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Title: Engineering Comparison of High-Speed Rail and Maglev Systems: A Case Study of Beijing-Shanghai Corridor

Authors:

DR. RONGFANG (RACHEL) LIU, AICP, PE
NEW JERSEY INSTITUTE OF TECHNOLOGY
UNIVERSITY HEIGHTS, NEWARK NJ 07102
TEL: 973-596-5884, FAX: 973-596-5790
Email: RLiu@adm.njit.edu

YI DENG
NEW JERSEY INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
UNIVERSITY HEIGHTS, NEWARK NEW JERSEY 07102
EMAIL: YD7@NJIT.EDU

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Abstract

The need for high-speed ground transportation systems (HSGT) has become more urgent than ever evidenced by congestions in both urban and intercity travels. Congestion problems are no longer confined to densely developed urban areas or industrialized countries but also spread into suburban regions and developing countries. Characterized by the high speed, operating reliability, passenger riding comfort and excellent safety record, HSGT presents a vital solution for our congestion problems, be it intercity or urban.

There are two distinguished technologies under the general HSGT umbrella: High Speed Rail (HSR) and Magnetic Levitation (Maglev). Sharing some common characteristics of HSGT, such as very high speed and riding comfort, these two technologies are dramatically different in terms of guideway requirements, propulsion sources, operating characteristics, environmental impacts, and costs. On-going debates among the academic community have not presented any strong evidence to favor one over another in lieu of specific corridor alignment.

This paper focuses on the engineering comparison of HSR and Maglev systems and their potential implementation in Beijing and Shanghai Corridor. It is undeniable that cost, political will, and social and culture acceptance play vital roles in the eventual realization of any technology. However, limited by the capacity of a research paper, the emphasis of this manuscript is on the overview of technology, comparison of operating characteristics of HSR and Maglev and the implications of their potential application in this 1,300-kilometer long corridor from Beijing to Shanghai, the top economic, population, and culture engine in China.

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High Speed Ground Transportation, High Speed Rail, Maglev, Engineering comparison, China

1. Introduction

Doubtlessly, mobility is better enjoyed than any time in the past. Modern transportation modes, such as automobiles, buses, trains, and airplanes, are not limited to industrialized Western countries, but also become more and more prevalent in the developing countries and even rural and remote areas. In the United States, automobiles and air travel serve most of the intercity market. In some corridors their market share is up to 97% (U.S. Department of Transportation, 1997). In China, intercity trains serve about one third of the passenger volume while the automobile share is increasing dramatically (Qingzang Railway Network, 2003).

The congestion in automobile and air transportation associated with increased travel has caused many problems of public concern, among which are prolonging travel time, increasing costs, growing accident rates, worsening environmental pollution, and accelerating energy consumption. On the contrary, high speed ground transportation, characterized by high speed, operating reliability, passenger ride comfort, and excellent safety record, is considered one of the most promising solutions to alleviate the congestion.

Under the HSGT umbrella, there are basically two distinguished technologies, High Speed Rail (HSR) and Magnetic Levitation (Maglev). Both provide higher operating speed. However, they have dramatically different engineering specifications, costs, and environmental impacts. Various organizations in the world are facing difficult decisions, when choosing or settling on a specific technology, in a particular corridor. Due to the complexities of HSR and Maglev technology and diverse environmental conditions in different corridors, it is not an easy task to select the most efficient and cost effective technology in any given corridor. However, an accurate description of respective technologies detailed breakdowns of cost elements and unbiased presentations of environmental impacts should all bring positive contributions to the decision making process, which is the main objective of this analysis.

The next section presents an overview of HSR and Maglev technologies. Section 3 compares the characteristics of HSR and Maglev in detail in aspects of speed, capacity, safety, etc. Section 4 describes the case study of Beijing-Shanghai corridor: comparing the potential engineering specifications and environmental impacts of either HSR or Maglev technology. Section 5 includes a summary based on the engineering comparison and case study of Beijing-Shanghai corridor and other corridors. Further studies and research areas are also highlighted in the last section of this paper.

2. Overview of HSR and Maglev Technologies and Comparative Studies

High Speed Ground Transportation (HSGT) is a definition that covers both High Speed Rail (HSR) and magnetic levitation (maglev) technologies. It is defined as a self-guided intercity passenger ground transportation system that is time-competitive with air and/or auto on a door-to-door basis for trips in the approximate range of 100 to 500 miles. This is a market-based, not a speed-based, definition: it recognizes that the opportunities and requirements for HSGT differ markedly among different pairs of cities.

Under the High Speed Ground Transportation, we can basically define three different categories of guideway transportation systems. They are:

- Accelerail
- New HSR
- Maglev.

Among the three major categories, the first large group represents majority of converted or improved rail services using existing freight or passenger rail tracks. For example the Acela and Metroliner in the Northeast corridor fall into this category. Due to the limited improvement that can be performed on the existing rail infrastructure, the highest operating speed for this group of rail is limited to 150 MPH. Therefore, it is not the scope of this paper to compare the conventional or an improved rail service to Maglev.

2.1 High Speed Rail (HSR) Technology

HSR represents advanced steel-wheel-on-rail passenger systems generally on new, dedicated rights-of-way. These trains currently operate in regular revenue service at maximum speeds of about 300km/h, but have been tested at over 500km/h through a combination of electrification and other advanced components, expeditious alignments, and state-of-the-art rolling stock. Prominent examples of New HSR include the French TGV, the Japanese Shinkansen, and the German Intercity Express (ICE), depicted by the photographs in Figure 1.

HSR trains have sophisticated, modern signaling and automated train control systems. HSR trains are a safe, efficient, reliable and pleasurable way to travel utilizing a fraction of the energy per passenger of automobiles and airplane jets. Little fatality occurred until the incident of June 3rd, 2003 when an ICE train traveling at about 200km/h crashed into a bridge near Eschede killing 102 people and injuring hundreds more on the main Hannover-Hamburg line (Cable News Network, 2000). These high-tech train systems have vastly improved technology with respect to traditional passenger rail technology. In additional, they have a proven record of efficient services in about a dozen countries. There are 4400 km of rail in numerous countries presently. Where they serve heavily traveled corridors, high-speed steel-wheel-on-steel-rail systems have been extensively proven in revenue service, carrying over five billion passengers to date (Railway Environmental Protection, 2002).

2.2 Magnetic Levitation (Maglev) Technology

Maglev is an advanced transportation technology in which magnetic forces lift, propel, and guide a vehicle over a specially designed guideway. Utilizing state-of-the-art electric power and control systems, this configuration eliminates the need for wheels and many other mechanical parts, thereby minimizing resistance and permitting excellent acceleration, with cruising speeds on the order of 300 mph or more. The new technology is better or competitive in many performance characteristics that include speed, acceleration, travel time, travel cost, comfort, convenience, health, capacity, flexibility, frequency, operational and schedule reliability (weather and equipment delays), accessibility, safety and security, system availability (origin and destination), and energy consumption.

Maglev technology for high speed ground transportation (HSGT) has been proposed for many intercity and regional lines. Germany has a Maglev technology ready for commercial introduction (Transrapid) and Japan has a competing and technologically different system under testing. In addition, the United States has several systems “on the drawing board.” On the New Year’s Eve of 2003, Shanghai Maglev started her maiden journey between Downtown Shanghai and Pudong International Airport, as depicted in Figure 2.

A decade earlier than the construction of the Maglev project in Shanghai, China, a number of feasibility studies of Maglev and High Speed Rail have been continuously carried out in the United State. At the conclusion of one of the latest feasibility studies focused on high-speed German Transrapid technology, two corridors, Baltimore-Washington and in Pittsburgh have been selected to proceed to the next phase of study, Draft and Final Environmental Impact Statement (DEIS and FEIS). Currently, however, expected funding to proceed has been halted.

2.3 Past Comparison Studies

There are a few websites or anecdote reports on the specifications of technologies (http://inventors.about.com/library/inventors/blrailroad4.htm) and projects (http://www.floridahighspeedrail.org/1_overview.jsp, http://www.bwmaglev.com/about/ridership_primary.htm, and http://www.cahighspeedrail.ca.gov/) but relatively few comparative studies dealing with HSR and Maglev. Among them, the authors would like to mention three publications that made the attempt (Najafi and Nassar, 1996; Phelan, 1990; and Vuchic and Casello, 2001). The comparisons conducted by Najafi and Nassar (1996) concentrated on qualitative and descriptive comparison of each technology, especially the development of historic events and motivations behind each technology. Specific definition for each technology and system is limited. And since the technology has been evolving constantly, some of the information collected and presented in 1996 or earlier is now outdated.

The master thesis of Phelan, completed in 1990, attempted to compare the HSR and Maglev technology as well as their costs. The methodology may be valid but the major portion of the data collected around or before 1990 is apparently out-of-date comparing to the new testing speed, newer generation of vehicles, as well as the implementing corridors.

On the other hand, Vuchic and Casello (2002) attempted to evaluate Maglev and compare it with High Speed Rail. Unfortunately, the work has been masked by the clear bias toward HSR and disfavor of Maglev. It also mixed the technological readiness and market values of each technology; therefore the value of the article has been heavily discounted.

The authors wish to present a different view based on our research and observation. It is certainly critical that both technology and market conditions should be optimal for a certain technology to be implemented. Marketing conditions go through cyclical and geographical variations closely related to the local and regional economic, demographic and political environment. However, the technical merit of a transportation system should be independently evaluated and compared before it is totally rejected. Based on this philosophy, the authors have focused on the operating characteristics of Maglev and HSR and contemplated the incremental operability of each in order to present a precise and unbiased view. As a result, any particular corridor or location may select the appropriate technology for its specific service requirements.

3. Performance Comparison of HSR and Maglev

The fundamental reason for considering the implementation of HSGT is that it promises higher speed, which can easily equate to shorter travel time. Therefore, we need to look at the design specifications of each technology to examine potential improvement of each technology in terms of speed and travel time, and other advantages.

3.1 Speed, Acceleration, and Deceleration

Table 1 presents the experimental speed, design speed, operation speed, average operating speed, and acceleration rate for various HSR and Maglev systems. The design speed of Maglev is about 67% higher than that of the ICE train. The operating speed is the major indicator of the traveling speed and is usually lower than the design speed. The difference is in the same proportion for Maglev and HSR, namely, the operating speed of the Maglev is about 61% percent higher than that of the ICE train.

If the design and operating speed of each mode play a key role in the travel time comparison, acceleration and deceleration rate may be an even more important factor in terms of safety spacing and average travel speed over certain distances. The limited speed of HSR is always the main concern of railway professionals. Resistance increases as the speed increases, which limits the increase of speed of HSR. Application of advanced material and technology has enabled HSR to attain a maximum operation speed at 300km/h or higher. However, it is probably also the practical limits of HSR technology can reach. On the contrary, high speed potential is an inherent characteristic of Maglev. Since lift, guidance, and propulsion occur without physical contact, speeds in excess of 550 km/h are well within the technological limits.

Judging from the matrix presented in Table, we can safely conclude that Maglev generally has an advantage over HSR in terms of travel speed. Its operation speed is about 45% higher than typical HSR trains. Moreover, the Maglev train is not only fast, but also accelerates quickly to higher speeds. A Maglev train with acceleration/deceleration rate of $1 m/s^2$ (0.1g) is able to obtain the maximum speed in much less time and space than HSR trains. For example, the distance required for Maglev to accelerate to 300 km/h from a standing start is just about 4 kilometers, while HSR require more than 20 kilometers and over twice the time to reach the same speed. So this advantage of Maglev system results in much less loss of time for station stops.

Maglev technology also allows flexible route alignments. Maglev can climb 10% grade comparing to a maximum 4% for HSR. Maglev vehicles can negotiate tighter curves (horizontal and vertical) at the same speeds as conventional high-speed rail. Similarly, they can travel through a curve of the same radius at much higher speeds than conventional systems. For example, Maglev is capable of maneuvering curves of 2,350 meter radius at 300 km/h and cants up to 16° (Transrapid International, 2001).

3.2 Capacity

The capacity of a rail line is decided by the following factors:

- Passenger seats per section,
- Number of sections, and
- Headway.

The upper limits of train length and number of seats or passengers per section are usually decided by the demand limits imposed by propulsion power. Besides technical specifications, the length of the vehicle selected is closely related to population density and ridership demand.

As exhibited in Table 2, SKS has largest capacity among the existing HSR operations. Maglev's capacity is not constant. On the test line in Emsland, Germany, Transrapid vehicles comprise a minimum of two sections, each with approximately 90 seats per section. Depending on the travel demand, Maglev trains may be composed of up to ten sections, two end and eight middle sections.

Besides the individual train capacity, headway is another critical factor in determining the overall capacity of a particular rail service. Tested and true, the minimum headway for both TGV and SKS is about three minutes (Trainweb, 2002). The long time safe operation records of both HSR systems prove that such headway is not only a simple engineering desire or political will, but tested and true engineering applications in long span daily operations.

The headway for Maglev trains is largely decided by the length of sections since its propulsion power is transformed via activating guideway sections. A Maglev guideway section may only contain a single Maglev train at a particular time, which guarantees the safe spacing of Maglev operations. The typical Maglev guideway sections length is from 200 to 2,000 meters. In the case of Shanghai Maglev Project, the average guideway length is 1,250 meters. According to Transrapid International (2002), the theoretical minimum headway is 5 minutes. However, there has not been a single Maglev system designed to operate in such closely spaced headways. For example, the Berlin-Hamburg test line was designed to run with 20-minute headway. The Baltimore-Washington Maglev project is planning 10-minute headway (Liu, 2001) and so is the future goal of Shanghai Maglev, in operation since January 2003. At the same time, Philadelphia- Pittsburgh Maglev project is planning headway of 7.5 minutes.

3.3 Safety and Reliability

When discussing transportation strategy, safety and security are both linked. Several studies show that safety and security are two of the most important factors in project evaluation and are of greatest individual importance (Liu and Li, 2003). The factors affecting transportation safety and security are various, among which, the physical structure and guideway security patrols play significant roles.

High-speed rail is not yet operational in US, but the safety records of HSR in Europe and Japan are excellent. Shinkansen in Japan started in 1964 and has transported over 3 billion passengers without any loss of life or severe injury. The safety record of TGV technology is well proven throughout France. Since they became operational in 1981, TGV trains have traveled more than 1,000 million kilometers and safely carried more than 500 million passengers (Railpage, 2002).

Reliability is another factor that affects the passenger's mode choice decisions and is important for project evaluations. Results from Europe and Japan show that they have very good reliability. Shinkansen lines carry more than 125 million passengers annually in a high earthquake zone with a perfect safety record and a 99% on-time arrival rate and less than 1 minute average late time (Ran, 2002).

Maglev's concept has essentially eliminated the safety risks associated with the operation of conventional rail transportation systems. For example, the Transrapid vehicle wraps around the guideway and therefore is virtually impossible to derail. Redundancies achieved through the duplication of components as well as the automated radio-controlled system ensure that operational safety will not be jeopardized. The principle of synchronized propulsion on the guideway makes collisions between vehicles virtually impossible. If two or more vehicles were ever placed simultaneously in the same guideway segment, they would be forced by the motor in the guideway to travel at the same speed in the same direction. The grade separated, flexible route alignment (elevated as well as at-grade guideway) ensures that no other obstacles can be in the way. Energizing only the section of the guideway on which the train is traveling enhances operational safety and efficiency.

Compared to the operating experiences of HSR, Maglev technology may seem to have a scarce record. The Shanghai Maglev has been in operation for only 6 months, which may be too early to draw firm conclusions. On the other hand, the Transrapid Test Track in Elmsland has been operating for more than 20 years and close to a million passengers have ridden around the 40-kilometer (25-mile) closed loop. The Transrapid vehicles have accumulated over 500,000 miles of travel experience (Transrapid Inc. 2000).

3.4 Energy Consumption

In terms of energy consumption, Maglev trains are slightly better than conventional trains in general as exhibited in Table 3. The energy consumption of the Transrapid system with its non-contact levitation and propulsion technology, highly efficient linear motor (mounted in the guideway) and low aerodynamic resistance is very economical when compared to other transportation modes.

Similar to new generations of automobile engines, Maglev (Transrapid) consumes less energy while providing the same output as high-speed railroads. At the same output the super speed Maglev system consumes 20 to 30 percent less energy than the already very 'modest' railroad. In other words, with the same energy input, the performance of Maglev is substantially higher than HSR. The favorable aerodynamic properties and the non-contact technology make the Maglev more economical in energy consumption.

As consumers of energy, the transportation sectors are vulnerable to environmental and global warming concerns and the increasing volatile oil market. Reducing dependency on foreign oil is also an important criterion. The Maglev consumes less energy per seat-mile than conventional commuter trains due to the utilization of lightweight materials and improvement in the advanced technology.

3.5 Noise

Noise is another major concern of HSGT, not only for the passengers but also for those living near HSGT corridors. Considerable progress has been made in the last two decades in control of transportation noise at its sources, as well as in the reduction of noise impacts on various communities. Trackside noise reduction has also been a focus, with passive and active solutions. Acoustic walls can be built (and have been built in many places) to shield noise-sensitive areas from the track, yielding reductions of overall train noise on the order of 10 to 15 dBa.

The frictionless operation of Maglev reduces vibration, noise pollution, and maintenance resulting from wear. Comparing the noise levels at different speeds, we have observed that Maglev technology is much quieter than HSR trains in speed of 200-300km/h, as indicated in Figure 3. The fundamental reason is that Maglev operation does not produce any rolling, gearing, or engine noises. Because those noise sources predominate at low speeds, their absence provides Maglev much advantage in urban areas. For example, TR07 can travel about 25 percent faster than existing HSR trains before reaching the peak noise restrictions of 80 to 90 dBa. Such an advantage in speed will yield reduced trip times along noise-limited routes, which is most urban areas.

After speed of 250 km/h, aerodynamic resistance becomes the main source of noise with the increase of speed. As speed attains to 400 km/h; Maglev is still quieter than HSR at 300km/h though their difference becomes small. Even when at "respective" high speeds, data also indicates that Maglev is 5 to 7 dBa quieter than HSR (Transrapid International Inc., 2001).

4. A Case Study: Beijing – Shanghai Corridor

Many high-speed ground transportations systems have been implemented or proposed in different parts of the worlds since the 1960s. So far, Japan, Germany, and France are in the forefront of HSR implementations. A number of Maglev corridors have been selected and researched in the U.S, but no true HSGT system exists today. On the other hand, a new comer to the industry, China, is leading the way in testing the Maglev technology by building a test line of 30 kilometers from downtown Shanghai to the Pudong International Airport. The true mission of this test line is to explore or select an appropriate technology for the major arterial of the country: the Beijing and Shanghai Corridor.

4.1 Purpose and Need of the Proposed High Speed Ground Transportation along Beijing and Shanghai Corridor

Beijing (BJ) and Shanghai (SH) are the largest two cities in China, with over 13 million people in each city. The corridor between BJ-SH passes through the most prosperous areas of China, including four provinces and three metropolises, as presented in Figure 4. The vicinity of the corridor, which represents only 6.4% surface land area of the whole county, gathers 27% of population and generates one third of Gross Domestic Production (GDP).

More than 7% annual growth rate in GDP along this corridor dramatically increases passenger travel and freight movement demand. This creates tremendous pressure on the existing rail line along the Beijing-Shanghai Corridor. The Beijing-Shanghai rail branch with only three percent of total route length of the national railway systems (Ren, 2000), carried 45 billion seat-kilometres and 113 billion ton-kilometres in 1997. Speed increases along existing rail lines have reached their saturation point, limited by the capability of the existing technology.

Facing ever-growing travel demand, Chinese authority is motivated to seek faster, more efficient and cost-effective solutions to not only meet the demand but also continuously support the economic engine. Confined to the infancy of airline development, income levels of ordinary citizens, and travel habits formed through the past few decades, the major portions of passenger travel still rely on intercity rail service. Major train stations operate continuously (i.e., 24 hours per day, 7 days per week), and trains depart successively to meet the travel demand generated from various areas along the Beijing-Shanghai Corridor. A mere 8-minute headway is common at all in major train stations around the country (He and Fan, 2002)

The need for a HSGT system along the Beijing – Shanghai Corridor becomes paramount due to the vital role that this corridor plays in the Chinese economic development and its increasing congestion. The primary objectives of the proposed HSGT solutions are as follows:

1. Separate passenger and freight traffic: Due to the existing large volume of both passenger and freight, high capacity is the most important criterion for the proposed HSGT. Currently both passenger and freight trains share the same railways between Beijing and Shanghai. The annual passenger revenue varies between 14-20 million RMB and the freight flow ranges from 60 to 80 million tons since 1986. More than 240 trains are running along this corridor within a 24-hour period. Due to the speed distinction between passenger trains and freight trains, the speed of passenger trains is restricted to a very low level (Wang, 2001). When the proposed HSGT line is established, it will be possible to shift the passenger travel to the new line and dedicate the existing railway to freight movement.

2. Build a main trunk line to connect the major development centres between Beijing and Shanghai. Each of the metropolitan areas in the corridor becomes a hub within its own region in terms of railway network. The proposed HSGT would function as a major collection points to facilitate exchanges not only between Beijing and Shanghai but also among the regions of those metropolitan areas.

3. Provide economically competitive travel alternatives. China is still a developing country and personal income is relatively low when compared to that of Western world. The airline service industry is still in its infancy of developing stages with fairly expensive fares. Anticipating massive volume, the proposed HSGT should be able to provide relatively low fares with significant shorter travel times between different city pairs. Therefore, relatively low life cycle costs for each are preferred.

4. As the first HSGT corridor in China, the Beijing – Shanghai Corridor will still be a test bed for whatever technology is chosen. Limited by the economic and political conditions in the past, the majority of the massive railway network in China must be upgraded to accommodate higher speed and more comfortable rides. Therefore, it is critical for the Beijing – Shanghai corridor to provide useful lessons for the rest of the country.

4.2 Potential Deployment of HSR and Maglev in Beijing – Shanghai Corridor

As presented earlier, we have focused on the operating characteristics of Maglev and HSR in the Beijing – Shanghai Corridor. The eventual implementation of a particular technology will no doubt be affected by political will, market conditions, and economic factors, which are not fully addressed here due to the limited length and scope of the paper.

4.2.1 Travel Time

According to the Beijing – Shanghai Corridor HSGT Feasibility Study, the total length of the proposed corridor is around 1300 kilometres (Wang, 2001). There are many different plans with various station locations and alignment possibilities. For the purpose of this study, we have included 6 major stations besides Beijing and Shanghai as the north and south termini, respectively, as presented in Figure 4.

Based on the ideal, maximum speed of 300km/h and 450km/h, 6 stations, and acceleration rate of 0.4 m/s^2 and 1 m/s^2 for HSR and Maglev respective, we have derived the average travel times between Beijing and Shanghai as 4.5 for HSR and 3 hours for Maglev. Including station dwell time, practical travel time of 5 and 3.5 hours may be expected for HSR and Maglev, respectively.

However, when examining the alignment between stations in detail, we discovered many locations where neither HSR nor Maglev is able to operate in maximum speed due to curvature limitation or urban environment. Taking one of the proposed alignment (Shen, 2000), the total length is 1,462 KM, with 1,382 curves, 62% of the guideway is on a tangents and 38% is along curved alignment. In this case, Maglev may have inherent advantages to negotiate various curves or other diversified profiles, due to its higher acceleration rates and superior curving performance. Maglev is capable of attaining its top speed quickly once passing the curve limitations. The deceleration time and distance are both shorter so it can maintain ideal speed much longer. It is not surprising therefore that if the eventual travel time via HSR doubles that of Maglev even though the ideal analysis only presented about 50% difference. That is, the true travel time for HSR may be closer to 8 hours verses 4 hours, as opposed to our preliminary estimate of 5 hours versus 3.5 hours presented.

4.2.2 Capacity

The transit capacity is largely decided by the travel demand along the peak link during the peak hour along the peak direction (PLPHPD) (Liu, 2001). As depicted in Figure 4, forecast travel demand between Changzhou and Shanghai is 32 million passengers for the year 2010 (Ran, 2002). The PLPHPD volume along the same link can be as high as 11,000, which is used as the base for a preliminary operation plan. Among various responses to the Beijing- Shanghai HSGT corridor proposal, the Japanese team presented the super-large train model with 16 sections, 1674 seats (Hu, 2002). We used this as a representative of HSR, and calculated that 7 trains per hour are needed to accommodate the PLPHPD traffic along the peak link of Beijing-Shanghai Corridor, which converts to a headway of 9 minutes.

Similarly, using the Maglev capacity Transrapid International Inc. has presented to the Beijing – Shanghai HSGT Project, 10 sections with 1192 seats, we have calculated that 9 trains are needed. The headway for Maglev operation may be derived accordingly as 7 minutes.

Based on the above analysis, we can see that both HSR and Maglev are capable of providing the projected capacity without approaching minimum headways, 5 minutes for Maglev, and 3 minutes for HSR. However, the difference is that the 3-minute headway for HSR was tested and is utilized in various operations around the world, while the 5-minute headway for Maglev is to be proved in operation. In theory we can conclude that capacity, one of the main criterion that must be met for any transit development in China, is actually out of the critical path. Either HSR or Maglev is capable of accommodating the travel demand even when future growth is factored in. However, the real world operation may speak differently. Only 5% of riders travel between Beijing and Shanghai as evidenced by the current origin-destination patterns of the existing Beijing - Shanghai railway. Most passengers originate from many cities other than Beijing and Shanghai. They enter the trunk line either directly at the main stations or transfer from connecting rail lines. So we can assume that the majority of anticipated riders of Beijing- Shanghai HSGT will not be originating from the 8 stations along the trunk line.

Besides, there are still many problems regarding to capacity that need to discuss further. Since Maglev operates on entirely different types of guideway, it is impossible to bring maglev trains to existing railway networks. On this point, HSR may provide a distinct advantage for transfer connections, due to its good operating connection with other existing railway network.

To provide a total quantified analysis of each technology, we need to conduct detailed operation analysis, travel behaviour responses, as well as related life cycle cost for each scenario. Further analyses will be carried out, in a separate paper, based on the basic engineering comparison provided in this paper.

4.2.3 Environmental Impact

As presented in the early sections, several aspects of the environmental impacts, energy consumption, noise emission, and land use, are compared between HSR and Maglev. Among which, Maglev generally possesses slightly better advantages over HSR in all three aspects but the difference is not large.

With respect to land use, based on the data provided from the manufacturers, the land areas required at grade by either Maglev (Transrapid) or HSR (SKS) are very similar. That is every meter of double track for SKS will require 10.7 –11.6 sq meters ground area and 11.2 sq meters for Maglev. However, when built elevated, the land area required by the Maglev technology is smaller, about 1.5 square meters ground area for each double track guideway. Evidenced by the limited Maglev operations, both testing track in Elmsland in Germany and the Shanghai Maglev, the Maglev guideway is suited for elevated guideways and can be operated safety and efficiently. In contrast to the logic presented, Taiwan has selected HSR with the majority of the track elevated.

As we all realize, the Beijing – Shanghai corridor is located in the most economically prosperous region in China. The high industrialization and concentration of a large portion of the population in the nation keep the land values on the rise. Considering the densely populated and limited land resources, we argue that an elevated structure is a preferred choice. The advantage of compact right-of-way, tight footprint of guideway and an aerodynamic dynamic envelop, as well as its non-intrusive nature may give the advantage to Maglev.

Of course, the elevated guideway will cost more in terms of engineering structures than at-grade. Whether the increased engineering cost can offset the land use savings will mandate detailed value engineering analysis. Besides the dollar value of the land acquisition, another important factor is the environmental characteristics of the HSGT corridor. Whether a large number of urban structures have to be replaced or a large number of residents have to be relocated all contribute to the cost of the proposed project.

4.2.4 Operating Experience and Safety Records

As transportation engineers, we have to face the dilemma whether to cheer for an engineering marvel or accept a mature technology.

As we mentioned, the mature nature of HSR operations in Japan, French, and Germany certainly has provided HSR with rich experiences in construction, operation, and management, when compared to the only Maglev test track data in Germany and a brief maiden journey in Shanghai started less than a year ago.

The Shanghai Maglev, from Downtown Shanghai to Pudong International Airport, is the first commercially operating Maglev line in the world. It began its debut on December 31, 2002 and now is open to public. A single vehicle with three sections runs along the 30-kilometer long guideway at any given time even though there are several vehicles available. This brand new technology was embraced enthusiastically. The utilization rate was 100% with the hefty fare of 150 RMB, equivalent to $18, for the 8-minute ride. During the beginning period, it may be credited as a novelty ride and the true utilization is still to be seen.

Currently the Maglev is closed to public in order to test the operation of two vehicles simultaneously. In the test run, two vehicles are operated on different tracks toward in opposing directions, vis-à-vis, the highest relative speed may be up to 900 km/h, which is a true testing task since this operating scenario has never been executed along the Transrapid testing track limited by the single testing vehicle. This inability to test two Maglev trains passing each other has been of considerable concern to German consulting authorities. Another testing measure is the performance of 5-section vehicles. The Shanghai Maglev is scheduled to re-open in October 2003 when full revenue service will commence. At that time, the fare will be reduced to around 50-60 RMB, About $6 or $7. The system is expected to serve10 million passengers per year by 2005.

Projecting the Shanghai Maglev Project experience into the Beijing – Shanghai corridor, some engineers are concerned that the levitation height of 1 centimetre may create great challenges due to the length of the route, diverse terrain encountered, and potential seismic movement in zones within the corridor. Since the gap between the Maglev vehicle and guideway is only around 1 cm, variations of the gap distance should be controlled to less than 1 millimetre. Given the length of 1300 kilometres between Beijing and Shanghai, the guideway engineer needs to maintain a precision level that requires significant engineering inspection and qualify assurance and quality control (QAQC).

Furthermore, the proposed Beijing – Shanghai HSGT alignment crosses three seismic zones, Beijing-Tianjin-Tangshan area, Yanlu area, and Huanghai area. In addition, over-exploited underground water, especially in the proximities of Shanghai, has caused serious subsidence, which poses serious risks in construction and future operation for a super-speed Maglev train.

5. Summary and Further Studies

It is clear that both HSR and Maglev are sophisticated and technically advanced guideway technologies. While both technologies are capable of operating at the speed greater than 250 kilometers per hour, the design speed for Maglev is higher due to its inherited non-contact technology. It is true that all HSR systems including TGV, ICE, and SKS have tested speed in the magnitude of more than 400 km/h. Maglev, however, provides higher practical operating speed. In addition, Maglev, theoretically, may also consume less energy, emit less noise, and can be established in compact land use forms.

The capacity of both technologies is not challenged in the Beijing – Shanghai corridor and less likely to be a consideration in any other corridors.

While the HSR presents tested and safe 3-minute headway in Japan and French, the 5-minute headway by Maglev remains to be tested. HSR provides great advantages in accommodating the existing rail network with interchangeable operations. The Maglev guideway is dedicated, however, and would be isolated. The operating experiences will certainly play an important role due to the reluctance of any political party or organization to be labeled as supporting a project that may be considered a waste of time and resources.

It is certainly critical that both technologies and market conditions should be optimal for certain technologies to be implemented. Marketing conditions go through cyclical and geographical variations closely related to local and regional economic, demographic and political environments. However, the technical merit of a transportation system should be independently evaluated and compared before it is totally rejected. Based on this philosophy, we have focused on the operating characteristics of Maglev and HSR. However, it is certainly not our intention nor should be construed that other factors, such as cost, political will, cultural acceptance, economic condition, travel behavior response are not important. Quite to the contrary, those factors are so important that they usually present dramatically different outlooks when implemented in particular regions. Therefore, it is our belief that further studies along the lines of cost, network planning, social and political acceptance should be conducted before a particular technology is selected for the Beijing – Shanghai corridor.

Fortunately that Chinese government has commissioned a formal comparison study of HSR and Maglev, which is to begin in June 2003. Within the scope of the study, a test line will be constructed along Nanjing-Changzhou corridor where both technologies will be operated and evaluated. There is no doubt that the evaluation will play a vital role in the final technology selection for the Beijing –Shanghai corridor.

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List of Tables and Figures

TABLE 1. Specifications of Maglev and HSR Trains

Speed	TGV	SKS	ICE	MAGLEV
Experimental Speed (km/h)	514	443	407	550
Design Speed (km/h)	350	320	330	550
Operation speed (km/h)	300	300	280	450
Average speed (km/h)	250	260	200	290

Acceleration	ICE		Maglev	
	Distance (meter)	Time (second)	Distance (meter)	Time (second)
0- 200 km/h	4,400	140	1,700	61
0- 300 km/h	20,900	370	4,200	97
0- 400 km/h			9,100	148
0- 500 km/h			10,475	256

TABLE 2. Seating Capacity of Various HSR and Maglev Systems

Systems	ICE	SKS	TGV	Shanghai Maglev
Types	HSR	HSR	HSR	Maglev
Model	ICE-03	SKS-E4	TGV-D	TR-08
Number of Section	8	16	12	10
Seating Capacity	850	1,634	1,090	1,192

TABLE 3. Energy Consumption of Various HSR and Maglev Systems

Conditions	TGV	SKS-700	ICE-3	Maglev
Power (KW)	8,800	13,200	8,000	
In Constant Speed				
300 km/h			50 WH/PIkm	
430 km/h				55 WH/PIkm

FIGURE 1. High Speed Rail Trains

The Shinkansen Bullet Train

TGV 001

Inter City Express

FIGURE 2. Shanghai Maglev in Operation

FIGURE 3. Noise Levels of Various HSR and Maglev Systems

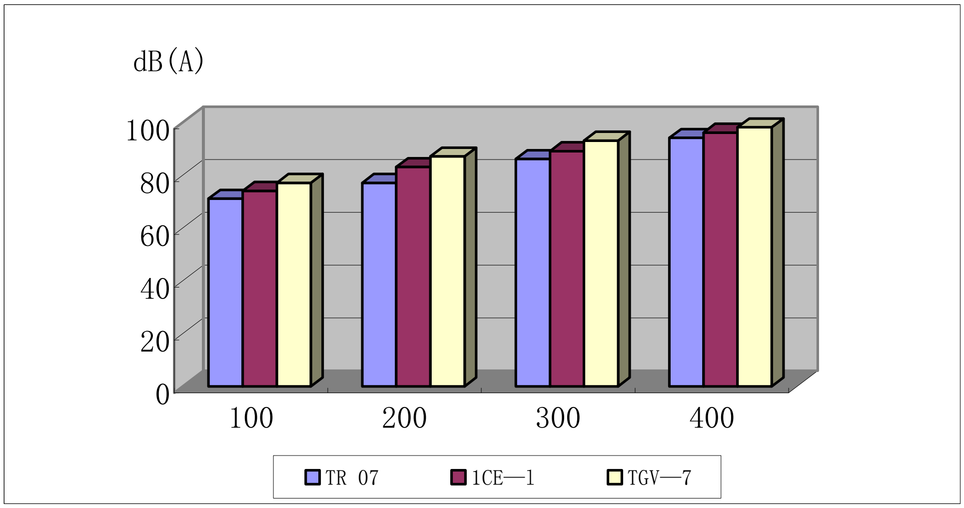

FIGURE 4. Beijing – Shanghai HSGT Corridor