Future Maglevs in China and Beyond

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Abstract
Shanghai maglev line shows that China will build more low cost maglev lines in future. A comparison of five designs tells the low cost is possible. Chinese engineers will fully utilize the NdFeB magnet to design their maglev and develop the most effective control system suitable for China and beyond.

1 High Speed Public Transportation Means in 21st Century

1.1 A Historical Perspective

Ground transportation speed has been increased dramatically since the invention of automobile in the beginning of last century. The performance of automobile improved from time to time. Now a safe, comfort, cost effective and energy save automobile has reached a quite advanced level. Due to the convenience of the automobile, most of the individual and average family owned one or several automobiles in industrial countries. Even in the developing countries, automobile is becoming the most important transportation means. In China, the economy is booming, automobile market developed rapidly. Following the fast growing automobile industry, the petroleum industry and highway building industry also expended rapidly. Unfortunately, no matter how wide the highway is and how fast the highway is building, the traffic jam always bothers people, and the air and noise pollution make people sick. Electric car is one of the choices to avoid such pollution, but still can not avoid the traffic jam. Human error on the operation also can cause the accidents just as bad as petroleum operated automobile. Therefore, peoples are looking for a better transportation means.

Scientists and engineers try hard to find out a better transportation means to meet the people's natural demand of fast and safe vehicle. In the early 20th of last century, somebody proposed to use vacuum tube to transport passengers, just as the vacuum tube widely used in the department store or big grocery stores to transport the payment and purchasing bills to the central accounting office, but never had a real application for transportation in the history. In 1930, a German engineer Hermann Kamper designed premature maglev. Unknown to many outsiders, in 1940, a young man in Shanghai published a paper by the title of " Flying Vehicle Dream " in his university publication and proposed to build such kind of transportation system in the mountain area like Chongqing because of the stiff gradient in that region, but never received sufficient support. In late 40th and 70th of last century, Professor Laithwaite of England published a book called "The Design of Linear Motor and Magnetic Levitated Vehicle" [1] and another book called "Transport Without Wheel" [2] after his successful research work.

He spent a great deal of his effort to persuade his government to adopt his proposal of building a demonstration track, but British government has no fund to support his project.

1.2 Recent Decades

In 1969, two American scientists James Powell and Gordon Danby patented their first maglev design using the repulsive levitation method. 1970, Railway Technology Research Institute (RTRI) of Japan National Railway (JNR) built a 7km test track, using superconducting magnet for levitation and superconducting linear motor for propulsion in Kyushu. The JNR's interest was for long distance high speed service. At about the same time, Japan Airline (JAL) was looking for an alternative transportation mode for potentially replacing short distance flights. Therefore Japan started the two types of maglev developments: long distance, long stator high speed maglev and short distance low speed maglev technologies. In 1972, JAL begin to develop HSST (High Speed Surface Transport) system and built a 200 meter test track using electrical magnet for levitation and linear induction motor for propulsion. Concurrently in Europe, the German Federal Ministry for Research and Technology has invested heavily and continuously on developing a long distance maglev since early 70th. The project and the system are named Transrapid and it has been a national priority project for more than 20 years from concept inception to application. It used electrical magnet for levitation and linear synchronous motor for propulsion. This is so-called the attractive levitation method. After several generations of test vehicles were developed and tested, eventually it reached 430 km/h at the Emsland Test Track in 1980's. Later, top speed of RTRI test vehicle has reached over 500 km/h. HSST concentrated on low speed urban transportation system with less than 200 km/h top speed. To a lesser extent, other countries like England, France, Switzerland, USA, Russia, Italy, China, Brazil, Korea, etc. also did their maglev research work during and after 1970. There was neither short of ideas nor enthusiasm. At the end, maglev seems to be the best choice. In the past few years we have seen the merging of technologies between the high speed regime and low speed ones. This is largely due to the application sites now tends to be city-to-airport or city-to-nearby-cities. Long distance maglev increasingly runs into too many environmental issues and too much investment to be committed at the onset. The coverage of long distance locations will be accomplished by sectional connections of more individual maglev projects. An exception will be the JAR maglev, which is designed for long distance only and will be developed in Japan as the main north-south line.

Escalating cost and the lack of political consensus finally ended the plan of building a Transrapid line between Hamburg and Berlin in Germany in 1999. In restoration, this project stoppage in Germany opened the way for Transrapid technology to be exported outside Germany. Many potential application sites around the world may now benefit from the German investment of maglev technology.

2 Shanghai Pudong Maglev Line Breaks the threshold for Maglev Deployment

2.1 The Pudong Airport Maglev Line

Planning to adopt a new area-wide modern transportation system for the entire Yangtze Delta Basin has been in place since the early 1980's. The Chinese government has selected matured German Transrapid system and built a demonstration line in the Pudong new district of Shanghai. One of the factors considered is the use of more concrete based guide way design in lieu of steel. If such a scheme is successful, then the total system cost will be reduced, particularly for China applications. The Shanghai Pudong Maglev Project is successful and thus becomes the first true application of maglev in the world. Not only residents of Shanghai, but also people all over the world who read the news about the first maglev commercial demonstration line in Shanghai believe maglev is workable. This is an important break through in the beginning of 21 century. It shows that maglev system could be accepted by those countries need.

January 1st of 2003, the "Flying Vehicle Dream" becomes true after 63 years in the same city of Shanghai! Passengers rushed in to buy the ticket but most of them could not get one, because the whole day tickets were sold out within first two hours early in the morning. However, the Shanghai application raises the question of the maglev future, particularly for China. It is obvious that there are more to be improved in terms of cost and simpler technologies, which in the end will cost less. This goal will be achieved by two means: development of total new maglev technologies and improvement of current technologies.

2.2 Technologies Now Under Development

US Congress passed the " Transportation Equity Act for 21 Century " in 1998, selected seven projects from seven states to participate in a one-year program of pre-construction study to identify the most promising project. Finally supported the project to develop low speed maglev in General Atomic Company of California and planned to build a commercial maglev line in the California University in Pennsylvania.

Starting 2000, the US Government has invested $ 37 million in addition to private investment of more than that amount to develop new maglev technologies. Basically with the basic technology improvements in the past decades, like Maglev2000 Company developed the so-called" second generation "of superconducting magnet maglev, General Atomic, Magplane, and MagneMotion companies developed the permanent magnet maglev, thus potentially reduced the capital and operating cost.

A joint venture group was formed for the application of a maglev system in Colorado, along the Highway 70 corridor ascending toward the Colorado Mountain where a 7.9 % grade is possible. This effort is still on-going with HSST technology as a base.
Another joint venture of maglev line is negotiating between Transrapid of Germany and US government.

China represents the most likely place for future joint venture applications because of its vast market and skillful firms.

3 Is Maglev Practical?

The advantages of maglev has been proved by the first commercial maglev demonstration line in Shanghai, but the cost to build this line and to operate this line are very high, most of the cities or countries could not afford to pay for it, so the high cost becomes the main stumbling block to promote this ideal technology. Chinese engineers try to modify the German maglev technology by adopting similar Chinese technology to reduce the cost. At the same time, several groups are working on different concepts to design new maglev models such as high temperature superconducting magnet maglev, new concept of permanent magnet maglev design, etc. Other countries also may have some new ideas of low cost maglev designs.

A table of comparison of five maglev designs is provided in APPENDIX B.

From this comparison, three American designs show the promise to reduce the cost substantially over the current technologies. This is accomplished by reducing the speed and size of the vehicle so that the guide way size and weight also reduced. This is obvious benefited from the recent fact of merging high and low speed maglev needs, It is without the historical burden of being developed for high speed and now to be refitted in a low speed environment. Furthermore, the frequency of the vehicle in service to match the variation of passenger flows in a day is increased. The size of the vehicle has been designed like an ordinary bus, therefore, the headway can be short, the number of vehicles on the one track at the same period of time could be much more than that of large size vehicle has long headway, the capacity of total passengers carried by the small size vehicle with short headway could be the same or even larger than large size vehicle with long headway, and the waiting time would be short, which makes the passengers happy. All these three designs are in the developing stage and all have a test track ready to build. They are vigorously pursuing the full test of the system in the next year or so.

4 Features of Maglev Application in China

4.1 Demands of Maglev in China

The basic requirements of the modern transportation system in China should be highly reliable, safe, comfortable, quiet, and pollution free. Maglev would be an ideal choice to meet these requirements. Therefore, a cost effective locally produced maglev system would become widely adopted transportation system in 21 century in China.

The vast territory and fast developing economy of China needs two kinds of maglev systems: speed below 160 km/h maglev suitable for urban and inter cities transportation; speed up to 500 km/h maglev suitable for long distance main line transportation. The huge population of China, especially in big cities, need maglev to solve the congestion of public transportation problem badly, the bus size maglev vehicle would be welcomed by all passengers in the cities, especially the safety, quiet, and pollution free features of maglev are superior to the ordinary bus and light rail train. This so-called low speed maglev actually has 160 km/h, which is at least double the speed of ordinary bus, passengers would be satisfied by this speed, and since maglev travel on its own guide way, don’t have to worry about the traffic jam of automobiles, so the traveling time could be guaranteed.

The high speed maglev is necessary to shorten the traveling time of long distance travel. The special feature of the high speed maglev is unbeatable, much faster than high speed train, much safer than airplane. The cost of high speed up to 500 km/h maglev would be higher than the low speed one, but if we design the medium size vehicle, single car run with short headway, still could reach the same capacity of passenger carrying as Transrapid in the same period of time but the cost of building and operating the system could be cut down dramatically.

4.2 Locations of Maglev in China

A " Schematic Diagram of the High-Speed Passenger Network in China " in the paper presented to " The 7th International Conference on Application of Advanced Technology in Transportation, Aug. 5-7, 2002 " by the Chinese delegation is provided in APPENDIX C. The diagram is their suggestion of high-speed maglev passenger network in the first half of 21st century, total length reaches 8000 km. The first demonstration line already built in Shanghai, the second one might be in Beijing to serve the Olympic 2008, the third one might be in Shanghai again to serve the World Fair 2010. The extension of maglev line from Shanghai to Hangzhou, or from Shanghai to Suzhou, Wuxi, Nanjing, or from Beijing to Tianjing, to Baoding, Shijiazhuang are all possible. From Guangzhou to Shenzhen, Hongkong and Zhuhai are all proper. Besides, Chengdu, Shenyang and other cities are also interested. Any city which has dense population and affordable economical capacity is a potential user of low speed maglev system. However, the cost to build and operate the maglev system must be cut down. If the cost could be close or below that of light rail train, all these cities would be happy to build the maglev.

It is wise to build the low speed below 160 km/h small vehicle maglev system for the urban or inter-cities short distance line first. After certain period of service, accumulated enough experience of practical operation, then get into the second step to build the high speed 500 km/h long distance line to fully utilize the special features of the maglev.

5 Strategies of Maglev Application in China

5.1 Low cost

The technology of maglev has been proved to be very reliable, but to promote it largely depend upon the economical feasibility. Before building the maglev, sufficient money to do the research work is necessary. Professor Laithwaite of England didn't get fund to build the test track, his beautiful research work had to stop. The person with " Flying Vehicle Dream " exhausted his limited fund, had to cut his project of making linear induction motor for weaving machine to replace the mechanical operation in 1949, he proposed two times to start the maglev research project in 1973, but no fund was granted. German Government spent a lot of money to support Transrapid and Japanese companies got enough fund to carry on maglev research work for a long time, and they both got great success. Their technology both reached in a mature stage many years ago, but up to now no one commercial maglev line was successfully in operation, German had to shut down the operated for a period of time maglev line, because the operating company didn't want to lose more money. It is a sad story, German engineers did such a good job, but both building cost and operating cost were too high Therefore, China must find out a much more economical way to promote their maglev network envision.

5.2 PM Utilization

There are three kinds of magnetic forces to levitate and push the vehicle of maglev system, namely:

electrical magnet, superconducting magnet and permanent magnet. German use electrical magnet for Transrapid maglev satisfactorily, Japanese use superconducting magnet for Kyushu 7 km maglev test line successfully, so as Maglev2000, and American use permanent magnet for three projects all very happy. China possess 80 % of rare earth natural resources in the world, Chinese NdFeB permanent magnet has the best quality and lowest price. Naturally, using NdFeB permanent magnet to develop maglev in China is the most favorable choice. China would be willing to learn from or cooperate with the companies already engaged in the permanent magnet maglev research work to adopt or modify their designs to build urban or inter-cities maglev lines.

NdFeB permanent magnet was invented in 1984, when the person had "Flying Vehicle Dream "attended the symposium to discuss the suggestions of maglev concepts in Saratoga Springs, NY in Aug. 23, 1991, he suggested to use NdFeB permanent magnet to develop maglev, but no body paid attention on this suggestion, because at that time all suggestions presented in that symposium were superconducting magnet for maglev research works. At that time, the highest magnetic strength of NdFeB PM was only 30 MGOe, now, new product of 50 MGOe is available in the market. If use 50 MGOe grade PM instead of 40 MGOe ones, which all these three companies in USA adopted, the amount of magnet used could be reduced and the weight of maglev vehicle could be decreased, so as the guide way structure. But right now, the price of high grade magnet is high, and the overall cost should be carefully evaluated. The price of high grade PM would eventually drop down when the possible higher grade of PM is developed. So this kind of study should always keep in mind.

5.3 Technology of Maglev:

Magnet for levitation, linear motor combined with magnet for propulsion, guide way for bearing the weight and guide the direction of the vehicle are well known by the electrical, mechanical and civil engineers. One can chose electrical magnet, superconducting magnet or permanent magnet for levitation, linear induction motor or linear synchronous motor combine with any kind of magnet for propulsion, and let mechanical engineer and civil engineer work together to design the guide way. Mechanical and electrical engineers need to work together to design the vehicle. The demonstration line built in Shanghai is a good "school" for Chinese engineers to digest the technology as a start, many maglev lines would be built one by one to fulfill the diagram shown in APPENDIX C.

China already has a strong team of engineers in maglev research field, other than the Shanghai " school ", they are learning more from German and Japan technologies because their experience and valuable information are priceless. Eventually, China will master every detail of all maglev designs in the world, and develop their own technology, create a Chinese standard of maglev technology, to be used by every maglev line in every where, so that to set the basis of connecting the separated local maglev lines together to become a perfect network. China will encourage the new ideas of maglev designs. May be someday they will pick up the low vacuum tube concept to reduce the air resistance and speed up the maglev vehicle in the tube.

6 Control System

To operate maglev smoothly without any problem, it greatly relies on control system. A successful maglev design should have the following control mechanisms:

(1) The levitation height should be automatically adjusted to maintain the constant air gap when the load of the vehicle varies.
(2) The vehicle could move to required position precisely with reasonable speed in normal operating condition.
(3) The vehicle would move forward, backward, or stop according to the command of higher-level central control station.
(4) If there is no more safety headway available for next movement, the vehicle would not move further. Having this feature, it becomes quite safe to exit from high speed guideway to station or merge into high speed guideway because it would eliminate any possible human operating error.
(5) The vehicle would keep the high speed movement if the guideway condition allowed.
(6) The vehicle could apply brake smoothly without uncomfortable damping at any time if received "stop" command from either its higher-level controller or the on-site operator's emergency control.
(7) The vehicle could start move under trained operator command or could be operated by ordinary people only if it was absolutely safe to move.
(8) The vehicle would stand still while passengers were moving in or out.
(9) Central control station could automatically rearrange the frequency of the vehicles based on the real-time status report of each vehicle.

In order to achieve the above requirements, each vehicle can only move within one section of the guideway. It would not travel to the next section unless get permission from that section. This is easily performed by programming the sequence of the power supply to the linear motor primary of each section. The software is designed to control the whole chain of vehicles on the same guideway, so that just in case an accident happened on certain vehicle or section, the nearby sections would respond immediately by status report in real-time.

Use linear induction motor (LIM) for propulsion, the cost of the guideway is relatively low. However, the primary of the LIM has to be placed on the vehicle, makes the system more complicated. In order to supply the electricity into the moving vehicle, it has to install the bus bar along the guideway and use trolley on the vehicle to collect electricity from the bus bar. Therefore, the mechanical contact between the trolley and bus bar will cause wear and need frequent maintenance. The primary of LIM on board the vehicle makes the vehicle heavier so the guideway structure should be strong enough to bear the fast moving heavy vehicles. Besides, the LIM has
slip, it is very hard to position the vehicle precisely.

Use linear synchronous motor (LSM) for propulsion, the cost of guideway is relatively higher than that of LIM, but the accurate position sensing and braking control is largely simplified. This feature makes it possible to operate with only a few seconds of headways between vehicles. Due to the light weight of the vehicle, the guideway structure is also low in cost. The over all cost might be less than that of LIM system and the convenience of the control makes the LSM more favorable.

The challenge is to operate the maglev vehicles with minimum energy consumption while moving efficiently without compromising the safety. Real-time status will be reported to central control station while the vehicle itself also has safety control mechanism. If any unexpected thing happened, the vehicle would react quickly and effectively to stop the vehicle because of the precise control to the LSM.

With cleaver design, the energy loss due to the braking process can be re-used for other purpose; therefore, the energy consumed for the braking process will be less than conventional transportation vehicles. The most energy consumption for the modulated LSM system happens only when vehicle passed by. Energy can be saved greatly through precise management of the power supply. Further more, since the gear train and wheel-rail interaction consume the most of the energy, LSM system energy loss for the propulsion is expected to be about 90% less than comparable wheel-propelled vehicle with comparable motor and inverter losses.

Air gap is the decisive factor for designing the control system. The bigger the gap, the easier the control system could be designed. Small air gap will costs a lot more for the control system.

7 Conclusion

The world first commercial demonstration maglev line already built in Shanghai at the beginning of 21^{st} century. It proved maglev is fast, safe, quiet, comfortable and pollution free. Eventually, the Schematic Diagram will become true in China. First step after the demonstration line is better to build the low-speed (160 km/h or so) short distance (200 km or less) urban or inter-city maglev lines to serve the big cities need it badly. Gradually spread to other cities. Then go to the second step to build the high-speed (500 km/h or so), long distance (over 200 km to 1500 km) main lines to shoulder part of the increasing burden of railways and airlines and make the travel fast, safer and cheaper. China will be the first country in the world build numerous maglev lines in the near future and their mature technology would eventually export to the countries beyond China in this century.

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APPENDIX A.   Further Strategic Considerations

1. Maglev for freight transport first

Freight transport is always more profitable than passenger transport because the vehicle design could be simpler and don't have to meet all kinds of human necessities. It also doesn't have to face complains from the passengers. The freight fee is a very small portion of the goods' value of the whole container. The owner of the goods only concerns the goods delivered to the destination safely and on time, some express delivery goods especially emphasize to guarantee the time of delivery exactly, but pay very little attention to the freight expenses. Railway transport for goods has lower price, but run according their own schedule, usually slow. So the big truck transportation business took over a great part of the freight transport. However, every truck needs a driver. Human error could cause accident and a great loss. Once the truck driver's union announces a strike, the whole system becomes paralyzed. If we use the low speed light maglev to do the freight transport business, the advantage of fast, safe, much less interruption by any reason, are superior to any other means. Owners of goods just load the container on the maglev flat top vehicle and get to the destination exactly on schedule.

This kind of maglev can also be used to transport the automobiles into or out from the big cities, where always have very heavy car jams on the highways especially in the rush hours of every morning and afternoon of working days. Car owners just drive the car on to the flat top of the maglev vehicle, sit in the car to relax instead of the stressful period used to be to pass the busiest district and then drive away freely.

Freight transport business always has ample supply of goods or cars. The same maglev can be used for both containers and cars. We can schedule the rush hours for cars only and other time for containers. The steady flow of operation would guarantee the business to make money.
After enough experience of operating the freight transport business, then step into the passenger transport business may be easier.

2. Linear Drive Module is the Basis of Successful Maglev Business

Linear synchronous motor (SLM) for propulsion of maglev is more favorable for control system. If we design several sizes of SLM standard blocks and levitating standard moving blocks to match them, and put into mass production, could reduce the cost significantly. Connect the standard SLM blocks together can make a track of any length. It can be used for maglev system also can be used for conveyer or elevator of any industry or military, like to convey the ore from the mine, transport artillery shell from the store room up to the deck of the war ship, to replace the traditional elevator and save the space and weight to store more shells also much faster and accurate than the traditional elevator. It can also be used to launch certain objects such as torpedoes and missiles tosave the fuel or maintain the same amount of fuel to make them more powerful. Another important use could be moving hazardous materials or extra heavy pieces to the fixed destinations by remote control to avoid the human risk. Maglev has no mechanical contact between the moving and stationary parts, do not need too much maintenance. All other carriers always have wears of the mechanical parts because of friction, so that need to have frequent maintenance.

3. Guide Way Design Has a Lot To Be Do Done

Current guide way designs are quite advanced but not perfect especially for changing the track. If use repulsive type of magnetic levitation or try to place the levitating unit inside of the two guide tracks instead of the outside of the one single track just like the railroad do, the changing track problem would be solved easily. It is of course not easy. Eventually, somebody would find out a much better way.

4. Strategic Plan

German government spent a great deal of money to support the Transrapid project for a long time, because they believe maglev is a rising new technology. Japan projects got ample of financial support, because they know this new technology would increase the economical growth pace and make money itself in the long run, so they were willing to invest so much money for the research work. It was understandable that China had no economical capability to support maglev research work in 1973. However, she has become the first country in the world to build a real commercial maglev line. It reflects China possesses far sight strategic mind in Maglev project. Chinese government has already drawn a beautiful picture of future maglev network. We believe if this strategic plan would become true, it would greatly improve not only Maglev industry but also lots of other related industries. We hope we would see a break down of yearly plan of maglev research, develop works and maglev building steps just like other great projects such as the Three Gorges Dam, water transporting from south to north, natural gas piping from west to east, etc. China would not miss any chance of leading or synchronizing the world science and technology like two score years ago.

Chinese science and technology had led the world few centuries ago. She would do that again.

APPENDIX B. Comparisons of Five Maglev Designs

ITEM	TRA [3]	HSST [4]	MP [5]	GA [6]	MM[7]
Levitation	**Electrical EMS**	**Electrical EMS**	**PM for low SM for high speed EMS induced in AL sheet by moving magnets**	**PM Halbach Array & Litz track, EDS**	**Electric coil control PM EMS**
Propulsion	**LSM long primary on track**	**LIM short primary on vehicle SS trolley, collect E from AL bus**	**LSM long primary on track**	**LSM long primary on track**	**LSM long primary on track**
Guidance	**Electrical**	**Electrical**	**E induced by moving magnet in AL trough**	**PM Halbach Arry**	**Electric coil control PM**
Speed Max	**500 km/h**	**180 km/h**	**402 km/h for high speed 250 km/h for low speed**	**160 km/h**	**160 km/h**
Average	**300 km/h**	**60 km/h**		**50 km/h**	**100 km/h**
Vehicle Size	**27x3.7x4.16 m**	**14x2.6x3.45 m**	**16x3.3x3.6 m**	**12x2.6x3 m**	**9x2.7x3 m**
Grade	**10 %**	**40 degrees**	**10 %**	**> 10 %**	**30 degrees**
Turn Radius	**650 m**	**25 m**		**18.3 m**	**18.3 m**
Passenger Capacity	**100x5=500**	**110x3=330**	**140 for high speed, 36 for low speed**	**100x4=400**	**36x1=36**
Vehicle Weight Empty	**45x5=225 T**	**15x3=45 T**	**45 T for high**	**9.5x4=38 T**	**5.5x1=5.5 T**
Full				**16.5x4=66 T**	**8.5x1=8.5 T**
No. of Vehicle/Train	**5**	**3**	**1**	**4**	**1**
Track Composition	**Steel beam with LSM laminated sheet steel core**	**Steel beam with AL plate**	**AL trough and steel beam with LSM laminated sheet steel core**	**Steel beam with LSM laminated sheet steel core**	**Steel beam with LSM laminated sheet steel core**
Electricity Supply	**Copper coils Of LSM**	**AL bus bar with SS trolley**	**Copper coils of LSM**	**Copper coils of LSM**	**Copper coils of LSM**
Air Gap	**10 mm**	**8 mm**	**100 mm for high and50 mm for low speed**	**25 mm**	**20 mm**
Cost(Track & Vehicle)	**$ 40 M/km**	**$ 40.5 M/km**	**$19.3 M/km**	**$ 20 M/km**	**$ 12,5 M/km**
Headway	**10 minutes**	**3 minutes**	**20 seconds**	**1 minute**	**4 seconds**

APPENDIX B. Comparisons of Five Maglev Designs (continued)

ITEM	TRA [3]	HS ST [4]	MP [5]	GA [6]	MM[7]
Waiting Time	10-20 minutes	5-10 minutes	40-50 seconds	2-3 minutes	20-30 seconds
Passengers /Direction	3,000 / h	3,600 / h	25,000 / h	12,000 / h	12,000 / h
Acceleration	1 m / s^2		1 m / s^2	1.6 m / s^2	2 m / s^2
Power Required	1,000 W / T		250 W / T		100 W / T

ABBREVIATIONS: **TRA—Transrapid, HSST—High Speed Surface Transport, MP---Magplane, GA---General Atomic, MM---MagneMotion, E---Electricity, T—Ton, EMS---Electromechanic Suspension, EDS---Electrodynamic Suspension, LSM---Linear Synchronous Motor, LIM---Linear Induction Motor, h---Hour, PM---Permanent Magnet, SM---Superconducting Magnet, AL---Aluminum, SS---Stainless Steel, m---Meter, km---Kilometer, M---Million, W---Watt, g---Gravity, m / s^2---Meter per Second Square**

APPENDIX C. Schematic Diagram of the High-Speed Passenger Network in China [3]