INTEGRATION OF HIGH-SPEED TRAIN STATIONS IN CITIES: THE CASE OF SPAIN AND VALENCIA CITY

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ABSTRACT

Specialists have been discussing the best locations for railway stations for a long time; the first railway stations were built in the 21st century, and afterwards cities grew to the point of leaving the stations in central areas. Central stations provide train trips with several advantages over other means of transport. However, high-speed railway (HSR) introduces new variables when considering the best location for new stations. In 2000, the author's team started the discussion and assessment of possible locations for the new HSR station in Valencia (Spain) and undertook two studies to analyse this issue. This article provides a theoretical framework for train station location and the analysis of the case in Spain. Furthermore, it synthesizes the results from researches performed in 2002 and 2006 as well as their implementation in Valencia. In addition, this article examines recent experience in relation to new high-speed train station placement, and the case of the 2,400-km-long HSR network in Spain by the end of 2015. Since the HSR network has a different track gauge in relation to the historical railway network, adaptations in the old stations or new locations were required. This situation allowed us to analyse the evolution of HSR in Spain and confirm theories about territorial impacts and optimal rail-network design, particularly in relation to the best location for new HSR stations. This article also looks into the evolution and current trends in modern railway planning, which have progressively changed in Spanish cities such as Madrid and Barcelona.

Keywords: city-HSR integration, high-speed train, HSR stations, intermodal air-train station.

1 INTRODUCTION

Historically, the Spanish railway network has used a special Iberian width (IB) with a 1,668-m gauge, different from the European gauge, which is 1,435 m (termed standard width or the International Union of Railways gauge (UIC gauge)). Integration of the European rail network will involve changing the Spanish rail network to the European width, an expensive process that may last for a long time. However, Spain now has the technology that allows mobile elements to change the width of the train shaft so that they can circulate on tracks with different widths.

The Spanish Rail Transport Plan, aimed at improving the conventional trains and railway network, was approved in 1987. A few years later, the Spanish government decided to postpone the plan and designed the first high-speed line (the *Alta Velocidad Española* services; AVE in Spanish) between Madrid and Seville, which was used for the first time in the opening of the Universal Exposition of Seville in 1992. This service offers 300–350 km/h speed and it inaugurated the new railway network with a UIC gauge in Spain. However, investment in this infrastructure consumed the entire planned budget for the conventional rail plan. The high-speed train station in Madrid was built by refurbishing the historical Atocha Station, located in city centre.

In Fig. 1, one can see the HSR network in Spain in 2015. As shown in Table 1, the new railroad network progressively extended, and as the high-speed network expanded, the number of passengers of HSR services also grew, as shown in Fig. 2.

It is of note that the number of passengers is low in relation to the length of high-speed lines built. According to Albalate and Bel [3, 4], the Spanish high-speed rail network is more extensive than the networks in France, Germany or Japan and the ratio of network length (km) per inhabitant is very high; accordingly, the passenger load per kilometre of network is very low. In 2014, Spain had about 10,000–11,000 passengers per kilometre of network

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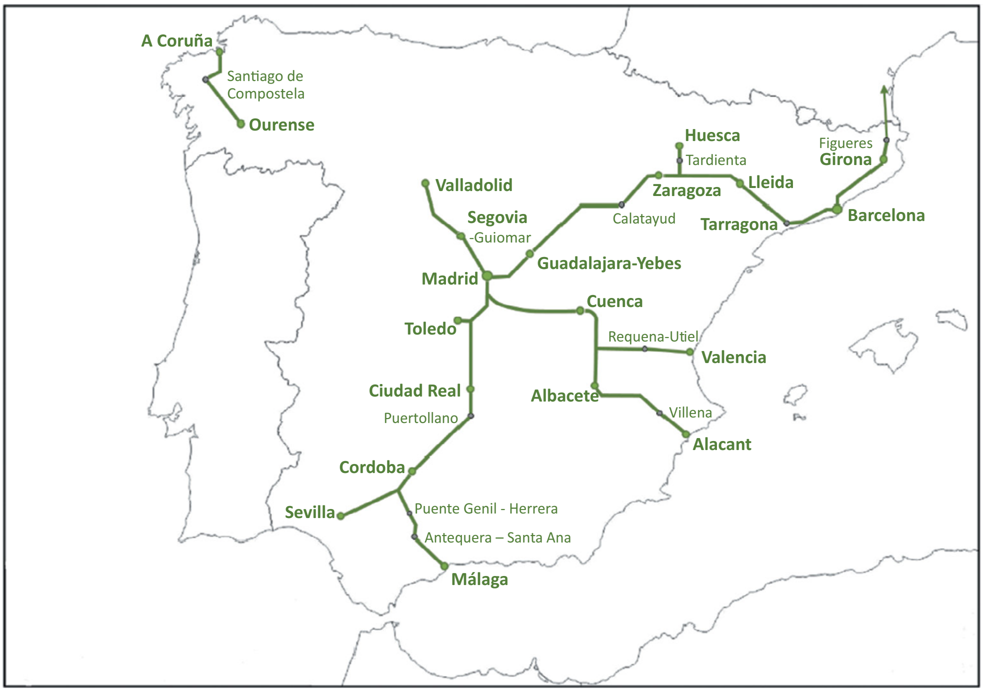

Figure 1: High-speed railway network in Spain, 2015. Source: ADIF [1].

while Japan had 58,121, and France 61,394 passengers per kilometre of network, in the same year. In units of passengers per kilometre of network (passenger-km), France has 25.1 billion passenger-km and Germany has 24.4, while Spain has 4.5. The intensity of HSR network use in Spain is very low; indeed, the expansion of the HSR network in Spain has been rather a political cause than technical and economic ones.

Whereas the historical rail network having a different width from the UIC European gauge has conditioned a lot of governmental decision making, the new HSR network was designed with the UIC gauge and can connect with the general European rail network. However, in general, the HSR network is designed for passengers, in other words, for light trains travelling at high speeds, which do not allow rail deformations.

Therefore, the HSR network usually has a different design from the merchandise rail network, which is planned for heavier and slower trains. In addition, the historical rail network can be used for conventional services and, if a third line is added to the platform, a valid network for both gauges can be generated. The best solution for changing the historical rail network is not clear and may differ for different sections of the network.

In the Spanish context, instead of prioritizing the transformation of lines with the highest passenger traffic, successive governments opted for an extensive transformation of the entire radial network to serve the greatest number of cities with passenger services, all lines departing from and arriving to Madrid (Bel [6]). In order to increase the use of this new infrastructure, ADIF improved the ‘average distance train’ services, that is those provided to cities that are relatively close to each other (see Table 2). Although the total number of passengers is low, these services promote more integration of nearby cities connected by the high-speed service in the metropolitan areas of Madrid and Barcelona.

Table 1: Evolution of the high-speed railway network in Spain. Source: Railway Infrastructure Administrator (ADIF; in Spanish, *Administrador de Infraestructuras Ferroviarias*) [1] and *Vía Libre* magazine [5].

Services start date	Stretch	High-speed railway line	High-speed length (km)	% railway
April 1992	Madrid–Sevilla	Madrid–Sevilla	477.8	3.86
October 2003	Madrid–Zaragoza–Lleida	Madrid–Barcelona–France	1,025.8	7.93
November 2005	Madrid–Toledo		1,049.9	8.17
December 2006	Lleida–Camp de Tarragona	Madrid–Barcelona–France	1,253.2	9.57
2006, December	Córdoba–Antequera	Córdoba–Málaga	1,253.2	9.57
December 2007	Madrid–Valladolid	Madrid–Valladolid-Galicia	1,492.5	11.18
December 2007	Antequera–Málaga	Córdoba–Málaga	1,492.5	11.18
February 2008	Camp de Tarragona–Barcelona	Madrid–Barcelona–France	1,600.5	11.89
December 2010	Mollet–Girona & Figueres–Pertús	Madrid–Barcelona–France	2,135.7	15.25
December 2010	Madrid–Cuenca–Albacete–Valencia	Madrid–Valencia–Murcia	2,135.7	15.25
December 2011	Ourense–Santiago–A Coruña	Atlantic Axis	2,225.4	15.78
January 2013	Barcelona–Figueres	Madrid – Barcelona – France	2,444.1	17.32
June 2013	Albacete–Alacant	Madrid–Valencia–Murcia	2,444.1	17.32

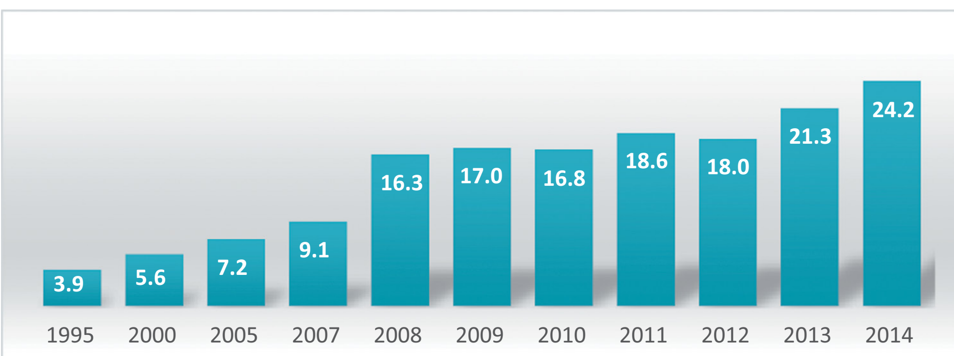

Figure 2: Evolution of high-speed railway passengers in Spain (millions). Source: Ministry of Development (Spain) [2].

Table 2: Passenger numbers for 'average distance' high-speed railways.
Source: Ministry of Development (Spain) [2].

	Passengers (thousands)	
Year	2013	2014
Madrid–Toledo	1,326	1,259
Madrid–Segovia–Valladolid	1,602	1,619
Zaragoza–Lleida–Barcelona	456	408
Sevilla–Córdoba–Málaga	834	826
Zaragoza–Calatayud	66	65
Zaragoza–Huesca	–	–
Madrid–Puertollano	1,121	1,080
Jaén–Cádiz	85	–
Valencia–Utiel–Requena	1	5
Figueres–Barcelona	743	638
A Coruña–Santiago–Pontevedra–Vigo	–	–
Ourense–Santiago–A Coruña	292	351

The aim of this article is to analyse the consequences of the new HSR services regarding city growth in Spain and confirm whether these new services promoted economic progress. In addition, the location of a high-speed station can have an important role in the success of new services in the city and, consequently, in the economic progress. In a second part, this article analyses this role. Finally, the article focuses on the case of Valencia, now in a provisional situation, to give recommendations according to the results of this study, especially aspects regarding the environmental and territorial conditions of the city.

2 POPULATION GROWTH IN CITIES CONNECTED BY HIGH-SPEED RAILWAYS

2.1 High-speed railways and economic growth

The traditional paradigm says, 'Infrastructures are necessary but not sufficient for economic development.' However, in Spain, between approximately 1997 and 2007 [7], – the period of property speculation – economic development was based on the construction sector: residential and public works, particularly the HSR network. In this period, Spanish society accepted the myth that 'new infrastructures are synonymous with economic development', and thus politicians in every city demanded HSR services.

Nevertheless, according to different authors, including Bernard et al. [8], the relationship between HSR services and economic growth is not clear. HSR can be regarded as a tool for economic and social activity but its usefulness depends on its applications.

In the next section, changes in the population of Spanish cities with HSR services are analysed to contrast the traditional theory: if HSR services were to produce a comparative economic advantage over cities without such services, there would be greater economic activity and a relatively higher population growth rate in cities with HSR services.

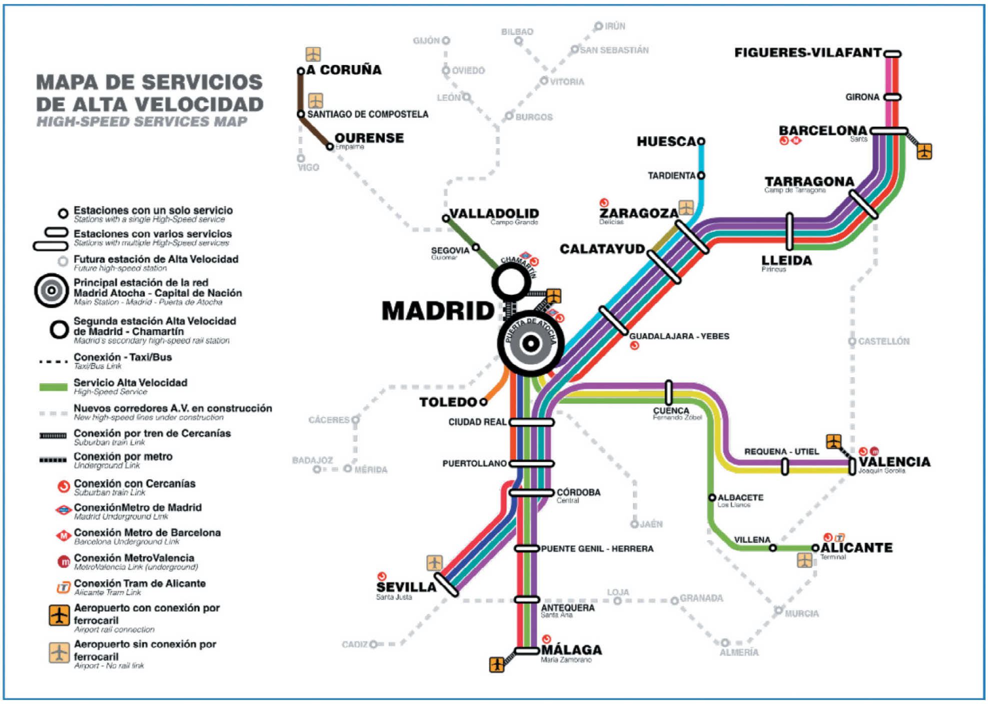

Figure 3: Map of high-speed train services in Spain, and links to France in 2015. Source: Wikipedia, 2015; verified information.

2.2 Population growth in Spanish cities with a high-speed railway service

Figure 3 shows a schematic map of Spanish HSR services, with verified information that well illustrates the services offered in 2015. Since 2013, when the connections between Barcelona, Figueres and Le Perthus (known as El Pertús in Spain) were finished, direct high-speed train services between Barcelona and Paris came into existence. The map clearly shows the relative locations of Spanish cities with high-speed services and their links to France.

Table 3 shows the evolution of population in Spanish cities after the implementation of HSR services; the change in the overall population in Spain serves as a reference to measure the population changes in individual cities served by HSR. Table 3 shows their absolute population and their changes during the periods of 1992–2007 (economic expansion cycle) and 2007–2015 (economic crisis cycle). The dates when the first HSR station services were put into use are also shown, and any effects that these HSR services produced on the population of each city are measured from that date. Population censuses predating the installation of HSR services are marked in red.

To analyse the different behaviours in different cities, cities have been grouped into five classes:

A. The cities of Madrid and Barcelona: both are metropolitan centres home to around 5 million inhabitants. In these cases, the population data are not significant for this analysis because the data only correspond to a part of the larger metropolitan areas. The distance

Table 3: Increase in population size of Spanish cities with the extension of high-speed railway services (dates shown in red represent data recorded when no high-speed railway services were yet present). Source: National Statistics Institute (*Instituto Nacional de Estadística*, INE), Spain, and the author.

	Initial HSR train station services	Population 1996	Population 2007	Δ % 1996–2007	Population 2015	Δ % 1996–2015
Spain		39,669,394	45,200,737	13.94	46,624,382	17.53
Madrid	Apr. 1992	2,866,850	3,132,463	9.26	3,141,991	9.60
Barcelona	Feb. 2008	1,508,805	1,595,110	5.72	1,604,555	6.35
Valencia	Dec. 2010	746,683	797,654	6.83	786,189	5.29
Seville	Apr. 1992	697,487	699,145	0.24	693,878	–0.52
Zaragoza	Oct. 2003	601,674	654,390	8.76	664,953	10.52
Malaga	Dec. 2007	549,135	561,250	2.21	569,130	3.64
Valladolid	Dec. 2007	319,805	316,564	–1.01	303,905	–4.97
Córdoba	Apr. 1992	306,248	323,600	5.67	327,362	6.89
Alacant	Jun. 2013	274,577	322,673	17.52	328,648	19.69
Albacete	Jun. 2013	143,799	164,771	14.58	172,121	19.70
Tarragona	Dec. 2006	112,176	134,163	19.60	131,255	17.01
Lleida	Oct. 2003	112,035	127,314	13.64	138,542	23.66
Girona	Jan. 2013	70,576	92,186	30.62	97,586	38.27
Guadalajara	Oct. 2003	67,108	77,925	16.12	83,391	24.26
Toledo	Nov. 2005	66,006	78,618	19.11	83,226	26.09
Ciudad Real	Apr. 1992	59,392	71,005	19.55	74,427	25.31
Segovia	Dec. 2007	54,287	56,047	3.24	52,728	–2.87
Puertollano	Apr. 1992	50,772	50,838	0.13	50,035	–1.45
Huesca	Dec. 2003	45,607	49,819	9.24	52,239	14.54
Cuenca	Dec. 2010	43,733	52,980	21.14	55,428	26.74
Antequera	Dec. 2006	40,181	44,547	10.87	41,141	2.39
Figueres	Jan. 2013	33,157	41,115	24.00	45,346	36.76
Villena	Jun. 2013	31,555	34,523	9.41	34,361	8.89
Puente Genil	Dec. 2006	27,472	29,093	5.90	30,167	9.81
Requena	Dec. 2010	18,795	20,440	8.75	20,621	9.72
Calatayud	Oct. 2003	17,078	21,040	23.20	19,724	15.49
Tardienta	Dec. 2003	1,087	1,022	–5.98	985	–9.38

between these two areas is about 600 km; therefore, the only clearly justifiable HSR connection is the one between them.

B. The cities of Valencia, Seville, Zaragoza and Malaga have central urban areas connected by HSR, with populations of around 500,000–700,000 inhabitants. These cities are the main centres of important urban areas with an overall population of around 1–1.5 million people; they all reported population growth rates for both periods (expansion and crisis) much lower than Spain as a whole. Of note is the case of Seville (urban area about 1.5 million people): it was the first city to connect with Madrid in 1992, but its population decreased, so connection with HSR services failed to boost economic development. Valencia's population (urban area about 1.7 million people) also decreased after linking to HSR services. Therefore, there was a little reduction in population in both cities.

C. The cities of Valladolid, Cordoba, Alicante, Albacete, Tarragona and Lleida have between 100,000 and 300,000 inhabitants. Regarding the population of Valladolid, it decreased, especially after the introduction of HSR services, and the population of Cordoba showed a similar pattern to group B. The population in the other four cities increased to a level above the overall growth of Spain, especially Lleida. With regard to these cities, the journey time allows Valladolid to enter the hinterland of Madrid (journey time 1 h 1 min), Córdoba enter the hinterland of Seville (journey time 42 min) and Tarragon and Lleida enter the hinterland of Barcelona (journey time 36 min and 57 min respectively).

D. This group consists of 15 intermediate cities with populations between 17,000 and 70,000 inhabitants. There were six cities with a very big population increase in this group, all of them located on the outskirts of the metropolitan areas of Madrid or Barcelona. Girona and Figueres are close to Barcelona, with journey times of 37 min and 53 min, respectively, whereas the following journey times are required to reach the edge of Madrid from the other cities: Guadalajara, 22 min; Toledo, 33 min; Ciudad Real, 51 min; Cuenca, 51 min. The exceptions were Segovia (27 min to Madrid) and Puertollano (1 h 13 min to Madrid); both showed a reduction in population after the introduction of HSR. The other cities showed a population increase, but lower than the overall increment in Spain.

E. Finally, there is the special case of Tardienta, a very small town with an HSR station, which showed significant population loss during the periods studied.

In Fig. 4, one can see the different hinterland of urban areas around the most important cities and their growth behaviour – cities with a decrease in population are in red; cities with an increase in population of up to 10% are in green; cities that increased their population between 10% and 40% are in blue. Thus, the analysis shows that HSR services produced a high increase of population in cities on the outskirts of urban areas with the highest level of economic activities.

In addition, in Fig. 4 one can see the main metropolitan and urban areas of Spain with HSR services (Madrid and Barcelona are the main metropolitan areas; Seville, Malaga, Alacant, Valencia and Zaragoza are urban areas). The increase of population in cities around the hinterland is bigger than the increase of population in the city area (Madrid, Barcelona, Seville, Malaga, Valencia and Zaragoza). This general rule presents some anomalies: Valladolid and Segovia, in the hinterland of Madrid city, decrease their population, whereas Alacant, the centre of Alacant city urban area, increases its population more than Villena city, in its hinterland.

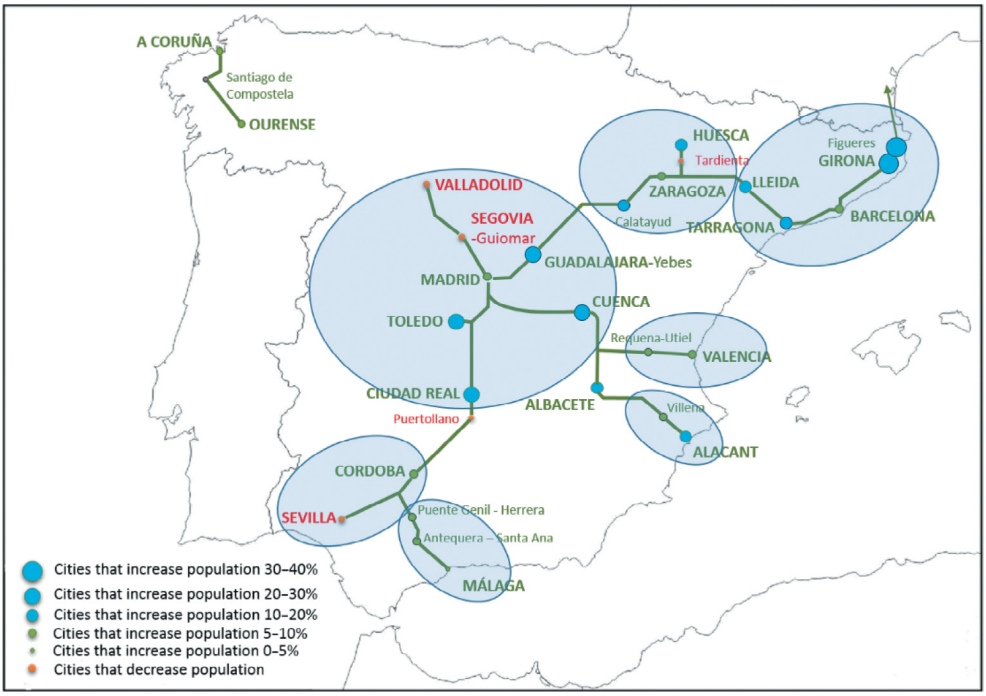

Figure 4: Territorial impact in system of cities by HSR services.

Besides, other factors must be considered in order to explain particular situations. Depending on the location of the HSR station and its integration with the city transport system, passengers may have other travel alternatives or, even, an HSR journey might not be a useful option.

3 LOCATION AND INTEGRATION OF HIGH-SPEED RAILWAY STATIONS IN SPANISH CITIES

3.1 Theoretical framework

The decision of where to locate HSR stations has decisive consequences on the functionality of the high-speed network. It is noteworthy that, in some cases, the journey time between city stations by HSR may be shorter than the journey time to the HSR station from the user's origin. In addition, travel by HSR may be complementary or an alternative to other modes of travel in the transport system. This question is particularly important in Spain for 'average distance' HSR services.

When the HSR services to Valencia (Spain) were planned, the author's research team, *UDR F. Eiximenis*, performed two studies to assess the best location for the new HSR station in the city: the first one, in 2000 [9] and the second one, in 2006. These studies allowed us to better understand the issue. This article explores and updates some aspects of these original studies.

The discussion about the best location for HSR stations is a long-standing one; classical theory postulates that the best location for conventional train services is in city centres.

Nevertheless, HSR services have special features and respond to distinct travel demands. On the one hand, HSR services are an alternative to air travel for distances between approximately 200 and 500 km, and accordingly, HSR services can be used as a segment of combined flights. On the other hand, the characteristics of the terminal cities justify HSR services, but several intermediate cities with smaller population, located along the route of the infrastructure, may not justify the placement of HSR stations. If these populations are to be serviced by HSR, the best locations for HSR stations must be decided because it is not possible to build them in every city along the network.

The first case corresponds to cities with regional airports. Authors including Widmer and Hidber [10, 11] and López [12] have studied the relationship between HSR and air transport. The second case has been studied by authors such as Zembri [13], who analysed the situation in France. He identified five types of new peripheral HSR stations in France:

1. Functionally independent conventional systems and HSR networks with a new peripheral station in addition to the historic station.
2. HSR line around the city, with a new station in addition to the historic one.
3. HSR line around the city, but without a new station in addition to historic one: HSR trains must connect with the conventional network to stop in the city.
4. Refurbishment of the historic station in order to accommodate the new HSR services; total integration of HSR services into the conventional services.
5. Interruption of the HSR line so that it connects with the conventional network and can arrive to the historic station.

In Spain, Pié (coordinator) et al. [14] studied the case of the Catalan stations and Menéndez et al. [15, 16] studied the case of Ciudad Real. They identified five possibilities for HSR stations in small cities (central station, border station, distant station, duplicate station on the border of the city and station shared by several cities). These five categories can be grouped into three basic types: central station, distant (or isolated) station, and border station. Thus, the location of every Spanish HSR station and their relationships with the urban development of each city can be analysed in this context.

3.2 Typology of high-speed railway stations in Spain

Table 4 shows the basic characteristics of Spanish HSR stations. The list is sorted by the inauguration date of these services. Madrid and Barcelona, coloured in blue, are at the centre of big metropolitan areas with hub airports. Seville, Cordoba, Tarragona, Malaga, Valladolid, Valencia, Alicante and Zaragoza, coloured in brown, are the centres of urban areas with regional airports. The rest are intermediate cities with no airports, except for cities in tourist zones such as Girona.

The characterization of HSR stations is based on the following:

1. The line position: when the station is at the end of a line (EL), the train has to change its direction to continue its journey, thus causing time loss. In the contrasting case, the station is on-line (OL);
2. The station position relative to the city centre: Central station (C) or station isolated outside a city (I) or on its border (B). In the second case, the distance to the city centre in kilometre is supplied;

Table 4: Characteristics of Spanish high-speed railway stations.

City	population 1996–2015	Station name, inauguration year	Line position	Position	Building	Relationship to old network
Madrid	9.60	Atocha (1992)	EL	C	ROS	IS
		Chamartín (2007)	EL	B	ROS	IS
Seville	–0.52	Santa Justa (1991)	EL	C	N	IS
Cordoba	6.89	Central (1994)	OL	C	ROS	IS
Ciudad Real	25.31	Central (1992)	OL	B	N	IS
Puertollano	–1.45	1992	OL	C	ROS	IS
Huesca	14.54	2001	EL	C	ROS	ISI
Zaragoza	10.52	Delicias (2003)	EL	C	N	ISI
Lleida	23.66	Pirineus (2003)	OL	C	ROS	IS
Guadalajara	24.26	Guadalajara–Yebes (2003)	OL	I; 8 km	N	DS
Calatayud	15.49	Calatayud–Jalón (2003)	OL	B	ROS	IS
Toledo	26.09	2005	EL	B	ROS	IS
Tardienta	–9.38	2005	OL	C	ROS	IS
Tarragona	17.01	Camp Tarragona (2006)	OL	I; 11 km	N	DS
Antequera	2.39	Santa Ana (2006)	OL	I; 11 km	N	DS
Puente Genil	9.81	2006	OL	I; 4 km	N	DS
Malaga	3.64	Maria Zambrano (2006)	EL	C	ROS	ISI
Segovia	–2.87	Segovia–Guiomar (2007)	OL	I; 7 km	N	DS
Valladolid	–4.97	Campo Grande (2007)	OL	C	ROS	IS
Barcelona	6.35	Prat de Llobregat (2008)	IO	NA	ROS	IS
		Sans (2008)	OL	C	ROS	IS
		La Sagrera (2008)	OL	C	N	IS
Cuenca	26.74	Fernando Zóbel (2010)	OL	I; 4 km	N	DS
Albacete	19.70	Los Llanos (2010)	OL	B	ROS	IS
Requena	9.72	2010	OL	I; 6 km	N	DS
Valencia	5.29	Joaquín Sorolla (2010)	EL	C	S	DN
Figueres	36.76	2010	OL	B	N	DS
Girona	38.27	2012	OL	C	ROS	ISI
Alicante	19.69	2013	EL	C	ROS	IS
Villena	8.89	2013	OL	I; 4 km	N	DS
Spain	17.53					

3. The type of station building: new building (N) or refurbishment of an old station (ROS). When a historical station is refurbished, it usually has a central position in the city. In the case of a totally new station built in a new location, the station is usually on the edge of the town or isolated from it.
4. The relationship with the old (or conventional) rail network: integrated station (IS), integrated station and intermodal hubs (ISI), and duplicate stations (DS). Stations are integrated when they can serve both conventional and HSR services; that is the conventional and HSR networks meet at the station. Stations are integrated and intermodal when the station design additionally allows passengers to transfer to other transport modes, for example by including a bus station. Finally, duplicate stations mean that there is one station for conventional trains in one place and another HSR station elsewhere, with no rail connection between them.

Concerning the two largest urban centres, additional information is required. An HSR connection between both station in Madrid, Atocha and Chamartin does not currently exist, and therefore the Madrid–Segovia–Valladolid line does not directly connect to the lines from Madrid to other cities. However, an HSR Atocha–Chamartín connection line via a tunnel is presently under construction and is due to finish in 2016. In Barcelona, two stations (Sans and La Sagrera in the city centre) were initially planned, but the municipality of Barcelona and the Catalan government petitioned for a third station at the airport. Finally, the HSR line was diverted to establish a station in the city of El Prat de Llobregat, which is near the airport, and connect it by shuttle train (currently under construction).

The case of Tarragona is special because the station is temporary: its final location will be near the airport, in the centre of the Tarragona–Reus–Valls urban area.

Some stations, such as Puente Genil–Herrera or Requena–Utiel, which serve several small towns, are shared.

Segovia and Guadalajara stations were associated with real estate development, and thus are located outside these cities. Both Segovia and Guadalajara urban developments failed and today these HSR stations are isolated. The stations of Tardienta and Requena are associated with logistical projects, but both failed and today these stations hardly have any passengers.

3.3 The functionality of different types of station

Firstly, research shows that there is no correlation between the characteristics of Spanish HSR stations and the evolution of city population. In fact, you can find all possibilities of increase in population for each kind of cities. For this reason, in Table 4, stations are sorted by the year when they came into operation. Data show that location of the HSR stations (design of infrastructure on an urban scale) does not necessarily have a consequence in the increase or decrease of population (dynamic process on a territorial scale). On the other hand, it is obvious that the design of railway infrastructure on an urban scale has consequences on urban mobility and efficiency of urban transport. So it is necessary to analyse each case and consider other factors.

When the first HSR lines were planned, the locations of the HSR stations were originally planned as adaptations to the historical stations where possible; in general, historical stations now have central positions, since cities have grown around them. A good example of this is the Madrid (Atocha)–Ciudad Real–Puertollano–Cordoba–Seville HSR line, which does not include any planned intermodal stations at the airports. On this line, only Ciudad Real showed a population increase higher than that of the whole of Spain. Therefore, this new infrastructure failed to generate greater relative activity along its route, with the exception of Ciudad Real, whose population increased by 25.31%.

Ciudad Real (and similarly, Toledo) is a small city with a technical university and a few technical businesses; it specializes in the service sector. The HSR journey time (51 min) located both these cities within commuting distance to Madrid and it allowed them to integrate into the hinterland of Madrid metropolitan area. According to Garmendia [17], the HSR connection also facilitated changes in behaviour of people living in zones up to about 30 km from Ciudad Real and Toledo. For example, people in this zone use HSR service to go shopping in Madrid.

In contrast, Puertollano, the next station from Madrid, at a distance of 37 km or 15 min travel time from Ciudad Real, showed different results. Puertollano is a mining city, with related industries; therefore, HSR services provide no special advantage to its citizens or the city industrial sector. Consequently, Puertollano is out of hinterland of Madrid. This fact suggests that a one-hour trip time by HSR marks the boundary of hinterland of Madrid metropolitan area.

On the other hand, HSR services on the Madrid–Guadalajara–Calatayud–Zaragoza–Lleida and Zaragoza–Tardienta–Huesca lines started in 2003. The evolution of Lleida, and to a lesser extent, Figueres and Girona, with their HSR integrations into the Barcelona metropolitan area, was similar to that of Ciudad Real. Huesca and Calatayud also showed a comparable progression with respect to the Zaragoza urban area, with intensity analogous to Figueres and Girona (See Fig. 4).

A special case is that of the Guadalajara–Yebes station, which was built 8 km away from the city centre in association with a speculative real estate, named Valdeluz. Guadalajara city has a historical train station in the city centre connected with Madrid, which offers 59 conventional services a day in each direction, with a journey time to Madrid of 36–55 min. In contrast, the HSR services only offer nine services a day in each direction with a journey time of 22–26 min, plus the commuting time required from Yebes station to the city centre, and fares that are more expensive. Together, this means that people only use the conventional services, not the HSR services [18]; this is illustrated by the fact that, from November 2009 to November 2010, the conventional station had 2,412,480 passengers, while the HSR station had only 6,764 passengers.

You can observe a similar situation for the Segovia–Guiomar station. In this case, the journey time to Madrid by HSR (Chamartin on the Segovia line) is about 30 min while it takes about 2 h to go from Madrid (Atocha) to Segovia centre by conventional train. However, Madrid–Chamartin is not connected to Madrid–Atocha by HSR, which can add up to an hour extra travelling time. In fact, in contrast to Ciudad Real and Toledo, neither Segovia nor Valladolid has been integrated into the Madrid metropolitan area, and both have experienced a population decrease.

Both the Segovia and Guadalajara real estate development projects failed, leaving isolated stations. Other similarly distant stations are Antequera, Puente Genil, Cuenca, Requena and Villena; all these cities, except Cuenca, showed a moderate population increase, which was lower than the global increase in Spain. In spite of having an isolated station, Cuenca's performance, having integrated into Madrid metropolitan area, shares characteristics with Ciudad Real. Comparably, both Requena and Tardienta stations were built to promote logistics in the surrounding areas; both failed. These stations have almost no passengers: about 50 a day each.

If you focus your attention on cities marked in brown in Table 4 (centres of urban areas with regional airport), you can check that all cities have a central station in a new building or a refurbished old station and are integrated with conventional services. Tarragona and

Valencia, both in temporary situation, are exceptions. These two cities present particular situations that need special discussion, and thus it is explained in the next paragraphs.

Currently, Tarragona city has a temporary HSR station which is very far away (11 km) from the city centre. Nonetheless, the station serves all the Tarragona urban area and is provided with good bus services. Therefore, there is a lot of commuting between Tarragona and Barcelona (23 HSR services in each direction every day, with a journey time of 31–55 min), in addition to the conventional services from the city centre station. The final HSR station is planned near the airport, in the centre of the Tarragona urban area, but not in the centre of Tarragona city. It represents the only case of a city with a regional airport with an HSR station planned at the airport.

The fact that Tarragona will be the only example of an intermodal HSR station at an airport in Spain implies an urban-planning contradiction: if HSR services are to replace air services over distances of 200–500 km, it would be logical to establish intermodal stations at airports to facilitate multi-legged HSR-air journeys. Without any HSR-air intermodal stations, passengers must carry their baggage from one station to another in order to continue travelling, thus promoting an uncomfortable and dysfunctional user experience.

However, the new *Plan de Infraestructuras*, *Transporte y Vivienda* (PITVI: Plan for Infrastructure, Transport, and Housing in English) for the period 2012–2024 [19], which was completed in March 2015, supports the integration of different means of transport as a way to improve the functionality of the current transport system. In particular, it encourages connection of the HSR network to hub airports, such as Madrid–Barajas airport, via intermodal stations, and explores the possibility of applying this option to other cities where there is a potential demand.

4 THE CASE OF VALENCIA

4.1 Project backgrounds

The case of Valencia is even more special. In 2003, the Ministry of Public Works (Ministerio de Fomento), Regional Government and City Council of Valencia signed an agreement to locate future HSR station in city centre, right next to the current station. This political action removes the study of other possible alternatives. But in fact, now the project is not executed and is not programmed because of economic crisis.

The author's research team has studied the case of Valencia since 2000, when a study [20] about how to best integrate an HSR station into Valencia City was carried out, concluding that the best location was at the airport. Now Valencia airport is connected with the city centre by the underground metro system. Placing the HSR at this location would increase access for cities such as Castelló and Albacete (populations 142,285 and 143,799, respectively in 1996) to the vicinity of the airport, and in consequence, could increase the potential passenger demand for HSR services.

Based on the agreement of 2003, a study of alternatives for HSR project with it environmental impact study was realized. In 2006, the environmental assessment was approved for a selected alternative. This alternative defines a project with a central station next to historical station and a new train infrastructure drawn through the agricultural land north of Valencia (about 15 km). Now this project is not executed.

Now, Valencia City has a temporary HSR station in a temporary location (in service from 2010). Actually, this current HSR station of Valencia has a special characteristic. The station is neither exactly in the city centre nor on the outskirts, but located in an intermediate situation. The station is not integrated in the old conventional station in the centre of

Valencia. The new temporary station is at a distance of 1 km from the old station. You need to take a bus to change station. However, some services for the long-distance journeys by conventional train stop at the old station and some stop at the new station. Depending on timetable, passengers must go to one of the stations and, in case of train-combined travel, they probably need to change station. It is a case of non-integrated station. The new station is neither integrated with public transport systems as the underground, which has a station 200 m away from the train station. In addition, the new station is the end of line, which produces delays in transit travels.

Therefore, it is possible to do a more rigorous analysis and change the plan to a final design of HSR infrastructure in its urban area according to experiences and analyses already exposed, functional conditions, and also the geographical conditions around the city.

4.2 Geographical conditions

The city of València is on the Mediterranean coast. The city centre is 4 km from the sea port. In the south, the protected area of Albufera Natural Park is located. In addition, the north and south of the city are surrounded by agricultural land of very high quality. In this situation, the metropolitan area should have planned the tracings for large infrastructure projects to minimize environmental impacts on the territory. But actually it has not. Now there isn't metropolitan plan. And historical metropolitan plans, currently not in force, planned the tracings for road infrastructures but not for train infrastructures. As a result of this situation, the new high-speed rail infrastructure built in the southern entrance of Valencia produced strong impact on the territory (destruction of agricultural land, fragmentation, barrier effect, etc.). According to the tracing alternative selected to northern entrance, environmental impacts can be played in the northern area.

Besides, it is necessary to consider other territorial issues. The current territorial policy in Valencia, according to the European policy, requires green infrastructures to be designed for future preservation and maintenance, before planning any other use for the land. However, the current project traces the new HSR infrastructure through the historic Horta of Valencia from the north exit of Valencia City to the town of Puçol (about 15 km). The historic Horta of Valencia occupies a large area and has special features [21]. This area is in process of protection and the new HSR infrastructure will produce a high environmental impact.

4.3 Functional conditions

The author's team developed a second proposal in 2006, for integrating HSR into Valencia City: one station in the centre city and a second one at the airport, as shown in Fig. 5. In Fig. 6 you can see the proposal for central station.

This proposal is in accordance with the results of this study: one integrated train station in the centre of Valencia (an on-line station which allows transit without delays) and a second station at the airport (also on-line and out of the protected area of Horta of Valencia). The central station can be integrated with T2 line of underground public transport.

Figure 6 shows the proposed network around the city centre, which would also have allowed the construction of a new Great Avenue crossing the entire city. This is now impossible due to two residential buildings located on the route of the avenue. Our proposal plan changes the location of these buildings to create the new Great Avenue. This urban project allows building the new station in a central position.

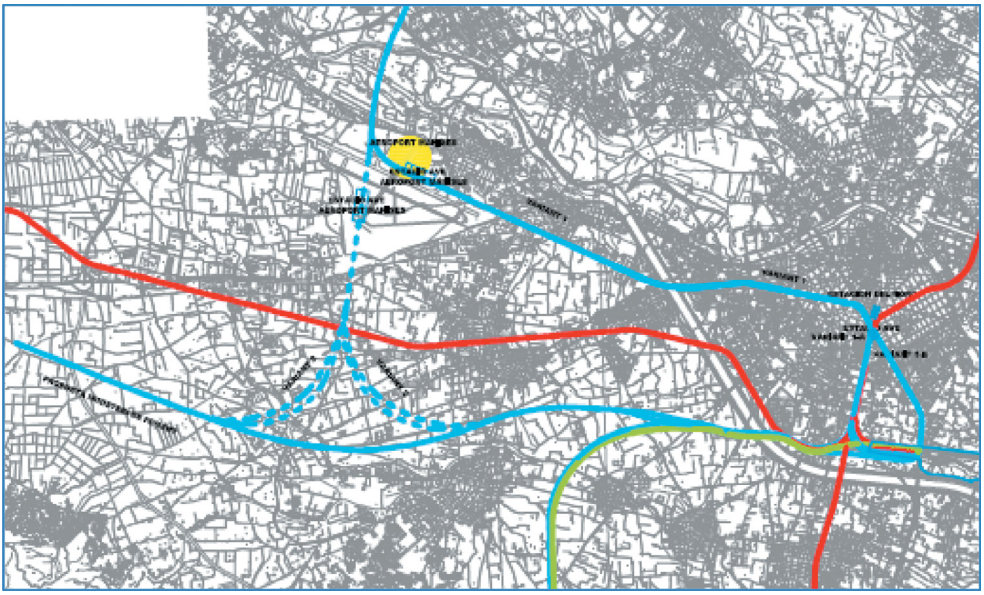

Figure 5: Study of the solutions for integrating the high-speed railway station into Valencia City (2006) with two stations, in the city centre and airport (the conventional line is shown in red; the planned high-speed line is shown in blue; the line eventually built is shown in green).

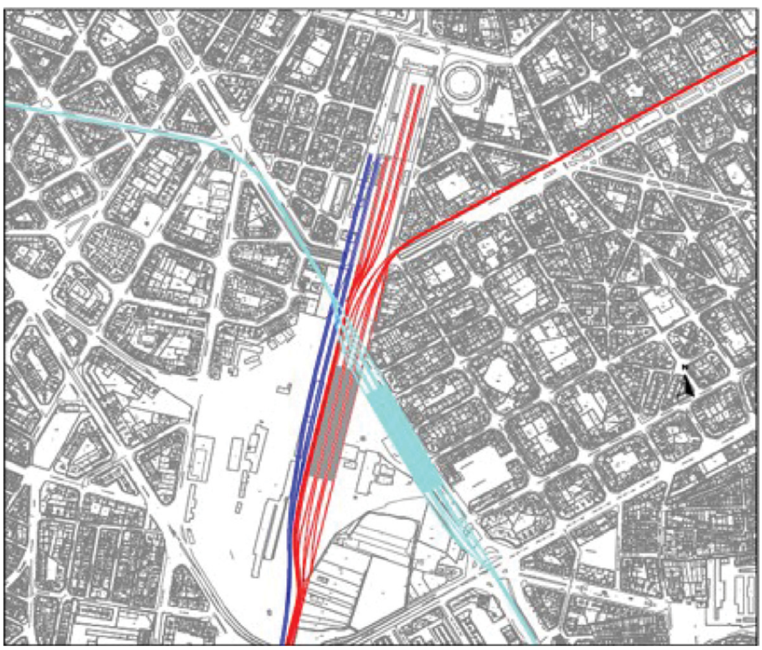

Figure 6: Study of high-speed railway station solutions in Valencia city centre, 2006: terminal station and on-line station accommodating both rail gauge widths (Iberian gauge in red colour and UIC gauge in blue colour for two levels).

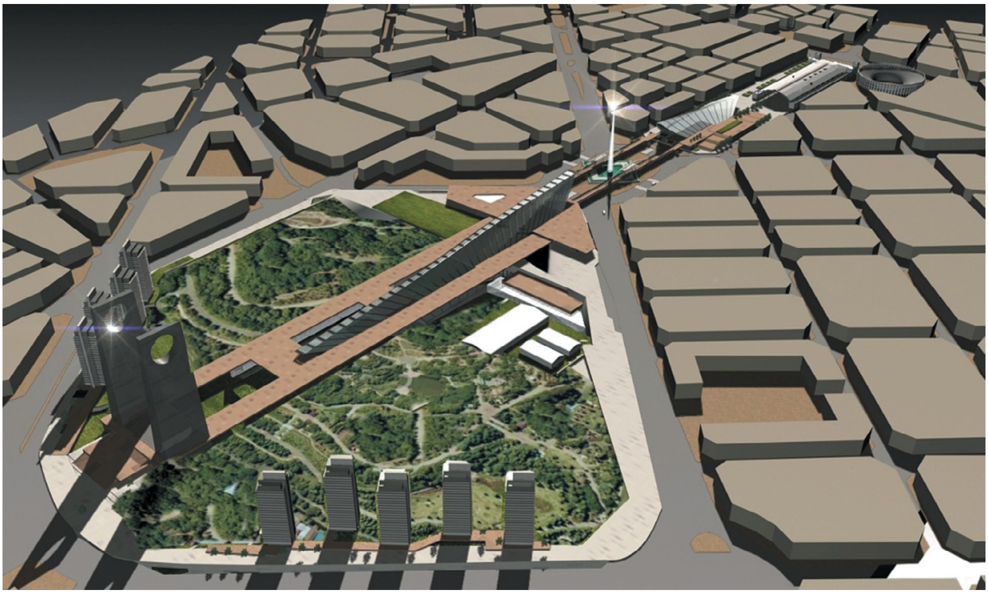

Figure 7: Three-dimensional simulation of high-speed railway station, a Central Park and a new Great Avenue. *UDR F. Eiximenis* proposal, 2006. Design by architect Carlos Prieto.

Figure 7 shows a virtual project 3-D simulation. Architect Carlos Prieto, in collaboration with architects Roberto Gómez-López and Pablo Cadeneau, designed public spaces and station buildings. This design is only a possibility but it allows us to visualize the proposed final urban landscape in the area.

This proposal allows preserving the historical agriculture zone around Valencia City as a part of the city's green infrastructure, and additionally it improves access for potential passengers to the HSR services because of increase access from hinterland of airport directly by HSR.

5 CONCLUSIONS

In the Spanish case, the intensity of use of the HSR network is very low with respect to other countries. Decision making was conditioned by the fact that the historic train network for conventional services has a different track gauge (Iberian gauge) from that of the UIC (standard gauge). The new HSR network was built to use the standard gauge and with adequate geometric conditions suitable for high-speed rail travel, whereas, in general in Spain, these conditions for a large part of the conventional network are not adequate for that type of use. Consequently, the rail network in Spain was transformed into a double passenger-service network: an HSR network and a regional/suburban conventional network, alongside other services (suburban service on the metro gauge, and freight). The analysis of population evolution in cities with HSR services shows five types of cities. In general, the cities with HSR services increase population. On the whole, the cities with the strongest growth are those located around the hinterland of metropolitan areas or urban areas. However, some anomalies must be pointed out: Seville – the first city connected with Madrid by HSR – along with some cities in the north hinterland of Madrid metropolitan area has lost population.

No new HSR stations in intermediate-size cities can be justified, more specifically:

1. stations that were built associated with real estate urban developments that failed;
2. stations that were built associated with logistical projects that failed; and
3. stations in intermediate-size cities with small population.

It is obvious that the design of railway infrastructure on a urban scale has consequences on urban mobility and efficiency of urban transport, depending on the type of station chosen and its location: an on-line or end-of-line station; a central station, on the border or isolated; a new station or a refurbished old one; integrated conventional services with HSR services and with urban public transport.

Nevertheless, our analysis does not find any correlations between the characteristics of Spanish HSR stations and the evolution of city population. Data show that the location of HSR stations (the design of infrastructure on an urban scale) does not necessarily have a consequence on the increase or decrease of population, but it is a dynamic process on a territorial scale.

Steps should now be taken to promote and increase the use of the HSR network; improving the efficiency of intermodal travel should help to achieve this goal. HSR-air intermodal stations increase the transport system efficiency because they allow combined tickets across different transport modes to be bought, allow passengers to collect their baggage at the end of their journey, and minimize the travel time between segments while maximizing safety and comfort.

In the case of Valencia, it is possible to design train infrastructure for the metropolitan HSR network coherent with the results analysed in this article. This design consists in a system with two stations: an integrated station (HSR and conventional services) in the city centre and an intermodal station (HSR-air) at the airport. In Valencia City, this proposal is also compatible with the conservation of the historical agricultural zone around the city, in accordance with European policy, as a green infrastructure.

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