berlin Central, Zaragoza Delicias), signifying a desire to create a landmark building that serves as both a transportation node and a social place. Station buildings are highly functional, with different platforms in walking distance from one another. Passenger services such as business class lounges, multiple information kiosks and ticket booths, cafes, and free wi-fi are common. Some larger stations (Berlin Central, Leipzig Main Station, Puerta de Atocha, Barcelona Sants) include shopping malls, a possibility that should be considered for some California HSR stations. All stations have excellent wayfinding features with easy-to-read, standardized, and frequent signage, and all include adequate bicycle parking.

At the *station-neighborhood scale,* clever urban design has often helped to minimize the barrier created by the tracks and station infrastructure and integrate the station to the surrounding urban fabric and street network either by consolidating, covering, trenching or bridging over the rail tracks, and strategically placing station entrances to connect well with surrounding streets.

At the *municipality level,* all studied HSR stations are well-connected via public transit and/or metro with different city areas and important destination points (airports, downtown and other sub-centers, universities, hospitals, commercial centers, etc.). Because of this good connectivity with transit and availability of alternative transportation modes, the amount of parking space in the studied stations is considerably lower than the projected parking needs for HSR stations in California.

The new high-speed infrastructure compresses time and space making some cities much more accessible. Thus, in Spain, after the advent of the HSR, it became much easier for tourists arriving in Madrid to visit places like Toledo, Córdoba, or Seville. At the *regional level,* the possible complementarity of a station with neighboring stations along the HSR line should be considered in determining the desirable land uses around the station. This is likely more important for second-tier cities that may attract more visitors and tourists if they are only 60-90 minutes away from first-tier cities.

Operational connectivity of HSR services is also very high, particularly in Germany, which features integrated ticketing options and transfer of luggage services from one mode to the other. Both systems also have significant levels of coordination with transit operators of conventional services, and coordination of municipal, state and federal entities for the provision of unified design and safety standards, signs, and maintenance.

Conclusion

The German and Spanish case studies can provide lessons for the California HSR system. They have achieved high levels of intra-city and inter-city connectivity, and have found ways to integrate local and regional railway services, buses, and even airline services so as to complement rather than compete with one another. This entails both an operational aspect involving coordinated scheduling of different modes for easy links and short transfer times, as well as a spatial aspect (easy physical access from one mode to the other, visual connections between platforms). Additionally, while the HSR stations in Germany and Spain often incorporate services similar to those found in an airport, the most successful European stations are not designed as airports (inward-oriented and cut-off from the rest of the city). Instead, they are designed as both functional transportation nodes but also outward-oriented, social hubs with high levels of connectivity and good integration to the surrounding city fabric.

Acknowledgement. This study was funded by the Mineta Transportation Institute.

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Interviews

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