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The Preliminary Analysis of Introducing 500 km/h High-Speed Rail in Korea

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Abstract

Following the success of the KTX (Korea's first high-speed rail system) with a maximum operating speed of 300 km/h opened in 2004, experts in Korea started a research on the development of key technologies for high-speed rail (HSR) with a top speed of 500 km/h. This paper is a preliminary analysis of the research. It first reviews HSR experiences around the world, in terms of traffic and economic impacts of HSR, and presents a preliminary analysis of 500 km/h HSR in Korea. It is estimated that introduction of 500 km/h HSR with a 54% of travel time reduction will increase HSR passengers to about 9.8 million (about 78% of market share) between Seoul and Busan. It is a 23% of growth compared to the base scenario. Along with conventional rail passengers, air passengers are expected to be significantly impacted by the 500 km/h HSR. As a function of HSR travel time, the estimated market shares of both KTX and 500 km/h HSR compared to air are very comparable with previous international experiences. Based on the forecasted traffic, estimated total benefits are $758 million per year.

Keywords : *High-speed railway, Travel demand forecasting, Economic benefit, Market share*

1. Introduction

Since the success of the Shinkansen in 1964, the world's first high speed train connecting between Tokyo and Osaka metropolitan area (515 km), high-speed railway (HSR) has primarily been dominated in Japan and Europe. There are about 50 HSR lines with a maximum speed of 250 km/h or more in the world. As of 2011, the length of HSR lines in operation in the world is about 15,231 km, representing 43.5% in Europe, 54.0% in Asia, and 2.5% in other countries (UIC 2011a). This number is expected to reach 41,997 km by 2025. The countries with advanced HSR technology have shown positive effects of the system, not only in the technology development, but also in wide benefits. The benefits of constructing HSR include reducing travel times, relieving congestion on established modes of transport, improving access to markets and commerce, decreasing environmental impacts (i.e., carbon footprint in comparison to road and air transport) and spatial effects and regional development (i.e., creating industry growth and export opportunities).

While most of HSRs are being operated in Europe and Asia, China is currently the largest rail technology market in the world. China is trying to lead the world in a key next-generation HSR technology, by aggressively investing $300 billion by 2020 in HSR (Wikipedia, 2013). In the meanwhile, the first HSR in Korea, known as Korea Train eXpress (KTX), was started in 2004. Following the success of the KTX with a maximum operating speed of 300 km/h, experts in Korea started a research on the development of key technologies for HSR with a top speed of 500 km/h. This paper is a preliminary analysis of the research. It reviews HSR experiences around the world, including traffic and economic impacts of HSR. It then presents preliminary impacts of the introduction of 500 km/h HSR in Korea on travel demand forecasts, HSR market share, and economic benefits.

2. HSR Experiences and Impacts of HSR in the World

The Shinkansen system in Japan is the first dedicated

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HSR system in the world. It is famous for the busiest, safest and most reliable system in the world. The Shinkansen Tokaido line connecting between Tokyo and Osaka was opened in 1964. It reduced the travel time between the cities to two and half hours from six and half hours. The success of HSRs in Japan is attributed by high population densities. There are over 8 million population in Tokyo locating about 400~700 km from most other major cities, which is an ideal distance for rail. The construction costs of the Shinkansen Tokaido line was relatively low at $0.92 billion in 1964 (Albalate and Bel 2010). However, costs of new lines such as Sanyo, Tohoku and Joetsu were considerably high due to complexity of constructions (about 30% of Japanese lines run through tunnels). Annual ridership of all Shinkansen lines was about 350 million in 2007 (Invensys 2012), while 138 million passengers traveled in the Tokyo-Osaka route and 88 million passengers traveled in the Tohoku Shinkansen route in 2010 (CaHSRA 2012). Because of the higher demand, operating revenue surpasses $19.7 million, and the benefit of travel time savings are estimated at 400 million hours per year.

In Spain, the first HSR line, named AVE (Alta Velocidad Espanola), was opened in 1992 between Madrid and Seville. Spain has five of the new lines as of 2011, and AVE system is the longest HSR network in Europe and the second in the world. AVE lines have reduced journey times by an average of 60~70%, compared to the conventional rail system. AVE carries 29 million passengers per year, including 10 million passengers between Madrid and Seville and 6 million passengers between Madrid and Barcelona (CaHSRA 2012). The average construction cost was cheaper than other European countries at $14.6 million per km, compared to over $36.6 million per km in Germany because of low rural population densities, which reduced costs of acquiring land for track construction (Invensys 2012). The length of track in Spain is about 2,057 km, and the government announced the plan to build a further 9.000 km of HSR by 2020, costing $100 billion. According to Invensys (2012), Spain's success of HSR system is attributed to two factors: lower travel time between city centers in two and half hours, and lower fares than air that compete well with air transport.

France is the second country to develop HSR technology. TGV (Train a Grande Vitesse) was opened in 1981 between Paris and Lyon in a length of 1,896 km. Annual ridership was about 114 million passengers in 2010, including 31 million passengers between Paris and Marseille. The TGV services have generated $1.75 billion in profits (CaHSRA 2012).

China initiated planning HSR in the early 1990s. Through a series of "speed-up" campaigns to upgrade the speed and to build dedicated HSR lines, China began to operate a first HSR service on a dedicated HSR line (Beijing-Tianjin line) in 2008. The line covers a distance of 120 km in 30 minutes. Since then, the progress is very remarkable. As of 2011, China has the world's longest HSR network with 6,299 km in operation, 4,339 km under construction, and 2,901 km in planned (UIC 2011a). The annual ridership in 2010 was about 290 million passengers (17% of the total carried in China) by the HSR lines (Bullock et al. 2012). Along with an ambitious plan on the future development of the railway network, China began serious investment in HSR. The government spent $14 billion in 2004, $22.7 billion in 2006, $26.2 billion in 2007, $49.4 billion in 2008 and $88 billion in 2009. To meet the goal of HSR lines of 25,000 km by 2020, the government plans to spend $300 billion (Wikipedia, 2013).

Following the success of HSR in the world, the U.S. Conference of Mayors announced a report on the economic impact of HSR on four U.S. cities, including Los Angeles, Chicago, Orlando, and Albany (Economic Development Research Group 2010). The report estimated impacts of HSR, creating 150,000 new jobs and $16 billion in new business revenues in total.

3. Analysis of Impacts of 500 km/h HSR in Korea

One of the most significant effects of introducing HSR with a top speed of 500 km/h is the reduction of travel time. The longest and busiest KTX line in Korea is Gyeongbu corridor, connecting between Seoul and Busan, with a length of 409 km. The lowest journey time by KTX between the two cities is currently about 130 minutes. This section presents existing travel demand between the two cities, and analyzes ridership forecasts and economic benefits of introduction of 500 km/h HSR. Note that costs estimation is out of the scope of this analysis, because it is a premature stage to assess costs of 500 km/h HSR. There is no specific plan on construction of a dedicated high-speed railway for 500 km/h yet.

3.1 Travel demand: Existing and future

A sketch planning method was utilized in this paper for the travel demand analysis. Although this method is simpler than a traditional 4-step model, it is a very useful tool in the very beginning phase of a project to determine or prioritize initial issues. Two primary data used in this analysis are KTDB (Korea Transport DataBase) and actual count data. Note that this paper presents results of travel demand analysis between Seoul and Busan as a case study, instead of all HSR lines in Korea, because the most signif-

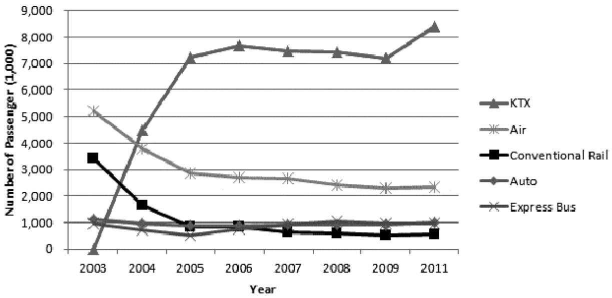

Fig. 1 Passenger traffic by transportation modes
Data Sources: Statistics for 2003~2009: KORI (2009), Statistics for 2011: TCS data from Korea Expressway Corporation, Expressway and rail data from KTDB, and air passenger data from Korea Airports Corporation

icant impact of introducing 500 km/h HSR will be experienced in the longest line. However, total economic benefits presented in this paper are the estimation from all HSR lines in Korea.

3.1.1 Actual traffic

Before the introduction of KTX, the journey time by conventional trains was 4 hours and 40 minutes between Seoul and Busan. When opened in 2004, the travel time by KTX was decreased to 2 hours and 50 minutes. Fig. 1 shows actual records by transport modes between the two cities from 2003 (before the introduction of KTX) to 2011. After the opening of KTX, number of passengers by KTX was steadily increasing until 2006, and the market share of KTX was about 60%. Although number of passengers by conventional trains was impacted by KTX, market share of total rail passengers was increased from 32% to 67%. Introduction of KTX has induced a significant modal shift away from air travel: about half of total travelers between the two cities used air in 2003, but this number was dramatically decreased by half due to KTX. Passenger traffic from 2009 to 2011 shows the effect of the second phase of the Seoul-Busan line in 2010 (there was a construction across the urban areas of Daejeon and Daegu). During this period, the number of passengers by KTX was slightly increased, but the impact on air transport was minimal, compared to the period of 2003-2004.

3.1.2 Travel demand forecasts

Based on actual data and KTDB data, travel demand was forecasted. The opening of KTX led to a travel time reduction of 48%, and the travel time elasticity of demand was found at about -0.5. Table 1 shows the result of annual traffic forecasts by scenarios as a representative year of 2021. Scenario-1 is the alternative with an introduction of HSR (called HEMU-430x) with a top speed of 430 km/h that can connect between Seoul and Busan in 90 minutes, while Scenario-2 is the alternative with an introduction of 500 km/h HSR connecting between the two cities in 60 minutes. About 8 million passengers are expected to travel by KTX in the base case scenario (do-nothing). They are expected to increase to about 9.1 million by HEMU-430x and 9.8 million by 500 km/h HSR. These are growths of 15% and 23%, respectively compared to the base scenario. As expected, air passengers are significantly impacted by HSR, decreasing by half. The traffic by conventional train is also affected.

3.2 HSR traffic converted from other transportation modes

Introduction of HSR with a speed of 500 km/h will impact passenger behaviors, thus converting trips presently made by other transport modes to HSR. It is interest-

Table 1 Travel demand forecast by scenarios (Unit: 1,000 passengers(%))

Classification		Auto	Express bus	Air	Rail		Sum
					HSR	Conventional rail	
Seoul ⇔ Busan	A. Base case	968 (7.7%)	894 (7.1%)	2,218 (17.7%)	7963 (63.4%)	510 (4.1%)	12,554 (100%)
	B. Scenario-1 (HEMU-430x)	850 (6.8%)	763 (6.1%)	1,536 (12.2%)	9,138 (72.8%)	267 (2.1%)	12,554 (100%)
	C. Scenario -2 (500 km/h HSR)	782 (6.2%)	687 (5.5%)	1,141 (9.1%)	9,818 (78.2%)	126 (1.0%)	12,554 (100%)
	Comparison ((B-A)/A)	-12%	-15%	-31%	15%	-48%	-
	Comparison ((C-A)/A)	-19%	-23%	-49%	23%	-75%	-
	Comparison ((C-B)/B)	-8%	-10%	-26%	7%	-53%	-

Table 2 Diversion factors resulting from introduction of HSR

Routes	Periods	% HSR traffic converted from:			
		Auto	Conventional Rail	Air	Bus or Induced
Paris-Lyons	1980 to 1985	11	40	20	29
Madrid-Seville	1991 to 1996 forecast	6	20	24	50
Madrid-Barcelona	Before & after HSR	10	10	60	20
Thalys	-	34	47	8	11
Eurostar	-	19	12	49	20
Seoul-Busan	Before & after KTX	17	50	29	5
Seoul-Busan	Before & after 500 km/h HSR	34	50	15	1

ing to find where HSR demand comes from, and to compare conversion trips with experiences in other countries. Along with evidence in European routes (Preston, 2009), Table 2 presents the conversion rates by the introduction of KTX and 500 km/h HSR in Korea. Note that although induced traffic was found in some countries, it is not normally estimated in Korea, thus conversion from express buses is supplemented for the Korea cases.

In the Seoul-Busan line, most of passengers switched to KTX were come from conventional rail (50%) and air (29%). On the other hand, introduction of 500 km/h HSR is estimated in a different shift pattern: most of conversions are still made from previous conventional rail passengers, but 34% and 15% of passengers switching to 500 km/h HSR is estimated to transfer from auto and air, respectively. This implies that most of potential users of 500 km/h HSR are already changed to KTX from air, and fewer passengers are attracted to switch to 500 km/h HSR. Compared to the average results in Table 2, excluding “Bus or Induced” the case of introduction of KTX has a similar conversion pattern to Paris-Lyons, while the case of 500 km/h HSR has a similar pattern to Thalys.

3.3 Competition with air

HSR is known as the preferred mode of travel over air in the distance of between 200 km and 800 km, as Japan’s experience shows that HSR has no competitive advantage over 1,000 km. This section analyses the market share of HSR compared to air (percentage of HSR by the sum of HSR and air markets) as a function of travel time of HSR. For the comparison with experiences around the world, 11 dataset is collected from available data and all of them are HSR lines with above 200 km/h speed. As Fig. 2 illustrates the result, the highest HSR market share is the Paris-Brussels line (95%) with a length of 310 km and a travel time of 1 hour and 25 minutes. The longest HSR line is the Tokyo-Fukuoka line (1,175 km), and the travel time is about 5 hours.

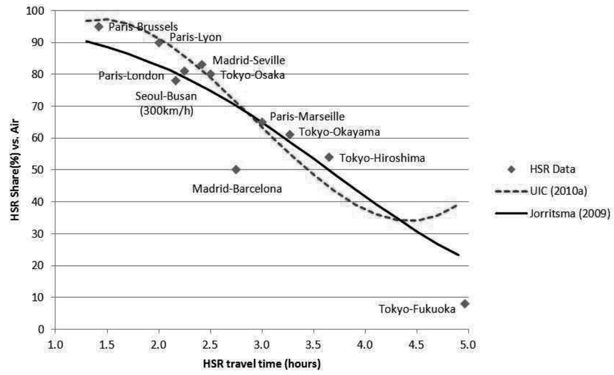

Fig. 2 Market share of HSR compared to air
Data sources: Adapted from UIC (2011b), de Rus(2008) and APTA(2011)

The current KTX shows the market share of 78% compared to air (22%) in the Seoul-Busan line (409 km in 130 minutes). It is comparable with data to other countries. In addition, the forecasted market share of 500 km/h HSR (90% with the travel time of 60 minutes) is also fairly comparable with data. Considering that modal split may be attributed by the route-specific nature such as relative HSR fares to air, the similarity of experiences is remarkable, except the Madrid-Barcelona case. The two lines are depicted in Fig. 2 for comparisons with estimated lines presented by previous studies. The dotted line is the study of UIC (2010) based on train’s shares using European routes, and it found a third degree polynomial fit line. However, it does not illustrate correctly over 4.5 hours or less than 1.5 hours of railways. On the other hand, Jorritsma (2009) shows a reasonable trend line of the rail market share compared to UIC (2010), and it is comparable to the data used in this paper.

3.4 Economic benefits

In Korea, the Preliminary Feasibility Study (PFS) was

Table 3 Estimated economic benefits per year ($million)

Types	Alternative-1 (HEMU-430x)	Alternative-2 (500 km/h HSR)
Travel time savings	352	483
Operating time savings	130	275
Total	482	758

introduced in 1999 for budget planning and setting priorities prior to the detailed feasibility study. Economic analysis in the PFS system utilizes a benefit-cost analysis. Benefits include vehicle operating costs savings, travel time savings, accident costs savings, noise costs savings, and parking costs savings. Since the first two categories are comprised of a large portion of total benefits, they are the main targets of the analysis in this study. The valuation of vehicle operating costs savings is estimated based on the equation in Eq.(1), which shows the difference of vehicle operating costs before and after an improvement. Operating costs benefit in this study is estimated using average speeds for each mode type and average vehicle occupancy rates (1.55 for auto and 9.98 for bus).

$$VOCS = VOC_{Before} - VOC_{After}$$

Where, $VOC = \sum_{l} \sum_{k=1}^{n} (D_{ik} \times VT_k \times 365)$

D_{ik} = vehicle-km for link (l) by vehicle type (k)

VT_k = vehicle operating cost per km by vehicle type (k) on each link, and

k = mode type (auto, bus, truck, etc.)

The valuation of travel time savings are estimated based on the fact that the travel times by each passenger are improved by higher speed of HSR, and those passengers have opportunity costs savings, so that they can utilize times saved from the reduced travel time of HSR for other activities. Similar to the calculation of operating costs savings, travel time savings are estimated by the difference of valuations of travel times before and after the introduction of 500 km/h HSR using average value of times. Average values of travel time used in this study are $15, $59, $6, and $11 for auto, bus, conventional rail, and HSR, respectively. The estimated economic benefits per year for the two alternatives are summarized in Table 3 (as a representative year of 2021). Note that they represent estimated economic benefits in all lines in Korea, including Gyeongbu and Honam lines.

4. Conclusions

Since the success of the first high-speed railway in Japan that inspired European railways, the world's transportation policy-makers have become increasingly interested in HSR. HSRs are being operated in at least twenty countries in the world. In Korea, KTX with a top speed of 300 km/h began operating in 2004, and the upgrade version, HEMU-430x, is currently being developed. In the meanwhile, Korean experts discuss the need of key technology developments for the next-generation HSR aiming at a top speed of 500 km/h that can reach from Seoul to Busan in about 60 minutes. This study is a preliminary study to assess impacts of 500 km/h HSR in Korea. It examines analysis of traffic demand forecasts based on actual experiences of KTX, the competition of HSR with air, sources of passenger transfers to HSR, and economic benefits, particularly focusing on operating costs savings and travel time savings. The economic rationale for the construction of new HSR depends heavily on the expected volume of demand. It is estimated that introduction of 500 km/h HSR with a 54% of travel time reduction will increase HSR passengers to about 9.8 million (about 78% of market share) between Seoul and Busan. It is a 23% of growth, compared to the base scenario. Along with conventional rail passengers, air passengers are expected to be significantly impacted by the 500 km/h HSR. It is also found that as a function of HSR travel time the estimated market shares of both KTX and 500 km/h HSR compared to air are comparable with previous international experiences. Based on the forecasted traffic, the estimated total benefits are $758 million per year. HSR with such a high speed as 500 km/h might not be immediately operated for commercial purposes in Korea because of infrastructure and safety issues. Nevertheless, the investments on key technology developments of HSR need to be continued because the Korean government recognizes the needs of such investments to strengthen the competitiveness of HSR in the world. By gaining a reputation of the advanced technology developments with higher speed and low costs and a strong track record with safety and reliability, Korea will be in a position to make strong demands on overseas technology transfer. For the further study, a cost-benefit analysis would be expected, once the cost estimation of infrastructure for 500 km/h HSR is conducted.

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