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An Evaluation of Maglev Technology and Its Comparison With High Speed Rail

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Abstract
High speed rail (HSR) systems have a proven record of efficient services in about a dozen countries. Recently, Magnetic Levitation (Maglev) technology for high speed ground transportation (HSGT) has been proposed for many intercity and regional lines in Germany, Japan, United States, and other countries. Maglev developers claim that their system can achieve higher speeds, have lower energy consumption and life cycle costs, attract more passengers, and produce less noise and vibration than high speed rail. This article presents a systematic comparison of the proposed Maglev system, specifically the German Transrapid, and high speed rail systems.

The analysis reaches the following conclusions on the three most important system characteristics. First, recent developments of HSR have reduced the advantage of Maglev in higher speeds, so that the differences in travel times on typical interstation spacings would be small. Second, high speed rail has a huge advantage over Maglev due to HSR's compatibility with existing rail networks. Third, high speed rail involves a lower investment cost, while operating costs on Maglev are still uncertain. Energy consumption is estimated to be lower for high speed rail. All other features, like riding comfort, system image, grade climbing ability, noise, etc., are not significant enough to make one mode superior to the other. Thus the benefits of high speed rail strongly outweigh Maglev's small travel time advantage. Based on this conclusion, the soundness and direction of US federal policy of investing in Maglev systems while neglecting high speed rail and Amtrak is questioned.

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Any proposal for an entirely new transportation mode requires a thorough system analysis that must address, among others, the following questions:

1. Is there a demand for the new mode?
2. Is the proposed new mode feasible, and shown to be operationally ready for implementation?
3. What is the current state of existing modes serving this demand?
4. Does the proposed mode as a package of benefits and costs improve upon the current modes?

The purpose of this article is to analyze a proposed new mode of guided high speed ground transportation (HSGT), Maglev, and evaluate its technical, economic, social and other aspects. The need for high speed ground transportation modes is discussed in the following section. To provide the relevant background and needed understanding of issues involved in introducing a new mode of

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transportation, the developments in high speed ground transportation are presented. Two sections focus on present status of high speed rail networks and speeds, and Maglev transportation system development. This leads to the next section with the very important comparison of Maglev with high speed rail systems, including technical, operational and network/system aspects of these two transportation modes. Lastly, a review of US federal policy with respect to high speed ground transportation is presented.

This article draws heavily on previous research work evaluating the proposed Baltimore—Washington Maglev System[1] presented in an unpublished report by this paper's prime author.[2] This original report led to substantial debate on the viability of Maglev systems.[3]

HIGH SPEED GROUND TRANSPORTATION

The Increasing Need for HSGT

The need for high speed ground transportation systems has greatly intensified in recent decades. All industrialized countries have faced two serious transportation problems in urbanized regions and in major intercity corridors. First, highway and street congestion have become a chronic problem, causing longer travel times, economic inefficiencies, and deterioration of the environment and quality of life. Second, congestion problems are occurring at airports, with similar high user and social costs.

Under these worsening transportation conditions, high speed ground transportation has emerged as a vital concept. HSGT is by far the most efficient means for transporting large passenger volumes with high speed, reliability, passenger comfort, and safety. While highway and air traffic consist of thousands of vehicles driven by individual drivers following mostly advisory traffic control devices, high speed ground transportation is a physically guided system on fully controlled ways with fail-safe electronic signal control. This provides not only an order of magnitude higher safety but also reliable operation even under capacity conditions.

While high performance and environmental compatibility are necessary features of HSGT, the high speed is critical in determining the optimal role of this mode. Conventional railways operating with maximum speeds of 100 kilometers per hour—km/h—(in the US, with the exception of the Northeast Corridor, maximum speeds are still limited to 125 km/h only) cannot compete with freeway travel in the same corridors. Similarly, because of the speed restrictions on high speed rail, air travel dominates on distances exceeding 300-400 km. Thus, railways were losing their market, except when highway congestion, restricted parking or other factors made travel by other modes very inconvenient.

The Importance of High Speed and Its Optimal Values

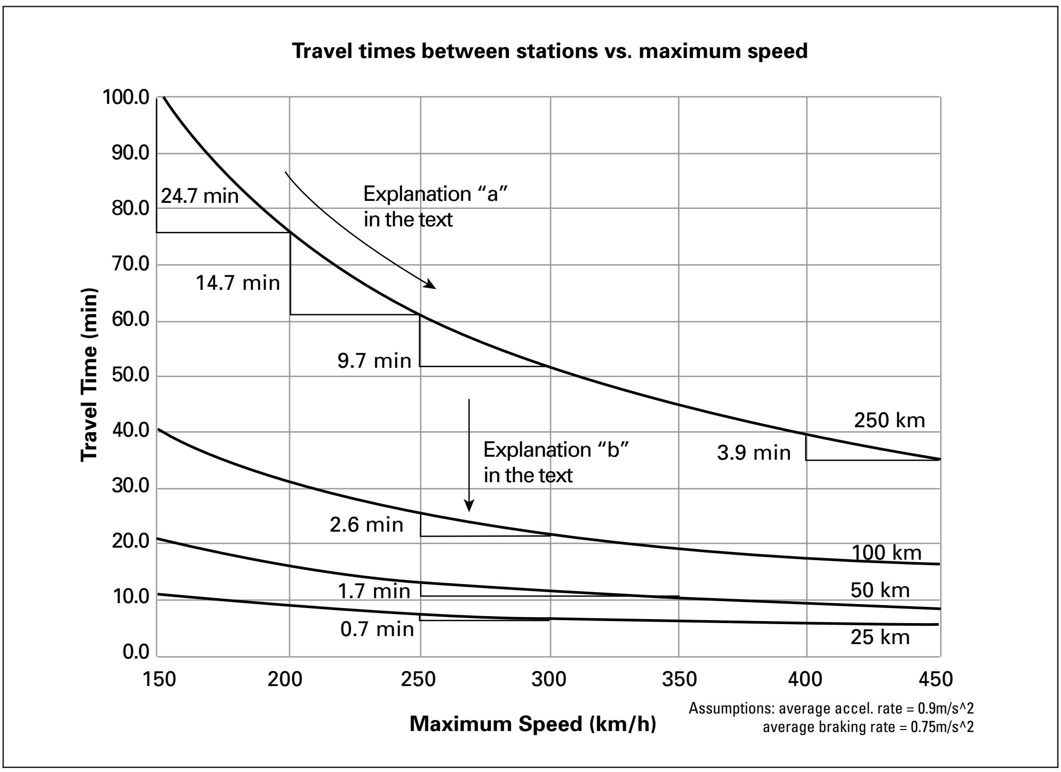
One of the goals in building HSR systems has been to increase the domain in which railway is the superior mode not only in convenience but also in speed or travel time. This goal has been successfully achieved in many locations. The introduction of the first Train a Grande Vitesse (TGV) on a new 417 km long line between Paris and Lyon in 1981, resulted in switching most of the air travel on this link to TGV.[4] Developers of the German Intercity Express (ICE) set the goal that high speed rail should offer average travel speed twice higher than the car and half as high as air travel (including the advantage of railway in center city delivery, instead of remote airports). The introduction of an electrified line with Acela trains is expected to divert many trips between Boston and New York from air to Amtrak. Based on these advances of high speed ground transportation in increasing its optimal domain, it is now considered the range in which it can have a dominant role is between 100 and 1,000 km, depending on the relative speed of high speed ground transportation and its competitors in a given corridor.

Reducing travel time is critical to its success. However, the limits to which top speeds should be increased deserves careful scrutiny:

a. **Increases in maximum speed have decreasing marginal gains in travel time savings.** As illustrated in Figure 1, on a 250 km long interstation distance an increase in maximum speed from 150 to 200 km/h reduces travel time by 24.7 minutes; from 200 to 250 km/h saves another 14.7 minutes. A further speed increase from 250 to 300 km/h saves only 9.7 minutes. If maximum speed would be increased from 400 to 450 km/h, the gain would be only 3.9 minutes. This shows that for any given distance, the marginal value of increasing the maximum speed results in decreasing travel time savings. In other words, the speed increase from 200 to 250 km/h is much more effective than an increase (hypothetically) from 400 to 450 km/h.

b. **Travel time reductions due to higher speeds depend very much on the length of run between stations.** This is also shown in Figure 1. For example, if maximum speed is increased from 250 to 300 km/h, travel time will be reduced by 9.7 minutes on a 250 km long run; the same speed increase would bring only a 2.6 minute travel time saving on a 100 km long run, and a negligible saving of 1.7 minutes on

Figure 1: Impact of Increases in Maximum Speed on Travel Times for Different Station-to-Station Distances



a 50 km long run. This shows that the benefits from high speeds are great on long interstation distances but very small or negligible on short distances.

c. **Marginal cost of increases in maximum speed (in system design, construction, operating costs, etc.) grows more than proportionally with speed.** In addition to increased precision required in guideway and vehicle design, energy consumption increases with the speed due to the exponential increase of air resistance.

To summarize, the cost-effectiveness of investments in designing higher speed systems decreases as the maximum speed grows.

These facts show that the optimal domain for high speed ground transportation systems is on long interstation lengths, such as 100 km. On shorter distances, the gains in travel time are so small that it is difficult to justify the high investment. For example, very important and functional lines between center cities and airports (Frankfurt, Zürich, and London-Heathrow are outstanding examples) may not be candidates for HSGT (as proposed for Pittsburgh, Baltimore, Munich, and Shanghai), because they require much higher costs and bring very little additional benefit, regardless of technology.

d. **It is also important to emphasize that with respect to maximum speed there are two very different concepts:**

—Maximum experimental speed for any transportation system technology is the speed reached under specially planned and arranged conditions, for which the guideway, power pickup, signals and vehicles are specially equipped; the test is usually done under special operational arrangements, safety precautions, etc.

—Maximum operating speed is the speed for which the system has been designed for regular, daily operation under normal conditions. The entire system—its infrastructure, vehicles, controls, reliability, etc., must be designed so that this speed can be operated on a daily basis, withstanding the handling of passengers, reasonable weather variations, and operated by qualified personnel (but not an entire team of specialists supervising and intervening in every minute of system operation).

Maximum experimental speed is very important for evaluation of the system's characteristics and potential for development. However, it is the maximum operating speed that defines actual, achievable performance of the system. The difference between the two is quite large: maximum experimental speed may be as much as 50-80% greater than the maximum operating speed. Consequently, it is very important to distinguish these two speeds, and in comparing different systems, to always compare the two corresponding speeds. Comparing the maximum experimental speed of one system to the maximum operating speed of another system is false and highly misleading.

DEVELOPMENTS OF HIGH SPEED RAIL

A brief review of the development of the high speed rail transportation systems, the only technology currently used for high speed ground transportation, is given here. Through these years of extensive developments, high speed rail has been defined as rail systems providing regular services at speeds exceeding 200 km/h.

Developments in Different Countries Since the 1960s

Japan built the first high speed rail system, and thus initiated the concept of high speed ground transportation, when it opened the first Shinkansen Line in the Tokaido Corridor (Tokyo-Osaka) in 1964, with cruising (operating) speed of 210 km/h. This

Shinkansen Line was later extended to Fukuoka, including a tunnel between the islands of Honshu and Kyushu, with a total length of 1,079 km. The operating speeds have been raised, through improved infrastructure and rolling stock, to 240, 270 and, finally, 300 km/h. This line carries more than 400,000 passengers per day.

Progress in extending and further improving the Shinkansen is continuous. Shinkansen-type trains, which are somewhat smaller size and lower speeds, have been introduced also on some narrow-gauge lines (1.067 meters); double decker cars have been successfully introduced; new lines are being built; and speeds of 350 km/h are being designed. These lines have a reputation for high reliability, comfort and safety, and have operated for decades without a passenger fatality, despite the extremely high passenger volumes.

France opened its first TGV line between Paris and Lyon, 417 km long, in 1981. The line attracted high ridership from the beginning, including many previous car trips, newly generated trips, and the majority of airline trips on this intercity corridor. Cruising speed on this line has been 270 km/h.

In the following years, TGV Atlantique was built from Paris to the southwest, then to Lille in the north and the Channel Tunnel. Extension from Lyon to Marseilles on the Mediterranean Coast was opened in June 2001, with maximum operating speeds exceeding 330 km/h.

Germany was several years behind France in opening its first high speed rail line in 1991, ICE, between Hannover and Würzburg with a maximum operating speed of 250 km/h. However, Germany was the leader in upgrading a number of existing rail lines to the speed of 200 km/h, at a much lower investment than new high speed rail lines require. Although with less publicity, many lines in Germany have been operating at this speed since the 1980s.

Several new lines have been opened or are under construction in Germany, including Mannheim-Stuttgart, Frankfurt-Cologne, Berlin-Hannover, and Berlin-Hamburg.

Italy, Spain, Belgium, Sweden, The Netherlands, Taiwan, Korea, and several other countries have also been active in this field with some lines in operation in the former five countries, and some under construction in the latter two.

The United States has given much less attention to high speed rail than most of its peers. Similar to Great Britain, the government and Congress consider minimizing operating assistance to intercity passenger railroad services (Amtrak) more important than maximum passenger attraction. The imposed requirement by Congress on Amtrak to achieve economic self-sufficiency by 2003, has forced Amtrak to introduce extremely high fares. These fares prevent attraction of many trips from highways, where no self-sufficiency requirement is imposed.

The first high speed rail system in the United States, Acela in the Northeast Corridor, has been introduced only recently, in 2000. This progress is, however, only *upgrading of an existing line,* and that is happening decades after Japan, France, Germany, and other industrialized countries opened their first *entirely new high speed rail lines.*

Amtrak's Acela is the first high speed rail system introduced in the United States. Source: Amtrak.

High Speed Rail technology: French TGV train, Paris-Lyon. Source: F. Dechamps.

Present Status of HSR Networks and Speeds

In summary, high speed rail lines have been operating for 38 years with excellent efficiency and safety. Initially opened as individual lines, HSR has grown since the 1980s into networks with more than 1,000 km in Japan and a European system with integrated lines between France (with the Channel Tunnel to Great Britain), Switzerland, Germany, and Belgium. With many lines under construction, high speed rail will in a few years also connect Sweden, Denmark, The Netherlands, Italy, and Spain. They have been remarkably successful in attracting passengers and improving economic efficiency. Basic compatibility of all these rail systems is a fundamental feature for construction of this integrated international network of high speed ground transportation lines.

As noted above, maximum operating speed is the most important element of high speed rail, and its phenomenal progress in the world's most developed systems requires some elaboration. Test runs during the 1960s and 1970s gradually increased maximum experimental speeds from 250 to 350 km/h. A major breakthrough happened in Germany in 1988, when an ICE test train achieved 406 km/h. This was followed by another leap in the speed record in 1991, when on an experimental run, a TGV train established the record speed for rail systems of 515 km/h! Maximum operating speeds, achieved by hundreds of trains daily in several countries, are now in the range of 250 and 300 km/h, with the French TGV system recently achieving an average speed of 317 km/h on a 1,000 km run.

MAGLEV TRANSPORTATION SYSTEM DEVELOPMENT

Since the 1960s, more than 100 new guided transportation systems have been proposed as concepts, and several dozen of them have been physically developed and tested. As in every research and development process, many of these concepts were unrealistic and infeasible, but a few have progressed to full development and successful implementation. Examples are the ALWEG Monorail (Seattle, Tokyo, and several other Japanese cities), Westinghouse C-100 People Mover (in many airports, Downtown Miami), MATRA's VAL system (Lille, Toulouse, Chicago O'Hare Airport), UTDC's Skytrain (Vancouver, Toronto—utilizing Linear Induction Motors—LIM, similar to Maglev systems), and several others.

Magnetic Levitation (the Maglev transportation system) is another new technology for guided transportation systems with strong public appeal because of its unique feature: the vehicles are supported as well as propelled by magnetic forces, so that there is no physical contact between wheels and guideway surfaces. A brief history of Maglev developments is presented here.

Maglev for Urban Transportation

Research and development of Maglev transportation systems started in Germany around 1970, and it produced two systems: an urban transit system, Transurban, and an intercity high-speed system, Transrapid.

The Transurban system was believed to be ready for application and the government of Ontario contracted its manufacturer in 1973 to build a line in Toronto. However, after construction had started, the system faced technical problems in test operations, including difficulties with vehicles negotiating curves. The specifications of the system could not be achieved, and the project was cancelled.

Another version of an urban transit system utilizing Maglev technology was more successful. The M-Bahn system, also developed in Germany, was built and successfully operated on two short lines, in Berlin and in the airport of Birmingham, England. Both systems were later dismantled for nontechnical reasons.

Intercity Maglev Developments in Germany and Japan

Transrapid development proceeded because Maglev operating features are more effective when applied to high speed than to low- and moderate-speed transportation systems. Strongly encouraged and financially supported by the German government, Maglev has been researched and developed through a succession of models, presently reaching the eighth generation—Transrapid 8. A full-scale, 30 km long oval test track has been built in Emsland, Germany, where thousands of train runs have been performed, proving physical feasibility of this new system. It has also reached the maximum speed of 436 km/h on a test run, and it is claimed that the limiting factor was the length of the test track. The test facility has been open to visitors for many years, with thousands of persons having ridden the Transrapid system.

During the last 20 years there have been efforts to implement the Transrapid system. Numerous proposals were made in Germany for various new intercity lines, but the most serious proposal was for a new Berlin-Hamburg line.[5,6] The alignment and station locations were selected and the design was prepared in great detail. After eight years of intensive planning, design, and discussions of impacts and costs, a final evaluation was made of the entire project, including a comparison with high speed rail technology. The project was faced with escalating infrastructure cost estimates, increasing project complexity, decreased ridership projections, and lingering questions regarding the advantages of Maglev technology over HSR systems.[7,8] In February 2000, the decision was made to cancel the Maglev project and build the Berlin-Hamburg line with high speed rail technology.

The cancellation of the Berlin-Hamburg project raised various points and a question: this 292 km long line has a length where Maglev could fully utilize its high-speed performance, it connects the two largest German cities with intensive travel, and it can use an alignment without many obstacles. If Maglev is not feasible for that line, is there any potential for it in Germany?[8] Yet, Maglev promoters called for the allocated DM6.1B (US $3B) federal funds to be used for Transrapid demonstration projects at other locations. Among numerous proposals, two have become “finalists”: a 37 km long line in Munich, from the railway station in center city to its recently opened airport, and a 78 km long “Metrorapid” line from Düsseldorf to Dortmund, serving cities in the Ruhr area. The debate about these projects includes diverse views. Promoters expect benefits for

Maglev technology: German Transrapid train.
Source: Maryland Mass Transit Administration.

the German industry and potential for export; critics challenge the purpose of building Maglev on the lines where its high speed capabilities bring little advantage over the parallel railway lines at an extremely high investment and uncertain operating costs.

In addition to these serious technical studies and projects, there has been an intensive publicity campaign aimed at showing Transrapid applications in dozens of corridors around the world. Lists were published identifying 28 corridors in the United States alone, with a total length of 16,311 km as "candidates" for Transrapid. The potential export market was one of the arguments used intensively in Germany to secure government financing for system development and later implementation. Interestingly, a strong argument used by Maglev promoters in the US to get federal funding was that this system would have a strong export potential for US industry.

Research and development of Maglev technology in Japan dates as far back as 1962, but major efforts to develop a high-speed Maglev system began in the 1970s. The technology is somewhat different than the German Transrapid: the Japanese model utilizes superconductivity and the vehicle-guideway design is based on repulsive magnetic forces, while Transrapid uses attracting magnetic forces. The repulsive suspension technique is inefficient at low speeds, so that trains run on rubber tires up to the speed of 100 km/h before becoming magnetically levitated. This dual suspension makes vehicles more complex, but the tests of high speed running have proven the technological feasibility of the system.[9,10] In fact, the Japanese Maglev system, now known as MLX01, holds the world record with an experimental speed of 551 km/h. In testing, two Maglev vehicles met on adjacent guideways while traveling at a relative speed of 1,003 km/h![11]

Extensive planning of a new Tokyo-Osaka line has been underway in recent years. However, no final decision about construction has been reached. There is presently an effort to further develop the Maglev system, including modifications to the guideway, a significant change that will require a multiyear effort of development and testing.

In conclusion, extensive developments and testing of Maglev train technology have been made in Germany and Japan for several decades. Test vehicles have carried passengers on short lines at exhibits and test tracks. Major efforts to construct a line that will utilize this technology have been made for many years at many locations, but only one line has been committed to construction: During spring 2001 Shanghai signed a contract to construct a Transrapid line from the city to the airport. In Germany and Japan there is no line in operation or under construction yet.

COMPARISON OF MAGLEV WITH THE HIGH SPEED RAIL SYSTEM

Based on the analysis presented above, we can now answer three of the four questions presented in the introduction.

1. Is there demand for Maglev? Functionally, Maglev represents a high speed ground transportation system, for which there is an increasing need in many major corridors, as shown above in the high speed ground transportation section. It is likely that this need will increase in the future.
2. Is Maglev feasible? Maglev represents new technology: magnetic levitation and linear induction motor(LIM) propulsion. Clearly, to be deployed, a system must be physically and operationally feasible not only under controlled conditions, but also in permanent operation under "real world" conditions. This includes such external factors as public reaction, handling crowded conditions, adverse weather, incidental occurrences of technical defects, short power interruptions, etc. As explained in the above section focusing on Intercity

Maglev developments in Germany and Japan, all indications are that this question can be answered positively for both systems, Transrapid and MLX01. The Maglev system can be considered to be technically and operationally feasible.

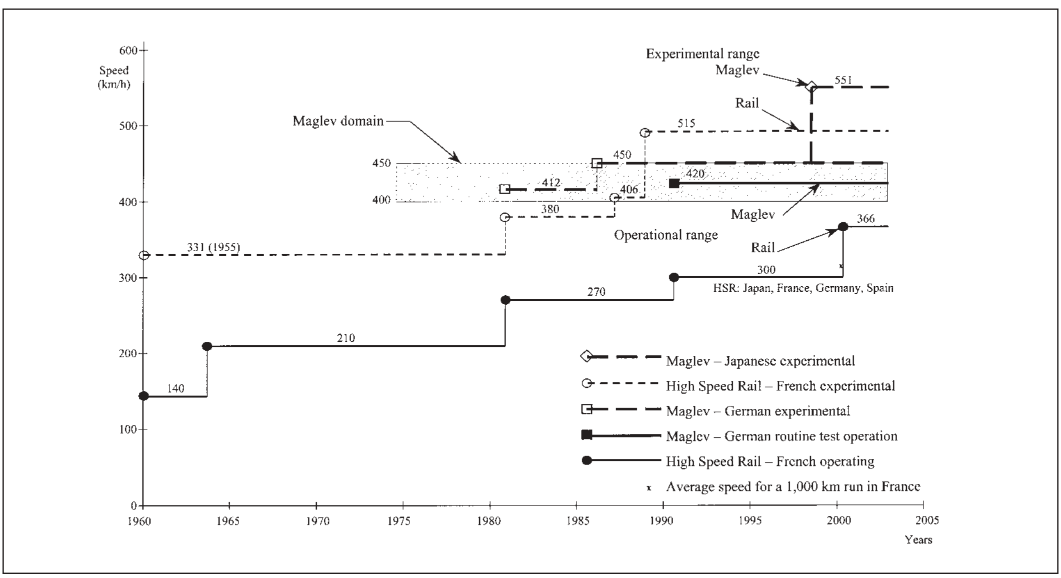
3. What existing modes are available for high speed ground transportation? High speed rail currently serves this demand and has a proven performance record (speed, safety, efficiency, reliability, etc.), and a known cost structure.
4. Is the proposed Maglev transportation system, as a "package" of performance, costs, positive and negative impacts and externalities, better than, or at least comparable to the existing systems which can provide the same type of service? This question, critical in deciding which mode should be selected for given lines or intercity corridors, is evaluated in a condensed form in the following section. This comparison is extremely important, but has been given little attention or avoided in the proposals for Maglev projects.

Common Errors in Comparing Modes

It is a common phenomenon that a new transportation system, utilizing a new technology or method of operation, is presented to civic and political leaders, and the general public—citing not only innovative features but also many features not unique to that technology. Often, comparisons are presented of a new, perfectly designed system with an existing system, designed many years ago, sometimes worn out from long operation. This kind of "promotional" presentation of new modes and systems has been used for many systems, such as monorails, pneumatic tube trains, GRT (group rapid transit), O-Bahn, and numerous others, most of which were either physically infeasible, or inferior to existing systems.[12]

A professional review of the specific differences between the new and existing modes is often performed later, and it obtains much less publicity than the promotional or "marketing" efforts. In most cases such systematic, objective comparisons show that many of the cited "advantages" of the new system

Figure 2: Maximum Speeds of High Speed Ground Transportation Modes



were actually not unique to the proposed system: that a newly built system with conventional technology would have many of the same features, while involving lower or no development costs, sometimes having lower operating costs, and proven maintenance procedures.

A rational, unbiased comparison of two technologies, based on a systematic evaluation of their major elements must be made. The two modes must be compared with each other as "packages" of their performance/costs/impacts. This is a standard methodology for comparison of alternative proposed modes for a specific area or alignment.[13]

Comparison of HSR and Maglev Systems

The experiences and data about the latest HSR and Maglev systems' performance, as collected from the technical literature, are used for the following summary review of the major characteristics of the two technologies.

Maximum Speeds and Travel Times

The widespread belief that Maglev would operate at much higher speeds than HSR comes from an incorrect comparison: maximum experimental speeds of Maglev systems are being compared with operating speeds of high speed rail. As discussed above, these two speeds are drastically different, and the proper comparison can be made only between the corresponding speeds. Thus, the comparison, shown in Figure 2, is as follows.

The difference between maximum speeds of Maglev and HSR has been drastically reduced in recent years.[14] The maximum experimental speeds of the two modes are in the same range: for Maglev (Japanese), it is 551 km/h, HSR (France) has achieved 515 km/h, and German Transrapid, 450 km/h.

With respect to operating speed, hundreds of HSR trains operate daily on several lines at the speed of 300 km/h, and an average speed of 317 km/h was achieved on the new Lyon-Marseilles TGV line. Infrastructure for the Madrid-Barcelona line is being designed for maximum speeds of 350 km/h, and top speeds on TGV have now reached 366 km/h. Since there is no operating Maglev line, a regular operating speed of that system remains to be proven. It would certainly be substantially lower than the experimental speeds. Therefore, assumed operating speeds on proposed Maglev lines are hypothetical, not more realistic than assuming the same speed for a high speed rail system.

If we assume, however, that Maglev achieves in operation 420 km/h, regularly reached in Transrapid test operations, the impact of this higher speed than high speed rail has on travel times on most interstation spacings would be small. As the diagram in Figure 1 shows, increasing the maximum speed from 350 km/h (HSR) to 420 km/h on a 100 km run results in travel time savings of approximately 1 minute.

Initial acceleration rates of high speed rail and Transrapid are comparable, because they are limited by passenger comfort. Transrapid has a higher acceleration rate than HSR in higher speed domains, which gives it an advantage on long interstation spacings. Yet, in most cases this results in a small percentage reduction in travel time.

Maglev promoters correctly claim that Transrapid can travel faster through curves with limited radii and negotiate gradients of up to 10%, while high speed rail is limited to 4%. The fact is, however, that most of these features are irrelevant in actual applications. Excessive guideway superelevations in curves are not acceptable for vehicles which have standing passengers, and it would be hardly practical to design a high speed ground transportation line with 8-10% gradient, regardless of technology. Thus, in actual design it becomes obvious that these technological maximum capabilities seldom translate into higher operating speeds. For example, simulation of the proposed Baltimore-Washington Transrapid line shows that it would have an average speed of 183 km/h. On a line with similar length, the Japanese Shinkansen travels at 209 km/h.

Consequently, Transrapid still has higher maximum speed and acceleration in high-speed ranges than high speed rail, but its advantage in travel times over typical inter-station spacings would be quite small. Even on spacings of 100 km, the difference would be about 1 minute.

Intermodal Compatibility and Network Aspects

Maglev's switches are much more complex than rail switches. Therefore Maglev is less capable of serving different branches or interconnected networks. The Maglev system is primarily conceived as a mode to serve long distance travel by a single shuttle-type line, rather than a connected network.

High speed rail, with its simple switches and extensive existing networks, is designed and operated as a transportation network, with benefits to both the operator and the passenger. With the exception of the Japanese Shinkansen lines, all other high-speed rail lines, although designed to different standards for high-speed operation, allow their trains to extend their running to existing rail facilities. This results in great benefits from lower construction costs (joint use of tracks, yards, maintenance and other facilities and entire sections of lines), shorter implementation times, fewer environmental impacts, lower external costs, and reduced local opposition to construction.

While building new sections for high speed operations, providing connections to existing lines extends the reach of the high speed rail network, allowing high speed trains to be routed to cities not directly on new lines. For example, ICE trains in Germany go from the new high speed line between Hannover-Würzburg to Hamburg, Frankfurt and other cities at speeds of 200 km/h or less. Similarly, Amtrak's Acela trains could operate to Harrisburg at speeds which that line allows. This network integration ability results not only in great convenience to passengers, but also reduces the need for transfers, which can often offset the travel time gains achieved by high speed rail.

Thus, the intermodal compatibility and network aspects of high speed rail make it superior to the Maglev system.

Investment Costs, Operating Costs, and Energy Consumption

Guideway and station construction costs depend very much on the alignment, primarily whether the guideway is constructed at grade, aerially or in tunnel. Maglev requires entirely separate rights-of-way, special facilities that are incompatible with existing systems. This results in substantially higher investments in terminal areas, particularly in tunnels, due to its larger profile. For any given alignment, estimates in the USDOT[15] report indicate that Maglev would have somewhat (10-20%) higher costs than high speed rail. Subsequent estimates for the seven US demonstration projects and several German proposals show a much greater cost difference, with Maglev expenditures about two times greater than those for high speed rail. In addition, HSR can use existing tracks for some short sections, particularly in downtown areas, where construction costs are highest. Consequently, with respect to investment costs HSR is significantly superior to Maglev in the same corridor and on a comparable alignment.

Maintenance costs are sometimes claimed to be lower (or even nonexistent) for Maglev, but this seems to be an unrealistic assumption. Maglev has a significant advantage due to its lack of physical contact with the guideway, but any change in highly precise alignment would require extremely costly repairs. Moreover, very complex electronic instrumentation on the guideway and on trains requires very sophisticated maintenance. Estimated maintenance costs per kilometer figures for the seven proposed Maglev projects in the US vary among themselves by as much as a factor of 10.[16] More information on this item is needed from suitable demonstration projects to make a valid comparison of the two modes.

Maglev does not have wheel resistance as rail vehicles do, but its magnetic levitation requires continuous energy consumption, which may be greater than the energy required to overcome wheel rolling resistance. Another factor in energy consumption is the use of the linear induction motor—LIM, which uses more energy than the rotating electric motor. It has been observed that systems utilizing LIM, such as the Vancouver Skytrain and the Toronto Scarborough line, use between 20 and 30% more energy for traction than similar rail vehicles with conventional rotating electric motors (in this comparison both types of vehicles are on wheels, so that levitation has no influence on energy consumption).

For all these reasons Transrapid is likely to have substantially higher energy consumption per square meter of vehicle floor area than the latest German high-speed rail train, ICE-3. An analysis by Hanstein[17,18] has shown that when correct comparisons between Transrapid and ICE-3 are made, i.e., consumption per square meter of car floor, the former shows higher energy consumption. Jäns[19] data confirm this. In conclusion, high speed rail consumes less energy than Maglev per comparable unit of train capacity.

Riding Comfort

Extremely high comfort—smooth ride and low internal noise—have been amply demonstrated on most of the existing high speed rail systems, including the Japanese Shinkansen, French TGV and German ICE systems. Visitors driven on the Transrapid and, particularly, on the Japanese test Maglev train, have often experienced considerable vibrations and noise levels. Thus, high speed rail still has an advantage over Maglev with respect to riding comfort.

System Image and Passenger Attraction

It is argued that a demonstration line of Transrapid is needed to test and evaluate public acceptance of this new mode, vehicle levitation and high speed travel. Actually, the greatest innovation among these elements is high speed travel, for which the public has already demonstrated acceptance with the introduction of Shinkansen and TGV, primarily because of large time savings. Innovative technical features, such as welded rails offering smoother ride and lower rolling resistance and high-speed rail switches, while significant for improved system performance, did not have a direct influence on passenger attraction.

It is likely that the shape and levitation of Transrapid trains would have very good public appeal. High speed rail systems, however, now also have a drastically different form and look than conventional railways had only 25 years ago, and new body designs are continuously being developed. It is therefore difficult to find any major difference between the appearances of the two modes. The long-term impact of these exotic features, however, is likely to be limited, as has been demonstrated by monorails. Since the demonstration projects of the 1950s and 1960s, monorails have been called the "system of the future." However, monorails are used only where exotic novelty is more important than passenger service and operating efficiency: Disney World, Las Vegas, and similar other locations. It should be noted that incompatibility of monorails with other modes is one of their major shortcomings.

It can be said that Transrapid would initially have an advantage over HSR with respect to public appeal; on the other hand, rail systems are known to draw a great public appeal with their rail technology and network operations with interline schedules,

Table 1: Comparison of Maglev and HSR Technologies in Critical Systems Characteristics

SYSTEM FEATURES	MAGLEV	HSR
a. Travel time factors		
• Maximum speeds	420 – 450 km/h (261 - 280 mph)	300 – 350 km/h (186 - 217 mph)
• Acceleration rates	Higher at upper speed range	
b. Intermodal compatibility		
• Network connectivity	None / single lines	Excellent / extensive networks
• Use of existing infrastructure	New and elevated guideways, tunnels and stations needed	New lines combined with existing lines and stations can be used
c. Costs		
• Investment costs[16]	$12 - 55 M / km ($19 - 88 M / mile)	$6 - 25 M / km ($10 - 40 M / mile)
• Operating and maintenance costs	Uncertain	Known
• Energy consumption[17]	Higher than HSR	
d. Additional factors		
• Riding comfort		Superior
• System image / passenger attraction	Excellent, plus initial innovation interest	Excellent / superior network accessibility
• Impacts on surroundings	Lower noise and vibration	Tracks mostly at grade

Sources: See Endnotes 16 and 17

Table 2: Selected Inherent Advantages of HSGT Technological Options

	Advantages of technologies with respect to each other (+ means the technology has an apparent inherent advantage)		
Selected Characteristics	**Accelerail**	**New HSR**	**Maglev**
Trip-time and revenue performance		+	+
Initial cost	+		
Autonomy from existing railroads		+	+
Through train potential over other railroads	+	+	
Service-proven technology and cost structure	+	+	

Source: See Endnote 15

etc., which Transrapid would not have. The passenger attraction would depend on the speed, comfort and integration with other modes, not differences in vehicle support and propulsion method.

It is not likely that either high speed rail or Maglev would have a significant advantage over the other in system image and passenger attraction.

Impacts on Surroundings

Indications are that Maglev, not having physical contact with guideway, has lower noise[20] and vibration along the line than high speed rail. Rail lines have an advantage in their greater ability to utilize at grade tracks in urbanized areas. In high-density areas both modes must use tunnels.

Conclusions

The preceding comparisons of Maglev and HSR systems features are summarized in Table 1. Their review shows the following differences in the three most important features:

1. Travel time: Maglev, despite higher top speeds and greater acceleration, has little travel time advantage in real-world applications.
2. Intermodal compatibility: High speed rail has an extremely significant advantage in its compatibility with other transportation systems and with built-up areas.
3. Cost structure: High speed rail is less expensive to construct, has a known operating cost level, and has an advantage in energy consumption.

The remaining features, such as riding comfort, system image, impacts on surroundings, as well as grade climbing capability, are of much lesser importance (and differences between the two systems are not major), so that they would not have a significant influence on mode selection.

The conclusion of this comparison is that the advantages of Maglev over high speed rail are few and they are very small. They are far outweighed by the advantages of HSR, particularly in system network and compatibility characteristics and investment cost. The limitation on networking and incompatibility with other transportation systems makes Maglev extremely inconvenient for integration in intermodal systems, which actually represent the "transportation system of the future."

Consequently, there is no positive answer to the basic question: "Why build a Maglev system?" While that system has some exotic features, Maglev is not competitive with existing high speed ground transportation systems, i.e., high speed rail. The usually implied superiority of Maglev over high speed rail, and its aura as a "system of the future," are based on an artificially created image of superiority in speed, lower energy consumption and better passenger attraction, none of which is supported by facts at this time.

COMMENTS ON FEDERAL POLICY AND ACTIONS

There is a large difference between the evaluation of the technology presented above, and the results of federally conducted studies. The FRA report, *High-Speed Ground Transportation for America,*[21] presents a conceptual comparative analysis of three possible systems for the Northeast Corridor: Accelerail (high speed trains on upgraded railroad lines), high speed rail with mostly new alignments, and Maglev. This analysis, reproduced here as Table 2, correctly shows that high speed rail has an advantage over Maglev in its ability to use existing rail lines (where desirable), and that it has "service-proven technology and cost structure."

However, being politically mandated to justify Maglev as a "solution," the report deceptively compares the speeds of the two technologies. For HSR, current operational speeds are set at 200 mph, while Maglev is evaluated at 300 mph, a speed even greater than Transrapid's experimental speed. The report merely mentions in a footnote that "French National Railways have successfully tested [HSR] at speeds well in excess of 200 mph." This unrealistic speed difference leads to passenger travel times computations that give Maglev an advantage over high speed rail. Thus, the conclusion of that report that Maglev has a higher benefit/cost ratio than HSR is based on confused concepts and incorrect assumptions.

The fact that the high speed rail has a "service proven cost structure," while the costs of Maglev are subject to many hypothetical assumptions further undermines the report's conclusion that Maglev would have a "higher benefit-cost ratio" than high speed rail in the Northeast Corridor. Thus, distorted facts about operating speeds and cost comparisons with drastically different reliabilities are used to satisfy the political mandate that Maglev should be proclaimed "superior" to the existing modes—Accelerail and high speed rail.

The entire US Federal Maglev Program follows the same pattern that has taken place in Japan and in Germany in the last couple of decades: it is a program promoted by technology suppliers, rather than by transportation operating agencies or in response to public needs.[22] Actually, there is neither an interest by operators, nor is there proof that the public would benefit more from Maglev than from other transportation systems. In spite of the claims of great significance of this system for industry, engineering research and development, as well as attraction of passengers exceeding that of any other mode, there have been few concrete proposals to finance these systems by private investors. All efforts on Maglev projects, in Japan, Germany, and the USA, are aimed at getting large amounts of public funds and only limited private participation.

The proposed Maglev Demonstration projects in the USA (Baltimore-Washington and Pittsburgh), in Germany (Munich and Ruhr), as well as the line under construction in Shanghai, are such short lines, that it will not be possible to test and demonstrate Maglev capabilities on them (high speed, reliability, operating costs, and others). A longer line with considerable passenger potential which is not served by a railway at present, such as Las Vegas-Los Angeles, would be a much more appropriate demonstration project.

The strong and persistent promotion and political support for this mode can be explained by the lobbying aimed at the general public and politicians who are laymen with respect to transportation systems technology. Again, the same pattern exists in all the countries: Maglev is promoted on a political basis, while it is strongly disputed by many professionals such as engineers and economists.

Most Maglev reports, in Germany and USA, include only superficial comparisons with high speed rail, and those comparisons are largely deceptive: Maglev is compared with existing or upgraded railroads, rather than with new high speed rail systems which would be the closest alternative to the proposed Maglev. Further, most benefits listed in support of the Maglev, such as the need for high-capacity, high-speed systems, reduction of highway congestion, environmental benefits, and others, are actually those valid for any high speed ground transportation: they are technology-neutral. The fact that most of these benefits could be achieved by high speed rail also, is not mentioned.

While both the German and Japanese Maglev system feasibility has been demonstrated, neither superiority nor equivalence of this technology with high speed rail has been proven. Disadvantages of Maglev in comparison with high speed rail strongly outweigh their advantages.

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(19) See note 6 above.
(20) See note 6 above.
(21) See note 15 above.
(22) See note 7 above.

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