High Speed Rail (HSR); TGV model; Shinkansen model; comparison; knowledge transfer

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HIGH SPEED RAIL TRENDS, TECHNOLOGIES AND OPERATIONAL PATTERNS: A COMPARISON OF ESTABLISHED AND EMERGING NETWORKS

Summary. This paper is set within the framework of the RailNewcastle Summer School program 2014 run by Newcastle University (UK). It presents a short history of high speed rail describing its main design and operational characteristics. The focus of the paper is on assessing the two key distinct models emerging from this trend: the Japanese or Shinkansen model and the French or TGV model. The study then applies these two models to an emerging high speed network such as the planned corridors in California (U.S.) to assess the extent of applicability and suitability of applying established high speed models to the Californian network. The results suggest that a suitable possibility would be to apply the French model for the operational aspects given the similarities in terms of geography, population distribution and distance. Implementing the lessons learned from the Japanese model in terms of construction and infrastructure design would be more suitable given the striking similarities in geological characteristics linked to the latent earthquake threat.

TREND KOLEI DUŻYCH PRĘDKOŚCI, TECHNOLOGIE ORAZ MODELE OPERACYJNE: PORÓWNANIE ISTNIEJĄCYCH I POWSTAJĄCYCH SIECI

Streszczenie. Artykuł powstał podczas programu RailNewcastle Summer School 2014, organizowanego przez Uniwersytet w Newcastle (Wielka Brytania). Artykuł prezentuje krótką historię kolei dużych prędkości, opisując główne projekty i charakterystykę operacyjną. Celem artykułu jest poddanie ocenie dwóch kluczowych modelów wyłaniających się z tego trendu: japońskiego (Shinkansen) oraz francuskiego (TGV). Następnie badane jest zastosowanie tych dwóch modeli dla wschodzących sieci kolei dużych prędkości, jak na przykład planowany korytarz w Kalifornii (Stany Zjednoczone), i poddanie ocenie użycia tych modeli w zakresie stosowalności i przydatności dla sieci kalifornijskiej. Wyniki sugerują, że odpowiedniejsze byłoby zastosowanie modelu francuskiego, głównie ze względu na operacyjne aspekty oraz podobieństwa w geografii, rozmieszczenia ludności i odległości między stacjami. Należałoby również zwrócić uwagę na rozwiązania konstrukcyjne systemu japońskiego, które mogłyby zostać zastosowane ze względu na podobieństwa geologiczne tych regionów i możliwość wystąpienia trzęsienia ziemi.

1. INTRODUCTION

High Speed Rail (HSR) has become one of the basic transport technologies of the twenty-first century [1]. While there is not a single definition of what constitutes HSR, Givoni's [2] attempt to describe HSR as: "*High speed can relate to the infrastructure capability to support high speed (this might explain the term 'high-speed rail' (HSR), in addition to the fact that train and rail (or railway) are often used synonymously), the rolling stock capability to achieve high speed and/or the actual operation speed achieved*"[2]. This definition will be considered for the purpose of this paper. In terms of speed, it is widely accepted that speeds of 250km/h or more for new dedicated lines and 200km/h or more for upgraded ones constitute HSR [3].

High speed rail services around the world are established and continue developing at significant pace. In addition to the pioneering networks in Europe (France in particular) and Asia (Japan) other nations in different parts of the globe are considering investing in HSR which in itself is a lengthy and costy process. This paper explores the some facts about the history of HSR developments where two distinct now mature models emerge i.e. the Japanese or Shinkansen model and the French or TGV[1] model. These are assessed and compared leading to proposing key aspects applicable to the emerging HSR network in California, chosen for its socio-economic and geographical affinity to the original two models.

2. BACKGROUND

HSRs have experienced a rapid change in the past decades around the world. The modern era of high speeed rail started in Japan when in 1964 the Tokaido Shinkansen started commercial operation reaching a maximum speed of 210 km/h [1], [4], [6]. The opening of the Shinkansen in Japan stimulated the developing of high capacity HST as proposed at the International Transport Fair in Munich, Germany; whereas the fully development of Europe's high speed rail service started from 1980s [7]. France is the first European country that developed HSR 17 years later, when the Paris to Lyon (TGV-PSE) was successfully open in 1981 [8]. In other countries such as in Germany the construction of HSR was in segments, e.g. "*from Fulda to Würzburg (1988, 90 km), from Hannover to Fulda (1991/94, 248 km), from Mannheim to Stuttgart (1985/91, 109 km) and from Hannover to Berlin (1998, 189 km)"* [8].

Other countries such as Spain, Italy, Netherlands, Belgium, Taiwan, South Korea and China have since joined the ever growing HSR movement. In 2008 the worldwide HSR network had approximately 20,000 km [6]. By the end of 2013 there were 21,472 km of high speed rail lines operating at 250 km/h or more with a further 13,964 km under construction plus 16,347 km planned [7]. China alone has seen a qualitative leap since the first high- speed rail line was completed on 1st August 2008. In teh following two years after that, a significant number of HSR lines have been added to its network e.g. Wuhan-Guangzhou, Zhengzhou-Xi'an, and Shanghai-Nanjing. An ambitious mid-to-long term Railway Network Plan established by the Chinese Ministry of Railway (MOR) in 2008

[1] Train à Grande Vitesse (TGV)

aiming at establishing a '4+4' network or HSR grid of eight corridors i.e. four corridors running north-south and four going east-west operating at maximum speeds of 300-350 km/h [8], [9].

Similarly, and in terms of maximum speed, the evolution of HSR has been very significant. The following Tab. 1 shows some speed records since the introduction of HSR [10]. These include operational and non-operational records.

Table 1

Selection of significant railway speed records

1964	Japan	Tokaido Shinkansen, 210 km/h
1981	France	TGV, Paris-Lyon, 260 km/h
1988	France	Word Speed Record (WSR), electric, 408 km/h
1990	France	WSR, electric, 515 km/h
2003	Japan	WSR, maglev, 581 km/h
2007	France	WSR, electric, 574.8 km/h

Achieving the phenomenal performance of HSR requires highly sophisitcated technology and technical configutations, not only for the rolling stock but also the infrastructure and signalling sub-systems. As summary, the main technical aspects of HSR are presented in (Tab. 2) [11].

Table 2

Main technical aspects of HSR

Average speed	The upgrade railway-over 200km/h The dedicated railway-over 250km/h
Power	Electric or hybrid High voltage connections Sub-stations: each 50-100 km Autotransformer stations: every 15 km
Infrastructure	Very rigid layout (more than a highway)
	Minimum radius: 3000-7250m
	High length of horizontal and vertical transition curves
	Maximum gradient: 40‰
	Maximum cant: 160-180 mm
	Earthwork: Maximum charge by axle should be established in 22.5-25 ton
	Track: ➢ Maximum axle load 17 tn ➢ Ballast or slab track ➢ Crossover each 20-30 km ➢ Sliding each 30-40 km
	Signalling: ERTMS levels in EU

3. MAIN MODELS OF HSR

The restrictions and needs imposed locally have meant that while HSR characteristics and technical aspects are well known and necessary, the approach for HSR implementation have been varied. This has resulted in four distinct models namely: i) Japanese or Shinkansen model ii) French or TGV model iii) titling HSR iv) MAGLEV HSR [2]. The Japanese or Shinkansen model has a main characteristic the use of dedicated lines that are in effect isolated from the rest of the rail network. The geographic and geological constraints in Japan (e.g. mountainous landscape and frequent earthquakes) also mean very high construction costs. In contrast, the French model is based on an integrated approach between

HSR and conventional lines. The geographic characteristics of France with large unpopulated areas and relatively flat means that construction costs are amongst the lowest [2], [13]. The tilting HSR model is based on the idea of using such technology on board of rolling stock to allow trains to increase their speed on conventional lines which usually feature tighter curves. The speeds achieved are not as high as with the other two models and it could be considered that nowadays, with speeds in excess of 300 km/h on new generation lines and rolling stock, such titling model is one step below HSR. Magnetic Levitation (MAGLEV) sits at the other end of the scale but it has not been fully implemented successfully. For the purpose of this paper the Japanese and French models will only be considered.

3.1. Japanese or Shinkansen model

The increasing capacity constrains during the 1950s in the Tokaido trunk line linking Tokyo and Osaka led to the birth of HSR [14], [15]. On 01 October 1964 the first revenue service on the line officially opened. One of the characteristics of this line and the subsequent Japanese HSR is the decision made at the time to build a new line on UIC International gauge of 1435 mm as opposed to the Japanese standard of 1067 mm effectively segregating HSR from the conventional network. In addition, the Japanese model is also shaped by the geographic and geological characteristics of the country. This mountainous topography, the high rate of earthquakes experienced and the high population density mean a significant number of tunnelling and technical challenges for the infrastructure construction such as slope protection, erection of avalanche fences and wind barriers, and seismic reinforcement of infrastructure are typically used to reduce the risks of natural disasters [16]. An estimated 30% of the whole Shinkansen network consists of tunnels [2].

The importance of the introduction of the Shinkansen affected the way other railways approached their strategic planning [4]. Smith R.A. stresses this point when he highlights the shift in Western European countries which were developing conventional lines while Japan were setting up HSR system. This caused a reassessment of the future development strategies being drawn in Europe leading to the realisation of the potential of HSR. The result of this shift was the launch of commercially successful high speed services in France (TGV) and Germany (ICE).

3.2. French or TGV model

The first TGV line (TGV Sud-Est) between Paris and Lyon opened in 1981 launching HSR in Europe and following of the footsteps of the success of Japan’s Shinkansen [13]. This new line reduced the travelling time between the two cities in about 2 hours for the 450 km distance covered. The new line also reduced that actual distance in 120 km or 20% of the total [17]

The success of TGV Sud-Est led to an early decision to build the TGV Atlantique, which reduced the travelling time from 4h to 3h between Paris and Bordeaux [13, 17].

The topography of France, its population density and the early decision to build the new HSR as compatible with the conventional network meant not only significantly less construction costs but also more operational flexibility. Indeed, the ability to operate on the conventional network has allowed accessing to more regions and passengers [2].

4. DIFFERENCES BETWEEN JAPAN AND FRANCE HSR

Population density varies significantly between Japan and France. While the Japan is a highly dense populated country with very large cities in relatively close proximity, France population is more distributed. The Shinkansen HSR requires connecting very large urban nodes such as Tokyo (30 million inhabitants) and Osaka (16 million inhabitants) which are 560 km apart [2]. Travel demand is also very high (in excess of 200 million passengers per year on Tokyo-Osaka) [15] which translates in longer trains and higher frequency needs. In contrast, France has longer corridors serving smaller cities with a comparatively lower demand e.g. TGV Sud Est carries around 20 million passengers per year [18].

Differences in the topography served by the two models have already been highlighted in this paper. This contrasting reality has a clear influence in the way HSR has been developed in both countries and hence their influence in a range of countries. For instance, Spain, one of the largest HSR networks in the world, has a topography and population density similar to that of France while its technical constrains due to a non-standardise gauge in the conventional network are closer to those faced by Japan 40 years ago. Hence, the Spanish network has a mixed approach that although is closer to the French model, uses the Japanese segregation aspects [2].

Operationally, the singular characteristic of the Japanese HSR network is their simple approach to railway operation and high level of automation which permit a high frequency with flexible services [19]. The Tokaido line between Tokyo and Osaka (515 km) currently operates 119 services a day in stark contrast with the 30 on the TGV Sud Est between Paris and Lyon (450 km) while the distances are not that dissimilar [18].

5. HIGH SPEED RAIL IN THE USA

5.1. Background

The primary focus of US railways has historically been on freight and conventional passenger service. Over the past fifty years, the US has been investing heavily in road and air infrastructure while ignoring investment and development of intercity passenger rail service [20]. Over the same period railways in Europe and Asia flouished, particularly the HSR phenomenon. Historically, the pursue of higher speed in railways began in the US at the same time as in the other countries. For instance, steam trains in the early 1900s exceeded the speed of 160 km/h. Similarly, tests trains in 1966 achieved 300 km/h [20]. The largest project of American high speed rail is currently the proposed California high speed network.

5.2. High Speed Rail in California, Characteristics, Current Situation and Future Plans

The California HSR project is to be the first high speed train system implemented in the US. According to the Californian High Speed Rail Authority High speed rail service would reduce the current San Francisco to Los Angeles travel time from nearly 9 hours to 2 hour 38 minutes, a speed that is highly competitive with air and much faster than by car. The system would provide service between Los Angeles and San Francisco with frequencies of up to 14 trains per hour.

The situation in California resembles that of France in the 1970s and early 1980s. It faces staring a potential HSR network. However, while in Europe the French corridors became a network that has been linked to other networks in Spain, UK, Belgium, Germany and beyond effectively working towards fulfilling the European vision of an integrated rail network, in the US the strategic plans give very limited opportunities to develop a country-wide network but rather a number of isolated sub-networks e.g. California, East Coast Corridor.

Geographically, California is a mix of mountainous areas with large valley sections which given the population distribution would allow a relatively low need for tunnelling. It reassembles the geographic and population aspects of France and Spain. The earthquake threat is akin with that in Japan. The late arrival of the US to the HSR market rather than a disadvantage it could be seen as an advantage [21]. The maturity of HSR across the world and the proven successful implementation of district HSR models during the past four decades could allow the HSR debate in the US to select a strategy that is demonstrated already unlike the pioneering Japanese and French efforts. The suitability of the TGV model to the operational characteristics of the Californian proposals could be combined with the design and construction guidelines that the Shinkansen model brings e.g. earthquake protection.

6. CONCLUSIONS

This paper has presented an overview of the background, developments and opportunities of high speed rail. The two distinctive pioneering models of HSR have been successful in their own right albeit with intrinsic differences given the geo-political, economic and topographic conditions in which were set up. While HSR is not a mature technology implemented around the world and in particular the economic first world, the U.S. is the one exception to this. The suitability of the French and Japanese models to the plans drawn by the Californian authorities have been discussed showing that lessons can be learned. All this suggests that high speed rail is a viable and attractive mode of transport in its own right.

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