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RESEARCH PAPER

Potential Applications of Maglev Railway Technology in China

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Abstract: From aspects of scientific value, technical feasibility and economical efficiency, this paper reviews practical demonstrations of transport projects related to the application of different types of maglev technologies in different countries. Based on the experienced progress, it summarizes the advantages and disadvantages of the world's maglev technologies in the possible development of China, and presents their technological and economic feasibility of different types of maglev systems and their current technical maturity from the viewpoint of engineering construction. Authors study the demonstration process of several maglev projects carried on in the countries such as Germany, Japan, America, Netherlands and U.K., and analyze the major technical parameters adopted, the relevant conclusions in engineering and economy and the reasons why these projects have not been started so far. The paper also reveals the environmental characteristics of maglev technologies in urban and intercity transport of China, studies the advantages of technical economy and potential risks to promote of maglev technologies in transportation practice. From the viewpoints of sustainable economic development, demand growths and governmental politics, the paper gives a preliminary analysis of the feasibility to apply maglev technologies in some regions of Yangtse Rive Delta, Zhujiang Delta and Beijing-Tianjin Region, and some intercity transport corridors between several important city pairs such as Shenyang-Dalian, Chongqing-Chengdu et al. Authors further estimate the economical efficiency for the application of maglev technologies. Integrated with the recent research progress of maglev technologies carried in China, the paper finally advances a series of policy suggestions for the development of maglev technologies in near future, which may promote the efficient practice of the technologies.

Key Words: maglev technology; intercity transport; passenger transport; benefit cost analysis

1 Introduction

Naissance and growth of maglev technologies originated from human's pursuit of travel speed. Since the past 80 years, a number of scientists have made several researches on the feasibility of applying this transport technology not relying on wheel-track contact without direct friction force to traffic projects and have realized commercial operation in Shanghai, China. Since China has a large population, the demand of applying this maglev technology not only comes into being in the intercity long-distance transport but also in the city traffic field, which is mainly materialized in the low-speed technology and light vehicles[1]. However, as to the problems of whether the maglev technologies can be promoted continuously and how to promote maglev technologies in China, experts and officials hold different points of view. Arguments mainly focus on three aspects: the first is the risk of project technologies, namely, whether the maglev technologies have had the project maturity for being generalized to the field of transport and production or not; the second is the economic risks for technology promotion, namely, if the economical efficiency of maglev technologies during the construction, operation, and maintenance of the projects can be accepted; the third is the risk of transport (production) capacity, that is, what is the level of the max production capability that maglev technologies can achieve.

In the early twentieth century, with the flourishing development of railway transport in various countries, the wheel-track transport theory drove to maturity stage. It was generally considered that: the limiting velocity of wheel-track was 300–380 km/h; only a new transportation system not relying on wheel-track could surpass this velocity[2].

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Table 1 Contrast of technical characteristics between normal conducting and superconducting maglev technologies

Representative technology	Type	Levitation air gap (mm)	Basic track model	Running velocity (km/h)	Accumulated data for trial running		
					Running mileage	Passengers	Deadline
German TR	Normal conducting EMS	10	T-model	400–500	352000 km	586000	End of 2004
Japanese ML	Superconducting EDS	100	U-model	>500	429000 km	86000	March 2005

In 1922, Hermann Kemper from Germany brought forth the theory of electromagnetic levitation. During the past 30–40 years, most of the problems related to maglev technologies at the technical level, no matter vehicle performance or operation control technology, have been solved, and some equipment developed has achieved the preliminarily assumed technical level[3]. The development of superconducting technology, the improvement of equipment manufacturing techniques and the upgrade of system construction level help to upgrade the application capability of maglev technologies. Currently, both the German TR (Transrapid) and Japanese ML (Maglev) can be regarded to have achieved the level for commercial application.

The research on the application of TR system in Germany began in 1968, and the early research paid equal attention to the normal conducting and superconducting systems. After 1977, Germany began applying itself to developing normal conducting maglev railway, and had developed the TR technology as to normal conducting maglev railway. In 1991, TR system became mature for technical application and accessed the international market before and after 2000[3]. Now, TR08 train has become the first product for Germany to compete in the international maglev market.

Japan has begun making research on the HSST (High Speed Surface Transportation, a kind of normal conducting maglev systems) since 1962, and then changed to study the superconducting magnetically levitated vehicle (Meglev) and has developed the ML technology as to superconducting Meglev since 1970s. In 2005, the Maglev Technology Practicability Evaluation Commission of the Ministry of Transport of Japan made an evaluation of “having established the practical basic technologies”[4].

In addition, a number of countries try to discuss the feasibility of hauling track based on maglev technologies. Successful construction of Maglev route in business is a challenging and commercioganic work to drive the technical level for transport and promote the development of national and regional economy.

2 Types and characteristics of maglev technologies

According to the attribute of coil conductors, the maglev technologies can be divided into the normal conducting type and superconducting type; while as to the levitation principle, maglev technologies can be divided into Electro Magnetic System (EMS) and Electro Dynamic System (EDS)[2].

In principle, the maglev technologies can be divided into two major modes, namely, “normal-conduct + EMS” (normal conducting EMS type) and “super-conduct + EDS” (superconducting EDS type). The TR technology of Germany adopts the former, while Japanese ML technology uses the latter, representing two kinds of current maglev technologies close to the practical level of the world, respectively.

2.1 German TR technology and Japanese ML technology

The technical indexes of TR and ML magnetically levitated transportation system vary with different system principles (Table 1)[3,4], which is mainly embodied in the aspects of track structure, levitation air gap, running velocity, energy consumption, magnetic field intensity and so on. The ML system with U-model track has bigger levitation air gap, higher reachable running velocity, more energy consumption and higher magnetic field intensity than the TR system with T-model track.

Differences of technical indexes will exert different impacts on route project and ecological environment. Since the noise of the systems mainly comes from air friction, within the velocity of 500 km/h, two technologies have similar influence on the noise of environment. Thanks to the application of electric energy, the superconducting maglev system consuming more energy will discharge more waste gas.

It must be pointed out that owing to the inadequate energy statistical data for TR and ML systems, the differences of the impacts of these two systems’ energy consumption on the ecological environment are mainly based on the theoretical or incomplete data inference.

2.2 Technical specialties of maglev technologies

As a kind of new transport technology, the maglev system, compared with the traditional means of conveyance, has some advantages as to the evaluating indicators like running velocity, acceleration, safety, reliability, project route selection, energy efficiency, environment protection, and so on[5,6]. However, the transport capacity of this system is only 40–50% of the high-speed wheel-track system.

In comparison with the wheel-track system, the running velocity and acceleration of maglev system have visible advantages (Table 2)[3,5]. The designed speed of TR08 and

Table 2 Speed and acceleration of TR train and ICE train

Speed (km/h)	200	300	400	500
Accelerating distance (km)				
ICE Train	4.4	20.9		
TR Train	1.7	4.3	8.8	19.3
Accelerating time (s)				
ICE Train	140	370		
TR Train	65	100	155	265

Table 3 Indicators of environmental impact factors for TR train and CIE train

Vehicle types	Speed (km/h)	Energy consumption (w·h/p·km)	CO_2 discharge (g·p·km)	Noise (dB, 25m's distance)	Area (m^2/m)
ICE train	300	51	25	90	14
TR train	400	52	21	88.5	12

MLX01 trains are 500 km/h and 550 km/h, respectively, far higher than that of high-speed wheel-track trains which is 300 km/h currently. When running in the level route, it is reckoned in theory that TR08 train takes 265 s and 19.3 km for acceleration to achieve the speed of 500 km/h, which are less and shorter than the corresponding values (370 s and 20.9 km) for ICE03 train to achieve 300 km/h, taking into account that MLX01 has greater acceleration than TR08, the above-mentioned D-value will be more obvious.

The conclusion of higher safety and reliability for maglev system is mainly based on the theoretical inference and accumulative data for trial running, and needs further inspection and improvement through actual operation. The collision of Emsland experimental maglev trains and service locomotive occurred on 22 September 2006 in Germany, which challenged the safety of the control system of the maglev trains.

As to the project route selection, the limit slope of Maglev route can achieve 100‰, higher than the maximum climbing ability of the high-speed wheel-track trains which is 40‰; the minimum curve radius of Maglev route under the speed of 300 km/h is 1,590–2,360 m, which is smaller than 3,350 m of high-speed wheel-track[3,6]; as the speed is upgraded to 500 km/h, the minimum curve radius of Maglev route will be larger, which, however, cannot be supported by observed data now.

According to the observed data of TR system, the TR trains running at 400 km/h has almost the same and even lower environmental impact indicators, such as system energy consumption, noise, waste gas discharge, site area and the like, than the ICE trains running at 300 km/h (Table 3)[3,6]. No observed data is available now to support the comparison of energy consumption and environmental impacts between the TR system and ML system with the speed ranging from 400 km/h to 500 km/h and the high-speed wheel-track system.

In addition, the actual running demonstrates that no matter whether it is TR or ML, the special magnetic field intensity of maglev system can remain at an acceptable level.

2.3 Economic characteristics of maglev technologies

As a large-scale traffic project, the construction cost for maglev system is high. Despite different points of view concerning the cost of maglev system and the cost of high-speed wheel-track system, generally speaking, most viewpoints and data show that expenses for building maglev system are more than that for high-speed wheel-track system[6]. Especially in the plain region, the project cost for high-speed wheel-track system is reduced, while the maglev system cannot make full use of its advantage of flexible route selection. In this case, the cost differences will be very visible.

Table 4 shows the cost estimation for several typical planned maglev routes[1,3,7–9], from which it is found that the cost of maglev routes is generally higher than that of high-speed wheel-track routes. If we further take into account the dense departures in the heavy haul marshalling and long-distance routes required for maglev trains to realize trunk transportation, the cost of maglev route will be further increased[7].

Low unit operating expenses for maglev system is the conclusion reckoned on the basis that unit volume of railway freight of high-speed maglev transportation system at the speed of 300 km/h has the advantage of lower energy consumption than that of wheel-track system. Low expenses for maintenance is owing to the fact that the maintenance of maglev system mainly focuses on the electronic equipment, for the passenger-kilometer expenses for maintenance of TR system is less than 1/3 of the ICE system[3].

What must be pointed out is, the conclusions above are mainly based on theoretical analysis, and the base data comes from the operating records of the maglev trial routes of Germany and Japan. As to the high-speed maglev system for commercial operation, taking into account, the factors like specific operating and organizing manners and maintaining ways, more operating data are required to support the applicability of conclusion. Therefore, the academic circle has great divergences of opinions on this conclusion.

Five years have passed since Shanghai maglev demonstration route which is 30 km long and has the max speed of 430 km/h was completed and opened to traffic for trial in 2002. Data shows that the final account for the project investments after this route was finished is about RMB 10 billion Yuan with the averagely daily traffic volume up to 8000 passengers or so. Making use of the materials for cost calculation of commercial operation, we can effectively analyze the characteristics of operating and maintenance expenses of the high-speed maglev system and make an objective conclusion.

Table 4 Planned unit cost for maglev route

Countries	China	Germany	Japan	America	
Route projects	Shanghai–Hangzhou	Munich Airport Route	Tokyo–Osaka	Baltimore–Washington, D.C.	Pittsburgh Airport Route
Total length (km)	175	37.4	517	62.5	87
Unit cost (static state)					
Planned annual price level (one-hundred million /km)	2.03 (¥)	0.43 (€)	160.5–191.5 (¥)	0.59 ($)	0.42 ($)
RMB (one-hundred million/km)	2.03	4.73	12.8–15.3	4.84	3.4

Table 5 Statistic data of TR technologies

Projects	Data	Date Recorded
Longest daily running mileage	2,476 km	August 15, 1990
Longest non-pausal running mileage	1,674 km	June 6, 1993
Highest speed in experimental base	450 km/h	June 10, 1993
Total running mileage	About 1 million km	December 2004
Running mileage of TR07 train	About 0.588 million km	December 1999
Running mileage of TR08 train	About 0.352 million km	December 2004
Running time of TR08 train	7,000 h	March 2003
Accumulated number of trial passengers	586 thousand	December 2004

3 Application demonstration of maglev technologies of countries all around the world

As the maglev technologies become mature day by day, countries all around the world are trying to build practical maglev routes. Materials show that Germany, Japan, and America have demonstrated the maglev technologies in various routes. The following is the analysis on the demonstrating process of maglev technologies of various countries, technologies adopted, economic parameters, and relevant conclusions.

3.1 Application demonstration of maglev technologies in Germany

In 1977, Germany began researching and developing the long stator driving system based on normal conducting technology and Electro Magnetic System (EMS). During 1980–1987, Germany established the Transrapid Vehicle Experimental Base (TVE) of Emsland. The following is about the running experiments for nearly two decades, technical performance that TR system has achieved currently and accumulated running data of TVE (Table 5)[3].

In 1991, TR system has achieved the stage of “becoming mature in application of technologies and being capable of building actual operating route”[3]. After about 15 years’ development, TR technology has become further mature and accessed to the international high-speed transportation market and made construction projects of TR system in America, China, Netherlands, Australia, Brazil, and so on.

However, as to the TR safe control system that has been put into commercial operation, especially in terms of how to guarantee the safety and reliability of the high-speed maglev transportation system under the conditions of large marshalling and high density, further demonstration and improvement are required likewise.

Maglev fire accident happened in Shanghai in August 2006 and the collision of TR experimental train and service locomotive happened in Germany in September bring forth new and higher requirements for the safety guaranteeing system and accident rescuing preplan of high-speed maglev system.

Berlin–Hamburg, Düsseldorf–Dortmund, Munich Airport–Urban Railway Station are three domestic TR routes planned in succession in Germany.

In 1992, Berlin–Hamburg TR route of 300 km or so was listed into the traffic route plan of the Federal Republic of Germany. In 2000, project of this route was suspended and finally abandoned. The reasons why this first planned German TR technology route with the highest normal conducting TR technology failed are typical and include three aspects in technology, economy, and politics.

The technical reason mainly contains the following factors, such as the reasonable establishment of electricity supply system, the standards for intersecting rail design of two routes and operating speed, route curve radius setting during actual operation, and the determination of the effective length of the turnouts failed to be well solved. Furthermore, the publics disbelieved this merging technology.

Economic reasons mainly include: first of all, the enormous and constantly increasing sum of investment estimation, from

1996 to 1998, the cost estimation of the whole route increased to 12.9 billion Mark from 8.9 billion Mark; second, the unoptimistic analysis on the project cost and gains, even if calculating as to the most optimistic economic estimation, the annual loss of this route would be up to 100 million Mark; third, the worse and worse operating situation of German railway, the after-tax incomes in 1999 were about 500 million Mark, which is less than that of last year; hence, the risk investment to operate a route that might cause loss was not allowed.

Finally, the fight for rights amongst the parties of Germany is the political cause to affect the success of TR construction project.

Munich airport route is planned to have a total length of 37.4 km with total cost of 1.6 billion EU, and is the only current TR railway construction project left in Germany (Table 6).

Relevant research and analysis pointed out that the transportation benefits of the TR transportation system of Munich airport route, especially the cut effects of time and expenses, are very evident. The whole mileage of this TR route lasts for 10 min and the current travel time for corresponding intervals is 40–65 min[3].

The TR trains of Munich airport route has high speed and high departure frequency, and will attract the passengers originally taking highways to the airport, thus further improve the traffic situation of highways. In addition, this TR route has visible advantages in the aspects including protection of ecological resources, reduction of environment burden, simplification of boarding procedures, and so on[3].

In 2006, this project entered the hearing stage. At the end of this year, Oberbayern Government made a conclusion for this project that the federal railway bureau was probably to make a decision of approving the project in 2007 or so. According to the optimistic estimation, this route would be constructed in 2007 and opened to traffic in 2009, but now there is not any official conclusion on the examination and approval of this project plan yet.

3.2 Application demonstration of maglev technologies in Japan

Japan began researching the superconducting maglev railway and developing the ML technology as to superconducting maglev railway since the beginning of 1970s. In 1977 and 1996, Japan finished the Miyazaki experimental route and Yamanashi experimental route in succession. The former merely made the most fundamental performance trial for the superconducting maglev railway; while the latter has a total length of 18.4 km, which is used for the running trial of practical application of superconducting magnetic levitation and is regarded as a section of the planned “Superconducting Maglev Chuo Shinkansen” from Tokyo to Osaka[7].

During 1997–2005, two phases of running trial were made for the Yamanashi experimental routes, to make comprehensive demonstration from three aspects of train performances (including running performance of single trains, running performance of pair trains, safety performance, reliability and endurance, equipment readiness, transport capacity and environmental impact along the route), spread effects (mainly refer to the influence of maglev technology on high-tech field), and comprehensive technical performance (including high-speed, mass transport capacity, punctuality, and economical efficiency) (Table 7)[4].

Based on this, the Maglev Technology Practicability Evaluation Commission of the Ministry of Transport of Japan declared that “basic technology of the state maglev practicality-orientation has been determined and can be put into practical play”, at the same time, determined the future subject and development direction—orienting toward the practicality to validate the performance like endurance through longer-term trial running and to develop technologies like high-temperature superconducting magnet that could reduce cost, and discussed about the operating way suitable for the operation route[4].

Table 6 Project data of TR route from Munich airport to urban railway central station

Station	MU	Marshalling	Annual estimated passenger flow	Designed speed	Mileage time	Departure interval
2 units	5 units	3 units	7860 thousand	350 km/h	10 min	10 min

Table 7 Statistical data of ML technology

Project	Data	Time recorded
Designed daily running mileage	2,500 km	March 2000–March 2005
Longest daily running mileage	2,876 km	November 2003
Highest intersection relative speed	1,026 km/h	December 2004
Total running mileage	428,785 km	March 2005
Total running days	312 days	March 2005
Accumulated number of trial passengers	85,776 passengers	March 2005

Table 8 Maglev route data for EXPO 2005 Nagoya–Aichi, Japan

Length (km)			Max slope (‰)	Min. curve radius (m)	Number of stations (U)	MU (U)	Marshalling (U)	Designed speed (km/h)	Mileage time (min)
Tunnel	Elevated railway	Total length							
1.4	7.5	8.9	60	75	9	9	3	100	17

Except for the ML technology mainly used for the heavy haul trunk railways and intercity railways, Japan also developed the normal-conduct-based low-speed maglev railways—Central High Speed Surface Transportation (CHSST) system, and used it as the urban vehicles. Compared with the ML system, CHSST not only has the same advantages, such as comfort, pollution free, safety, and reliability, as that of maglev transportation system, but needs less expenses for the construction and maintenance and has more mature system technologies[2,10], and also, the mass high density commercial operation route—Eastern Hill Route, has been accomplished.

The planned Japanese transport hub—Chuo Shinkansen will become a center routeway of the traffics of Japan, and will be one of the national construction projects as stipulated in the Law on the Control of National Shinkansen Railway of Japan. This route starts from Tokyo, ends at Osaka and passes through the neighborhoods of Kofu-shi, Nagoya-shi, and Nara-shi. The “Superconducting Maglev Chuo Shinkansen” (hereinafter, referred to as “Chuo Shinkansen”) is the candidate project of this route that uses the ML system[11].

The total length of the “Chuo Shinkansen” is 517 km with 8 stations from the east to the west as follows: Tokyo, Kofu, Iida, Tajimi, Nagoya, Kameyama, Nara, and Osaka, and the entire running time is about 70–80 min.

The cost estimation of “Chuo Shinkansen” is not checked and ratified as yet. In 1989, the total dynamic investment for “Chuo Shinkansen” jointly estimated by the Ministry of Finance, Ministry of Transportation and Railway Construction Institution of Japan was up to 5000 billion Yen. After this, JR Tokai Company which was the major investor of this route estimated that the total investment should be 3000 billion Yen. The “Symposia on Basic Project of Superconducting Maglev Chuo Shinkansen” held by the Ministry of Land and Traffics and JR Tokai Company in April 2003 brought forth that the total cost for the entire maglev system was about 8300–9900 billion Yen (about RMB 664–792 billion Yuan, and the unit cost was about RMB 1.28–1.53 billion Yuan)[7].

At present, this project is still at the feasibility research stage, and the detailed layout of the projects, technical standards, quantification of economic benefits of the project and construction capital sources still need further research and determination.

The eastern hill route (Table 8) is a domestic application route of Japanese normal conducting Maglev CHSST system[12] with a final account of cost up to 99.8 billion Yen and unit cost reaching 11.21 billion Yen/km (about RMB 897 million Yuan/km). The cost indicator is lower than the cost estimation of ML system, but far higher than any other currently planned or established high-speed maglev route.

At the end of 2004, the entire route was opened to traffic; on 6 March 2005, it was put into operation formally as the major vehicle for urban traffic and the world expo. This route is estimated to realize surplus at the fifteenth year and relieve of accumulated deficits at the twenty-sixth year.

3.3 Application demonstration of American maglev technologies

As to the development and application of maglev technologies, similarities exist between America and China.

First of all, both countries have made a certain scale of investment to the maglev technologies and mainly focused on the research and development and improvement of vehicle equipments and track structure.

Second, these two countries are both want of experimental route building technologies and experience of operation and maintenance for maglev train system, both to different extents rely on the maglev route technologies of Germany and Japan as to the construction of new routes, both stress on introduction and integrate with the existing technologies of Germany and Japan, so as to further develop the maglev railway systems that agree with their own technology development level and transportation demand law.

Development of maglev in America experienced a number of repetitions, which make America fall behind Germany and Japan as to the demonstration and running of maglev trains. The overall research level in terms of software and hardware of maglev technologies in America is certainly higher than that in China, but thanks to the completion and operation of Shanghai maglev demonstration route, China also has mastered firsthand data as to the construction and commercial operation of maglev transportation system. During the past tens of years, the federal government, enterprises and research and development institutions of America have invested $1.5 billion USD successively and obtained a breakthrough in terms of key maglev technologies, including linear DC synchronous motor, superconducting magnet, light synthetic materials and so on. Technology research and development, especially technical improvement of hardware successfully helps to reduce the manufacturing cost of various kinds of equipment.

The profession circle of America considers that “as long as we have fund guarantee, there is no any technical problems” to construct the 500 km/h (300 mph) maglev railway system, and the industry and academy circles have the capability of competing with other countries in terms of maglev research and development. The FRA has even decided to choose maglev technology as the next generation high-speed land transportation mode to facilitate the fast development of the country.

Data shows that America has made primary comparative studies of economy for 16 planned maglev routes, and further marked out and perfected 7 routes amongst. In 2001, FRA finally determined the projects of Baltimore–Washington route in Maryland State and Pittsburgh Airport–Pittsburgh–Greensburg route in Pennsylvania State, which were brought into the Bill of 21st Century Transportation Property of America by the Congress[13]. Currently, these two routes will get into the stage of final approval.

(1) Baltimore–Washington route is planned to connect the center of Baltimore and the Baltimore–Washington International Airport and will be further extended to the center of Washington with a total length of 63 km and the gross cost being up to $3.7 billion USD.

This route stresses on carrying commuters and shuttling passengers in this region. In the long-term layout, this route is probably to be extended to Boston northwards and Charlotte southwards, thus forming the traffic channel along the eastern seashore between these two cities.

In 2004, the FTA promulgated the comprehensive demonstration as to the planned Baltimore–Washington route with the conclusions as follows:

The route may produce sustaining and stable comprehensive economic benefits during the period of operation. It is anticipated to produce the regional market scale of $29.5 million USD directly every year and to provide 328 job opportunities during the period of operation. Taking into account the indirect effects and synergistic effects, these two figures will increase to $50.5 million USD and 437, respectively.

The construction of maglev system may help to increase the land value along the route massively and stimulate the regional economic growth. The undeveloped land surrounding the urban Station of Baltimore, the real estate within the walking distance of the station and the residential area will appreciate in value by 10–12%, and the office area, by 20–25%. What is more, the corresponding city construction can further encourage the growth of local investment, secondary development and real estate. It is conservatively estimated that, the undeveloped land surrounding the Station of Baltimore can directly or indirectly produce the office site of 3,250 m^2 and sales site of 930 m^2 and there will be 450 rooms available to directly serve the passengers of the station.

The construction project can attract travel and tourism and increase tourist earnings. The tourist travel by this maglev route is estimated to account for 4% of the total. By the year 2010, the number of tourists taking this route to Baltimore will be up to over 266 thousand with the gross turnover up to $236.6 million USD; the gross turnover will increase to $282.2 million USD by 2020.

The transportation benefits of maglev route will be remarkable. First, the travel time is shortened. The entire travel time is merely 18 min, which is much faster than any other transport modes; furthermore, the punctuality of maglev transportation system increases the reliability of interval travel time. Second, the structure of artery transportation modes is optimized within the region, and the highway transporting demands are reduced. After the completion of this route, 84.2% of its passenger source will be from the highway transportation and it will shoulder 2.9% of the traffic market shares of this region. Third, effectively relieve the traffic jam in expressways and upgrade the service level of expressways. Based on the reduction of VMT, the expenses saved because of the soothing expressway jam owing to maglev system in the region of Baltimore–Washington will reach $94.2 million USD by the year 2010. Fourth, the increase of volume of passenger transportation of BWI Airport is stimulated year by year. By 2010, the annual volume of passenger transportation of BWI Airport is estimated to be up to 15.4 million, thus greatly facilitating the BWI Airport to grow as the third largest airport of the Capital Washington, D.C.

Environmental-friendly benefits will be favorable. The VMT in 2020 will reduce to 792,000 km as a whole, and the maglev system substituting the vehicle transport will reduce the daily energy consumption to 1.2 billion BTU from the original 3.1 billion BTU. By 2020, 51 tons of volatile organic compounds, 156 tons of carbon monoxide and 463 tons of nitrogen oxide can be reduced every year, thus improving the air quality, reducing pollution and being propitious to form ozone.

The technology development of transportation enterprises is facilitated. The Baltimore–Washington maglev project provides a distinctive opportunity to the high-tech companies in this region. Hence, the high-tech manufacturing industry required by the transportation products will develop in an accelerated way. The Maryland State will complete corresponding industry and project bases so as to support the route construction and development.

(2) Pittsburgh Airport–Greensburg route is planned to connect the Pittsburgh International Airport and the urban area of Pittsburgh, and will be extended westwards to Monrovia and further to Greensburg. The total length of this planned route will be 87 km and the total cost, $3.5 billion USD.

This route will provide a new means of conveyance for the Pittsburgh passengers and relieve the current traffic jam to the

Pittsburgh Bridge. The maglev terminal building situated in the Pittsburgh Airport will become a transport hub to connect airplanes, maglev, buses, taxies, and cars. In the long-run layout, this route will be extended westwards to Cleveland and eastwards to Philadelphia, thus becoming a east-west corridor connecting Cleveland of Ohio State–Pittsburgh of Pennsylvania State–Harrisburg–Philadelphia, joining the northwards extended route of Baltimore–Washington Maglev Route in Philadelphia, and further forming a longitudinal and horizontal traffic network frame amongst the eastern coastal cities of America.

In July 2003, the FTA made a summary report on the planned Pittsburgh Airport–Greensburg route with the conclusions including the following:

Net present value of the project is unoptimistic. Only taking into account the direct and indirect economic benefits of the project, under the 10% discount rate and taking 20 years as a calculation period, the net present value of this project is $–841.55 million USD. The balance of payments can only be realized under the discount rate that is nearly 4%.

Provide fast, convenient, and reliable traffics for the airport, major residential and working population distribution center. First, the travel time in the region is greatly shortened. The travel time between the major stations will be shortened to 10 min or so from the original 30–60 min. Second, the structure of transportation modes is improved in the region. From 2008 to 2026, the maglev transportation system will partake 0.7% of the transportation shares and 25.4% of trunk transportation shares in this entire region. Third, the change of the structure of transportation modes can reduce the highway traffic of the region. It is anticipated that VMT in 2008 and 2026 will reduce 304 and 404 million vehicle mileage, respectively. Fourth, transportation economic benefits will be brought by the improvement of traffic environment and the total economic benefits in terms of consumer cost saving (the surplus of the actual cost compared with the cost anticipated by consumers for the same travel), and the reduction of jam cost and the reduction of environment protection cost will be $160.27 million USD in 2008 and $176.52 million USD in 2026.

The energy-saving benefits and environmental-friendly benefits of this project will be visible. Maglev transportation system will cause reduction of VMT. The net saving equivalent weights of energy consumption in 2008 and 2026 are reckoned to be 763×10^6 and $1,118\times10^6$ BTU, and meanwhile, the petroleum that will be substituted by coal in the target years is estimated to be 42,325,400 and 53,090,400 liters. Furthermore, as to the discharge of harmful gas in this region in 2008, the nitrogen oxide will reduce to 160 tons, and volatile organic compounds will reduce to 164 tons. By 2026, the former will reduce to 213 tons and the latter to 221 tons.

The regional economic development is facilitated. Depending on different influence degrees, during 2000–2025, the job opportunities of this region will increase by 10–70%. At the same time, maglev transportation system will improve the accessibility of the region along the route and improve the population scale of relevant towns, especially medium and small towns along the route. Population is reckoned to increase by 15%–90% from the year 2000 to 2025.

(3) Colorado maglev route is planned to use the Japanese CHSST system (Table 9)[10] and will be reconstructed to be the maglev technology suitable for the intercity transportation of America. Though this planned route has not yet been brought to the American layout procedure of public laws, the American-style CHSST technology has tended to become mature.

In June 2003, FTA organized the authoritative HSST experts of America and Japan to form a team of evaluation to assess CHSST system of Colorado State in an all-round way, and considered that the performance indicators of the system had achieved the designed requirements of FTA for the route[13]. The next step is to attach importance to consummate the safety guaranteeing system for the operation of the system, make every effort to directly and accurately calculate or make use of the operating data of the Japanese eastern hill route so as to determine the actual energy consumption, and to further assess the impact of this project on the culture, history and archaeological resources.

3.4 Analysis of experiences and lessons of project planning

In terms of the construction of high-speed maglev transportation system, America has successfully used the method of comprehensive planning and major construction. From the feasibility research of 16 routes to the comprehensive planning of 7 routes and to the determination of major construction of 2 routes, especially the means of economic evaluation in the selection of multi-route projects, all are worth learning.

Table 9 Planned data of Colorado maglev route

Total length (km)	Station (unit)	MU (unit)	Marshalling (unit)	Designed speed (km/h)	Min. departure interval (min)	Mileage time (h)	Max. passenger flow (person/day)
252.6	14	65	2	160	2	2.5	40,000

The American economic evaluation on route projects includes the single-track financial evaluation and network financial evaluation.

The single-track financial evaluation, based on the different discount rates (7% and 4%) and taking the year of 2000 as the base year of the period of calculation which lasts for 40 years, with the cost including basic construction cost, vehicle purchasing cost and new vehicle purchasing cost in the future, will calculate the income/cost ratios of the projects and select from them.

Network financial evaluation takes into account the long-term layout of surface high-speed traffic system and estimates the passenger flow and operational incomes after the maglev transportation system forms the network and the external incomes of the transportation network. In this way, it gets the income/cost ratios of the maglev system network and makes the selection.

The following conclusions are made through the economic evaluation on the project plans:

(1) Changes of discount rate and project construction period may affect the results of the financial evaluation remarkably, and a number of factors exert impact on the economic feasibility of the maglev projects. Different discount rates, different construction periods and different economic environments will have great influence on the economic feasibility of the maglev projects. For these reasons, the maglev construction shall go on according to stages and regions.

(2) Conclusion of the financial evaluation is unoptimistic. No matter whether the discount rate is 7% or 4%, only the incomes of the planned Baltimore–Washington route can cover the cost, and the other planned routes may cause different degrees of losses.

(3) Network benefits. Maglev transportation system will massively increase the passenger flow and operational incomes after it forms a network. Under the given conditions, the overall financial situation of the maglev system that has formed a network will be better than that of any single planned route visibly.

(4) External economic benefits. The most significant external economic benefits of maglev system mainly include: saving of plentiful petroleum consumption, reduction of discharge of CO_2 and other noxious gases, flow distribution of the highway transportation so as to reduce traffic accidents on highways.

It shall be pointed out that: the economic background in America for the maglev feasibility research is, to a certain degree, different from the actual environment of the economic development of China. The most remarkable difference lies in the transportation structure. The transportation network of America is highly developed. The expressway and aviation transportation are the common transportation modes, and maglev system that has formed network will mainly compete and link with aviation. For these reasons, the maglev ticket price used in evaluation is determined by 90% of the air ticket price at the same market. The domestic aviation market of China is still in the beginning stage at present, and a mass of domestic passenger converge at highway and railway transportation; however more can be learnt from their evaluation methods and evaluation system.

4 Probability of applying maglev technologies in China

4.1 Analysis on environment of developing maglev technologies in China

Compared with developed countries, the maglev technology research and development and construction environment in China has the following characteristics:

(1) In terms of technology, research and development of maglev technology in China started late, especially in engineering level. Despite of this, China has built the world's first commercial high-speed maglev line -- Shanghai Pudong Airport Line through cooperation with Germany in 2003, which has greatly promoted research and development in China's maglev technology. Through introduction, digestion and absorption, China has gradually possessed the capacity of innovation. For example, since the 1990s, the former State Science and Technology Commission formally listed the key technological research on medium and low speed maglev train in the “Eighth-Five” national research program led by China Academy of Railway Sciences, with participation of National University of Defence Technology, Institute of Electrical Engineering, Chinese Academy of Sciences (IEECAS), Southwest Jiaotong University, and other units. In May 1995, National University of Defense Technology succeeded in 1:1 single bogie manned operating in their laboratory. In 2001 the medium and low speed maglev test vehicle was off the assembly line and successfully passed the trial running. In July 2005 Maglev engineering test vehicle has been successfully developed. At present, China has successively set up a number of research bases and testing lines in Beijing, Changsha, Chengdu, Shanghai, Dalian and other cities, and carried out practical research on magnetic levitation technology of different types. Practical low-speed maglev train and test line of 2 km in Tangshan is in the works[10]. Independent R & D capability on the application of maglev technology is taking shape. Experience indicates that to catch up with and surpass the advanced in the progress of developing science and technology cannot be achieved overnight, particularly in engineering and technical field, we have to bear loneliness continuously, especially in the field of engineering technology. Consequently, we have to endure loneliness and make R&D and demonstration well in a practical way in the prophase of application of maglev

technologies.

(2) In terms of economy, the cost of unit transport capacity of maglev system is higher than that of wheel-track system. As a developing country, generally speaking, the fiscal budget capability of the Central Government, departments directly under it and majority of local governments is comparatively limited, whereas, some economically developed regions have already held the capability of building maglev lines. The demonstration experiences of various countries indicate that maglev system holds quite weak capacity to assume sole responsibility for its profits or losses, therefore, the regional and governmental departments should in the first place allow for the feasibility and fiscal capability of carrying out operation subsidies before any decision of building maglev system. Accordingly, each city must fully take into account the carrying capacity of local economy when plan the construction project of maglev system.

(3) Viewing from the market demand, there is still some space to develop many traffic passage systems in China, and this is where China is visibly better than developed countries during the process of building maglev system. This situation provides better demand environment for the development of maglev technology in China and increases the economic feasibility of this technology.

(4) Viewing from the policy environment, maglev, as a new technology, can produce sound industry driving effect, technology driving effect and media publicizing effect, and is easy to be preferred by relevant departments.

(5) From the aspect of the public and professional environment, main focus of all the social circles is the cost of maglev lines. By now, the investment and financing policies as to transportation have come into being in China, and created good conditions for investing and financing of maglev technology project. However, further study on feasible measures is still required in terms of specific methods of operation.

4.2 Objectives and principles of research and development of maglev technology

There are three objectives to study and construct maglev route in China: one is to solve the problem concerning insufficient supply of some massive traffic demand passages, and ensure the growth of corresponding regional economy and improvement of residents' living standards; second is to make China's advantages in the field of maglev application technology come into being, advance China's international impact on relevant field of maglev technology and create conditions for export of maglev technology through construction and operation of maglev route; third is to improve the national self-confidence of the governments and the common people of China by means of construction of maglev—this emerging technology project, and its international advancement.

Therefore, under the above-mentioned objectives, the guidelines for developing maglev technology in China include: on the basis of market demand, bringing into play the guiding function of governmental policies and funds, facilitating the introduction, research and development, assimilation and innovation of Chinese maglev technology through the state's integrated organization and development of production, learning and research of maglev technology and realizing the task of meeting transport demands and leading international level by means of maglev technology.

According to the actual situation of China, the following significant principles shall be taken into account for building maglev route in China at present:

(1) Fundamental principle of traffic demand. Significance of application of maglev technology is above all embodied by the traffic demand; therefore, the traffic demand principle is the first principle for promotion and application of maglev technology. Experiences indicate the most important reason why the routes of many countries came to an anchor during the process of demonstration lies in the shortage of demands.

(2) Principle of technical reliability. Maglev is a new transportation technology oriented towards passengers (human) and the public, therefore, principle of safety and reliability must be taken into account. We hereby need to emphasize the reliability not only from science aspect but also engineering technologies aspect.

(3) Principle of financial affordability. Public traffic system itself has some public benefit, hence its construction and operation needs governmental investments and subsidies. Undoubtedly, maglev is a kind of public transportation with more expense and higher quality. During its process of demonstration, relevant governmental departments shall have a comprehensive understanding and make an all-round plan for the investment in construction and subsidies for operation.

Therefore, from historical progress in science, technology and society, with the research and development of the maglev technology, the improvement of economic performance triggered by economic and technological development may provide additional opportunities for the application of the maglev technology.

4.3 Potential construction area

Now, different regions in China have different economic development levels. In terms of government's carrying capacity of shouldering economic subsidies, the eastern area is higher than the western area. Viewing from the economic carrying capacity, the Yangtze River Delta, Pearl River Delta, Beijing, Tianjin, and northern region of Hebei have the fundamental conditions to build the maglev route, specifically speaking, the potential space of future maglev technologies can be divided into three levels.

The first level includes the passages of Huning (Shanghai–Nanjing), Huhang (Shanghai–Hangzhou), Jingjin

(Beijing–Tianjin), and Guangshen (Guangzhou–Shenzhen) Port, which has better demand foundation, and also, the current traffic supply cannot meet the traffic demand.

The second level includes the passages of Chengyu (Chengdu–Chongqing), Zhengwu (Zhengzhou–Wuhan), Jiaoji (Jiaozuo–Jinan), and Shenda (Shenyang–Dalian). Local governments where these passages locate hold weaker economic carrying capacity. For this reason, maglev technology may be promoted after its maturity has been improved and cost of construction and operation has been further reduced.

The above-mentioned two levels belong to the short-distance passages, while the third level is to base on what is mentioned above, and consider extending the middle and long distance passages in those routes with economic carrying capacity like Jingguang (Beijing–Guangzhou) and Jinghu (Beijing–Shanghai) passages through accumulating operational experiences. Maglev technology helps to greatly shorten the distance between some big cities, improve the accessibility of intercity travel, and improve the service quality and level.

What's more, the airport mode established in Shanghai, China with many demonstrations in foreign countries is also proved to be attractive, considering that those airport passengers may hold stronger affordability. However, in most cases, the transport demand scale in the airport lines will not be too large. If combined with other land development objects along the lines to increase its demand, economic feasibility of maglev technology will be improved.

5 Conclusions

According to the aforesaid analysis on the demonstration of maglev route projects in different countries, the commonness is as follows:

(1) Complex influencing factors. The factors influencing the technical and economic indicators of the planned routes include, besides the technology adopted, route characteristics, technical indicators, development degree of technology and equipment techniques, and national economic level, which all impose some impact on the project.

(2) Common small-marshalling train mode. Now, the basic marshalling for the route train adopting TR technology is 3 carriages, and the normative marshalling using ML system is also merely 5 carriages. Running trials of ML trains demonstrate that only the MLX01 train achieving 16 marshallings can realize the transport capacity of current new trunk lines. The marshalling of route trains demonstrated is basically designed within the range of small marshalling. Therefore, compared with the requirements for actual commercial operation of trunk transport heavy haul marshalling, the gap is still great.

(3) Short distance route enjoys more favor. The distance of comparatively mature maglev routes is basically within the scope of 100 km (German Munich Airport route, 37.4 km; American Baltimore route, 63 km and American Pittsburgh Airport route, 87 km). This is not only thanks to the high cost, but also due to the risks of maglev system. Choosing short distance route is propitious to evade risks.

(4) Visible function orientation of serving airport. Currently, the major function of all the planned routes of various countries is the trunk transportation system based on airport (i.e. Franz Josef Strauss Airport of German Munich Airport route, Baltimore–Washington International Airport of American Baltimore route, Pittsburgh International Airport of Pittsburgh Airport route, Schiphol Airport of Netherland Amsterdam–Groningen route, etc.). There are two reasons for this: one reason lies in that the construction of other passages in these developed countries has been comparatively mature, and it is hard to find the route with favorable demand foundation; the other reason is, the ticket price acceptance capacity of the passengers in airport routes is relatively higher than that of travelers in urban areas. The high speed of the maglev train enables its role as a transport passage to connect the traffic distribution centers to have become more evident.

(5) The impact of the public recognition on the traffic volume of the routes has not been taken into account as yet. According to the demand estimation, most routes use the existing estimated technical routes and parameters, and do not pay enough attention to the research of the public recognition to the new maglev technologies.

(6) Most routes stress the qualitative analysis in terms of the evaluation of easing up traffic jam, protecting ecological environment, improving indirect benefits like land development benefits. Conclusions of these aspects, to a great extent, determine the public recognition and acceptance degree of maglev system, thus affecting the actual traffic volume and further influencing the accuracy of the demonstration results of the route plans.

(7) Comprehensive economic effects are favorable while direct economic benefit is unoptimistic. Transportation benefits, land value, effect of ecological environment protection and effect of driving industry development are all the major components of comprehensive economic effects.

Through the researches above, integrating with current maglev technology research and development practice of China, this paper brings forth some policy suggestions as follows:

(1) The overall plan for research and development and application of maglev technology should be made at the national level. This plan shall include the development plans as to research and development of key maglev technology, project implementing technology research and development of maglev project, plans of building maglev passage based on

traffic demands, investment and financing system for the construction and operation of maglev system, research on implementing plans of high-density operational organization and maintenance of maglev route and so on.

(2) Study the application space of maglev technology at the planning level, in order to avoid potential duplication of similar projects. Now the construction of wheel-track railway, such as intercity railway, high-speed railway and passenger line, is in the ascendant in China; therefore, primary and systematic analysis are made and demonstration on the potential passages of maglev routes are taken into account making a comprehensive (maglev system) transportation plan with professional level for the future 5–15 years. On the basis of satisfying the traffic demands, demand space shall be reserved for the potential construction of maglev routes.

(3) Specifically study the measures for construction investment and operation subsidies for maglev routes. Now there has been a comparatively mature system as to subsidies for urban public transportation, and the operation subsidies have been brought into track. But generally, maglev route needs to stride across the regions under jurisdiction of different local governments, such as Huhang route has to stride across Shanghai Municipality and Zhejiang Province, Jingjin Route covers Beijing and Tianjin (even includes Hebei Province). In this case, how to determine the responsibility of each party from the aspects of investment and operational system, including the investment and management by the Central Government, still needs further research. The determination of these responsibilities to a certain degree, guarantees the foundation for demonstration procedures and scientific conclusion of maglev project from the aspect of the system.

(4) Make full use of the existing operational experience and data of Shanghai Maglev Route, and speed up the research as to major technology and operational practice of maglev route. The construction of Shanghai maglev demonstration route creates quite advantaged conditions for the application of maglev technology in China, and it itself is also a blessed advantaged condition for research and development of maglev technology of China. Therefore, to share and make full use of the experiences and technical data of this operational route at national level may promote the research and development progress of maglev technology in China.

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