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HIGH-SPEED RAIL NETWORK AND PERIODIC TIMETABLE: A COMPARATIVE ANALYSIS OF OPERATIONAL CONCEPTS

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Abstract.

This paper compares chosen European high-speed railway (HS) networks in terms of their offer of HS passenger service. The criteria chosen for comparison are network topology, degree of service periodicity and degree of coordination between subsequent services. Only services with HS trains are taken into account. As a result, each examined network is classified according to prevailing approach to passenger service – either Line/Service (LS) Approach, where transfer connections are in general not anticipated, or Network (N) approach, with regular (mostly periodic) public transport lines and periodic transfer connections between them.

The comparative analysis has shown that geography had crucial impact not only on national (or regional) HS line network, but on the HS operational concept as well.

On trunk HS lines, which connect most populated agglomerations in particular country, there is always – at least during peak times – some form of periodic service, despite compulsory seat reservation (except state-owned carriers in Austria and Germany).

Half of analyzed networks can be characterized by N approach – at least on trunk HS lines or within central "core" part of HS network.

For Czech HS network, authors recommend to define a core network with application of Integrated Periodic Timetable.

Keywords: High-speed railway, operational concept, passenger service, periodicity.

1. Introduction

High-speed (HS) railway service network is a specific form of long-distance railway network. The reasons are longer average trip distance (due to higher commercial speed) and higher planned load factor of HS trains (due to rolling stock and infrastructure cost). HS railway very often beats car even in door-to-door travel time, which leads to unprecedented modal shift towards railway. For estimation of modal-split based on comparation of travel time, see for instance Vávra and Janoš [1].

Either this network is more complex – mostly in the case of state-owned carrier(s), or more simple. Two approaches for design of HS operational concept can be distinguished:

- Line/Service (LS) Approach
- Network (N) Approach

LS Approach focuses on origin-destination (OD) pairs and times with the highest demand. These OD pairs are mostly radial, i.e. to/from central agglomeration. Transit trips through this centre are perceived as secondary, i.e. there can be a connection in the central station, but transfer time can be very high, as timetable was not adjusted for this requirement.

N approach is based on services which operate in regular public transport lines. All services run through (at least mostly) equal route, with some degree of periodicity (either more service pairs daily, or with some period – at least some services, typically during peak times in relevant direction). Periodic transfer connections between these public transport lines are anticipated. The extremely periodic concept is Integrated Periodic Timetable (IPT, Taktfahrplan). For more detailed explanation, see for instance Weidmann [2].

The aim of this paper is to compare chosen national HS networks in terms of their topology and degree of periodicity of HS passenger services. Finally, each network operation will be assigned to (predominant) LS or N approach.

2. Methodology and Scope of the Analysis

Data on European HS railway network were taken from UIC High Speed Rail 2018 publication [3].

The timetable data, as of 2019/2020 railway timetable, were gathered from timetable websites or online publications of particular carriers [4–14].

For each analyzed national or regional network, following criteria were chosen:

- Network topology
  - ▷ One or two principal HS lines
  - ▷ Star (one center and radial HS lines)

- ▷ Raster network

- Prevailing degree of periodicity
  - ▷ No periodic service
  - ▷ Periodic service in peaks only
  - ▷ Partially periodic service on trunk routes
  - ▷ Almost fully periodic – with some minor irregularities
  - ▷ Fully periodic (with possible additional peak service)

Following HS networks were analyzed:

- Austria (ÖBB and WESTbahn)
- Germany (ICE)
- Thalys (Belgium, Netherlands, France and Germany)
- France (TGV incl. OUI)
- Italy (FS – Frecce trains and .italo)
- Spain

3. Results of the Analysis

3.1. Austria

Two principal HS corridors are planned in Austria. The first one, Western Railway (Westbahn) is partially in operation – from Vienna to Linz, with a short section westwards. In this section, there is mostly a parallel HS line to a conventional line, with frequent connecting junctions. Further sections are in construction or planned – new Lower Inn Valley Railway to Innsbruck and Brenner Base tunnel to Italy. The next corridor, currently in construction, goes southwestwards from Vienna through Graz and Klagenfurt.

Despite axis nature of these HS corridors, the operation there is fully integrated into national Integrated Periodic Timetable [4].

On the only Austrian HS line in operation, there are three HS carriers. All operate in zero-symmetric periodic timetables. State-owned ÖBB-Personenverkehr AG operates Railjet network, with regular periodic service. The first Railjet axis, Prague – Brno – Vienna – Graz, is operated in 2-hour period. There are periodic transfer connections with Railjet to/from Western Railway. However, this public transport line does not currently use any HS infrastructure [5].

On the Western Railway, there operate even two segments of hourly Raijlet services between Vienna and Salzburg [6]. The lower segment fulfills function of Intercity service, but uses the HS line from Vienna to Tullnerfeld junction only. The higher segment, named Railjet Xpress, serves only Vienna, St. Pölten, Linz and Salzburg. From Vienna, both segments depart interposed in common 30-min period, but in Salzburg they meet each other around minute zero. So, periodic transfer connections are enabled. Each 2-hours, an unit from Railjet Xpress proceeds directly to Munich.

From Salzburg westwards, there is hourly Intercity-like service, mostly operated by Railjet Xpress, but occasionally by Railjet, Eurocity etc. Similar kind of irregularities occurs from Budapest to Vienna, where mostly Railjet Xpress services operate, proceeding directly westwards. The service period from/to Budapest varies from 30 min to 2 hours.

Second HS carrier is German state-owned Deutsche Bahn (DB), with Intercity-Express (ICE) services to Frankfurt, mostly with 2-hour service period. Last HS carrier is (mostly) privately-owned company WESTbahn (not to be confused with Western Railway), which operates in mostly 2-hour period between Vienna and Salzburg [7].

Austrian HS operation can be classified as periodic, with few irregularities, and N approach.

3.2. Germany

German HS railway network creates a raster, in accordance with polycentric settlement of the country.

On the main (trunk) routes, there is mostly periodic offer of ICE services. Basic service period of a long-distance public transport line is usually 2 hours. There are many minor deviations in departure or arrival minutes, or in presence of intermediate stops of secondary significance (i.e. cities with population circa 100,000). Another deviations occur in days of service operation. For some services, there are alternative destinations, which may result in a gap in periodic service during some part of the line.

There are some cases of interpositions into half period on trunk routes (and even in the case of alternative routes, but same OD-pair, e.g. Nuremberg – Hamburg via Hannover or via Erfurt). On particular sections between major cities (which are usually principal railway nodes as well), one line of HS trains serves as "lower segment", serving middle-sized cities. Other lines of HS trains run through without stop [8].

German HS operation can be considered predominantly periodic, with N approach, albeit with many minor irregularities.

3.3. Thalys

Thalys is a joint venture of French SNCF (majority owner) and Belgian NMBS/SNCB state-owned rail carriers. Although predominantly periodic, Thalys services are not interconnected at all. The reason is probably comparably short travel distances, so any transfer would disturb the passengers. The service period is mostly 1 or 2 hours (peak), between Paris and Brussels even 30 min during peaks. From Brussels, there are 3 HS lines: to Paris Nord station, to Cologne and to Amsterdam.

From Amsterdam, 13 pairs of services run to Brussels, which include 10 pairs that proceed to Paris. The period is 1 hour, but there is a 3 hours peak gap from Amsterdam. From Cologne, 4 pairs of services run to Brussels, but there are more additional German ICE HS services that make together 1 hour period (with 2 pairs of services left out). From Paris, there is 30 min service period during both morning and afternoon

peaks, but there is no 1 hour period kept all day long. Peaks, there are 1.5 hour gaps between subsequent services [9].

Thus, despite periodic services (with many irregularities), Thalys network is characterized with LS approach.

3.4. France

French geography is characterized by strong dominance of Île-de-France (Paris agglomeration), where one out of six French inhabitants lives, and by transport network converging to Paris.

HS network is no exception. From four Paris dead-end stations, a four-pointed star network (as of 2020) runs out. Farther away, some HS railway lines (LGV) branch to various destinations. This network is completed by a HS bypass line, lying eastwards from Paris, with stops at Roissy – Charles de Gaulle Airport and Marne-la-Vallée-Chessy.

French HS service offer is mainly focused on direct connection of Paris with as many cities as possible – for smaller cities, there can be circa 2 to 4 pairs of Train à Grande Vitesse (TGV) services per day. This policy leads to more complex branching of TGV routes – much beyond branching of HS railway lines. Sometimes there run two coupled TGV units from Paris, and from some node station they proceed to different destinations. By nature, such policy makes periodic service offer hardly possible. Moreover, even on trunk sections of HS lines, common for more end destinations (e.g. to Lyon or to Strasbourg), there is almost no periodicity of service – only some groups of subsequent services during afternoon peak from Paris (or during morning peak to Paris).

There are two more factors that increase complexity and ambiguity of TGV service concept. The first one is phenomenon of stations, located directly on a HS line. In some cases, such station lies "in the fields", located between more comparably populated cities. Otherwise, this station serves a large city, but lies few to circa 20 km remote. So, there is another station in the city centre. In most such cases, there are both TGV services which serve the station on a HS line, and the others, which run to the centre.

The second factor is phenomenon of "TGV intersecteurs" services, which stop on bypass LGV, but not in Paris itself [10, 11].

French HS operations can be considered as practically not periodic, with LS approach.

3.5. Italy

Italian HS network consists of three north-south corridors, which merge together in Bologna. Then, a single HS line (including Direttissima HS line, whose construction started as first one in Europe) proceeds via Rome to Naples and Salerno. From Naples, there is a mostly completed HS branch to Adriatic coast (to Foggia and Bari). Moreover, in Sicily, there are two partially complete coastal HS lines from Messina to Palermo and to Catania. At present, they are served by conventional trains only. In northern Italy, there is an east-west corridor from Venice to Turin.

On the main (trunk) routes, there is mostly periodic offer of Frecce (literally "arrows") HS trains, but, contrary to Germany, these trains do not always operate in regular public transport lines. The service period of these trains, operated by state-owned FS (Trenitalia) carrier is 1 or 2 hours. The Frecce offer concept consists of three products, which differ in type of trainset:

- Red Arrow ("Frecciarossa") stands for HS train with maximum speed 300 km/h
- Silver Arrow ("Frecciargento") stands for tilting HS trains with maximum speed 250 km/h
- White Arrow ("Frecciabianca") stands for classical trainsets with maximum speed 200 km/h

Since majority of Italian HS lines are designed for 300 km/h, there are obviously services that cannot use this maximum speed, because of considerably lower maximum trainset speed. According to actual timetable [12] this situation occurs few times a day, and there is no lengthening of regular running times. In general, such heterogeneity of train paths leads to substantial drop in railway capacity utilization – see for instance Janoš and Kříž [15].

The competitor – Nuovo Trasporto Viaggiatori (NTV), with services labeled as ".italo" – operates public transport lines between Milan and Venice, and on three principal HS lines, further together to Rome and Naples, with few pairs of services proceeding to Salerno. Single pairs of services proceed directly to further chosen cities in northern Italy.

.italo services depart in general at regular, periodic times. There are five public transport lines (Milan – Venice, 3 HS corridors), with few lengthenings northwards. From Milan to Rome, besides line Turin – Rome (– Naples) there is in addition a non-stop line between these two cities. Both lines operate hourly, with few service pairs left out.

Another public transport lines operate in periods varying from 1 to 3 hours during the day, sometimes with even longer off-peak gap. Transfer connections are announced, but not anticipated in planning – the transfer time can reach up to 1.5 hours [13].

As a conclusion, HS passenger service in Italy (both state and private carriers) can be classified as predominantly periodic (at least on trunk routes), with N approach (state carrier FS), since there are periodic transfers to non-HS services with transfer time of 30 min or less.

3.6. Spain

Spanish HS railway network follows the country's specific – mostly mountainous – geography. Besides Madrid agglomeration and few middle-sized agglomerations, vast majority of population lives in coastal areas or in major valleys, where most of the largest

Spanish cities are located. Contrary to conventional network with wide (Iberian) gauge, HS network is constructed with standard gauge.

The HS railway network is star-shaped, with two central stations in Madrid. Chamartín station is a terminus of HS lines to northern and western coast. Atocha station is a terminus of remaining HS network (eastern and southern coast and some inland destinations like Toledo and Granada).

There are two main segments of HS service – AVE, and AVANT with Alvia [14]. AVE is a distinctly HS service with operating speed up to 300 km/h. AVANT and Alvia are lower HS segments with operating speed up to 250 km/h. While AVANT serves middle distances on HS lines, Alvia trains are equipped with gauge-changing device (for some services, Talgo trainsets are deployed). Thus, Alvia trains offer direct services far beyond HS network (mostly to regional centres in coast areas – mainly northwards from Madrid). Since many destinations and lower frequency (few service pairs daily), there is no regular period of Alvia services. In some cases, two Alvia trains (or two other HS trains) run coupled, at least during part of their route.

Spanish HS network is, in general, characterized by non-periodic service, and transfer connections are not anticipated. However, on trunk routes (from Madrid to Barcelona, Sevilla, Malaga and Valencia) and for some shorter distances (e.g. Madrid – Toledo), there is periodic service at least during peak times. The period is mostly 1 hour, with almost all-day 30 min period between Madrid and Barcelona, with additional peak services. There are even few direct HS services between Barcelona and Sevilla, and Euromed coastal HS services from Barcelona to Valencia.

The periodic service is not without various irregularities – either different stopping pattern for each service, or some 1.5 hour gaps between services. So, HS trains to Toledo depart from Madrid hourly, mostly in the minute 50, but in off-peak time in the minute 20.

As a conclusion, Spanish HS passenger service can be characterized as partially periodic, with LS approach.

3.7. Structured comparison of analyzed networks

Structured comparison of analyzed networks and HS operational concepts is displayed in Table 1.

4. Conclusions and Recommendations

The comparative analysis has shown that geography had crucial impact not only on national (or regional) HS line network, but on the HS operational concept as well. If there is a clearly dominant central agglomeration, the HS passenger service is usually driven by LS approach. The only exception is Austria.

On trunk HS lines, which connect most populated agglomerations in particular country, there is always - at least during peak times - some form of periodic service, despite compulsory seat reservation (except state-owned carriers in Austria and Germany).

Half of analyzed networks can be characterized by N approach - at least on trunk HS lines or within central "core" part of HS network.

On the other hand, because HS trains are very expensive, the carriers (even state-owned ones) focus on operational efficiency, at the expense of timetable simplicity and regularity. A notorious example is a 1.5-hour gap between subsequent services.

Czech Republic stands before strategic decisions on high-speed operational concept, since planning of HS lines is already almost in the beginning. The authors recommend to define core part of HS network with application of Integrated Periodic Timetable, and operation without compulsory seat reservation for at least part of a train. Open Access services should be enabled in such way that they would not disturb this concept.

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HS Network	Topology	Degree of Periodicity	HS Oper. Approach
Austria	1 principal route	Fully periodic	N
Germany	Raster	Almost fully periodic	N
Thalys	Star	Periodic	LS
France	Star + Branching	Periodic in peaks only	LS
Italy	Raster + 1 principal route + Branching	Periodic (trunk routes)	N
Spain	Star+Branching+Raster	Part. periodic (trunk routes)	LS

TABLE 1. Structured comparison of networks and HS operational concepts.

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