CHAPTER 4

Magnetic Levitation and Related Systems

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CHAPTER 4
Magnetic Levitation and Related Systems

Twin goals—to relieve air and ground traffic congestion and to be technologically competitive in transportation—have prompted considerable interest in the United States in high-speed ground transportation alternatives. The ridership levels enjoyed by high-speed rail systems[1] in France and Japan and in some high-speed rail corridors in other countries demonstrate the feasibility of high-speed rail technology and arouse interest in a guided ground transportation technology that is potentially even faster—magnetically levitated (maglev) vehicles. High-speed rail is an off-the-shelf technology, and could be operated in the United States over some existing rail right-of-way, if the track were upgraded appropriately. maglev prototypes have been tested extensively, but to operate, a maglev system would require new rights-of-way and construction of a new and different guideway.

The uncertainties about ridership, costs, infrastructure investment, and some technical issues that accompany any new transportation technology make it hard to assure the commercial success of either high-speed rail or maglev in this country. In fact, efforts so far to finance such new systems in the United States from private sources have not succeeded. In addition, only a sketchy regulatory framework currently exists here for these technologies. Moreover, it is unclear whether their environmental effects—principally noise and electromagnetic fields—are acceptable to the public, or which corridors have sufficient ridership potential and feasible construction costs. At this point, it is safe to say that intercity maglev will require some governmental support for system development, testing, and construction.

Despite these unanswered questions, supporters of intercity maglev and high-speed rail systems claim a number of benefits: superior safety, economic development near stations along the corridor, low air pollution, technology leadership and export potential from developing or implementing an advanced transportation system, independence from petroleum-based fuels, improved transport energy efficiency, increased tourism and employment, and reduced (airline competitive) travel time and congestion of other transportation modes. In addition to transporting passengers, both could carry low-density freight during offpeak hours, and their rights-of-way could be used for other purposes, such as fiberoptic cables and other communications links. Obstacles to both maglev and high-speed rail center around right-of-way acquisition, infrastructure costs, and an uncertain market.

High-speed rail technologies capable of speeds greater than 125 to 150 miles per hour (mph) have been commercially introduced on a wide scale in France, Japan, and, most recently, Germany. Generally considered for the same intercity corridors as maglev, such systems have received serious consideration in the United States in California, Texas, and Florida. A number of other areas have either completed studies or are now evaluating potential high-speed service.

maglev concepts can include one or many vehicles, but all include levitating and propelling a mass transportation vehicle or vehicles by magnetic forces. maglev systems are potentially quiet, efficient transportation alternatives that could make the Nation less dependent on petroleum, the source of 97 percent of U.S. transportation energy. A number of designs and applications have been developed or proposed for maglev, ranging from low-speed people movers to intercity trains traveling 300+ mph. Although maglev has not yet been used for high-speed commercial service, systems are under evaluation for several applications worldwide. For example, Transrapid technology developed in Germany is being considered for corridor and feeder routes in the United States and has been examined as a potential option for the Soviet Union, Saudi Arabia, and Canada. Opinion among high-speed ground transportation experts in this countryis sharply divided on whether to develop U.S.-based technology or adapt existing foreign technologies to U.S. condi-

1 These are steel wheel-on-rail systems that travel at sustained speeds in excess of 125 miles per hour.

tions. Table 4-1 describes the status of various intercity corridor projects, both maglev and high-speed rail, in the United States.

This chapter discusses various technologies and issues for maglev, including research and development (R&D), estimated performance characteristics, environmental impacts, costs, benefits, and the institutional framework surrounding maglev, including safety, regulation, and financing. Comparisons and contrasts for high-speed rail are provided in many instances, since it is an option that is available now. At issue are the appropriate Federal roles in developing U.S.-based technology, adapting existing foreign systems to U.S. applications, developing safety standards, and funding intercity corridors and demonstration projects.

System Concepts

maglev designs, which run the gamut from slow-speed people movers (50 mph or less) to high-speed (300+ mph) passenger vehicles, have been proposed for intracity as well as intercity applications. maglev vehicles, which could consist of one to any number of passenger cars, are supported, guided, and propelled by electromagnetic or electrodynamics forces over a dedicated (usually elevated) guideway (see figure 4-l). maglev systems generally fall into two categories, characterized by how the vehicle is suspended. The suspension technologies for proposed and existing maglev designs include electromagnetic suspension (EMS), which the high-speed German Transrapid uses, and electrodynamics suspension (EDS), used by the Japanese National Railways (JR) system (see box 4-A). Alternative designs have been proposed that incorporate automatic banking features to improve passenger comfort through curves while still maintaining high speeds. maglev concepts considered in this chapter are limited to multisection vehicles operating on trunk lines. Other concepts, such as single-vehicle operations serving offline stations, are described in box 4-B.

Although top speeds of 300 mph would dwarf the capabilities of any existing ground transportation system, additional time savings diminish over a given distance for successive speed increases. Station stop times at intermediate points, reduced speed through curves, and the additional time required for acceleration and deceleration also lower average trip speed and increase overall travel time. Thus, a straight route without unnecessary stops will enhance ridership prospects for maglev. Proposed station sites include city centers, airports, suburbs, and passenger terminals for other modes. Almost all maglev concepts currently envision just one system operator using the infrastructure.

Other potential advantages of maglev include enormous passenger capacity and vehicle consist[2] flexibility. Since maglev vehicles in some concepts could depart at intervals of 1 minute or less (current high-speed rail systems operate at 3- to 4-minute intervals), as many as 10,000 to 20,000 passengers per hour could be moved with 200-passenger vehicles. Because most maglev systems do not have onboard propulsion units (the power is in the guideway), small passenger vehicles might be feasible, which would allow direct, economical, point-to-point service without intermediate stops. For commuter and people mover applications, maglev offers no fundamental advantage over conventional rail technology, although it may produce less noise, be less costly to maintain, and be able to accelerate faster. Short, slower speed maglev routes have been proposed more for reasons of technology demonstration and possible economic development than for any dramatic improvements over existing technology options.

For passenger comfort, both the Transrapid and JR systems would require a route with little horizontal or vertical curvature to achieve revenue speeds as high as those reached in tests. Even high-speed rail systems, such as the French TGV, need a straight right-of-way in order to achieve top revenue speeds (presently 186 mph). Since a straight right-of-way is not feasible in many of the U.S. intercity corridors most in need of additional high-speed capacity, some designers have proposed a maglev system capable of high speeds around curves, through a vehicle that can tilt, a banking guideway, or both.

Tilting technology is not new; in fact, tilting trains are currently in use in Italy, Sweden, and Spain that

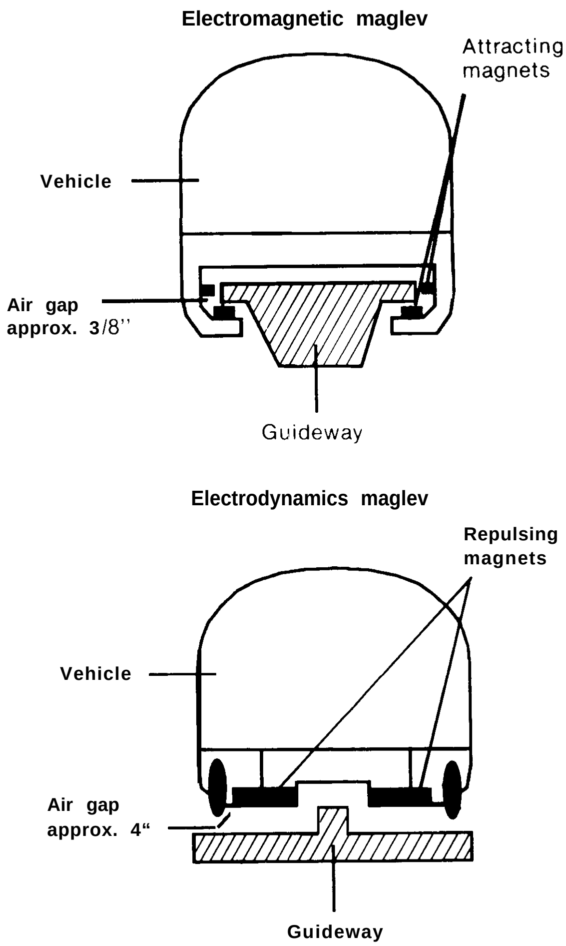
2 **Consist refers to** the order and number of ears in a train.

Table 4-1—maglev and High-Speed Rail Corridors Under Consideration

Corridor	Route length	Technology	Overseeing authority	Status and cost
Orlando Airport-International Drive	13.5 miles	maglev (Transrapid)	Originally the Florida High Speed Rail Transportation Commission (State legislature commissioned), now the F!orida Department of Transportation's Office of High Speed Transportation	The system was certified by the State of Florida in June 1991 with the stipulation that construction begin within 3 years and operation within 5 years. Preliminary estimates place the cost at around $500 million. The project is a privately funded venture with Japanese, German, and U.S. investors financing the project.
Tampa-Orlando-Miami	325 miles	Most likely steel-wheel high-speed rail	Florida High Speed Rai Transportation Commission	Originality supposed to be a public-private venture, the project has been put on hold due to lack of private investors. Originally the State investment was expected to total $6.8 billion, but that is likely to increase dramatically without private funds.
Houston-Dailas-Austin-San Antonio	610 miles	Steel-wheel high-speed rail (TGV)	Texas High Speed Rail Authority (authorized by State legisilature)	A franchise was awarded in May 1991 to a consortium headed by Morrison-Knudsen, which will build a TGV system. Southwest Airlines opposed consideration of public financial support for this system and took steps to ensure that State law prohibiting such funding was followed. Costs for the project are estimated to be $5.8 billion. Some public-private financial cooperation is expected.
Anaheim-Las Vegas	265 miles	Maglev (Transrapid)	California-Nevada Super Speed Ground Transportation Commission	in the summer of 1990, the Bechtel Corp. was awarded a franchise to build a system. Bechtel began an environmental impact study, planning for system construction in 1993.It recently pushed back that date 5 years. The project, originally thought to be completely privately funded, was estimated to cost $5.1 billion. Bechtel's announced delay has been caused by difficulty in lining up private investors.
Pittsburgh	Possible 19-mile demonstration project	Maglev (Transrapid)	maglev, inc. (consortium)	The group released a feasibility study recommending the building of a demonstration project connecting downtown Pittsburgh with the airport. Later projects would connect Pittsburgh with outlying communities in a three-State area. The group envisions starting construction of the demonstration project in 1997, but funding concerns have yet to be resolved.

SOURCE: Office of Technology Assessment, 1991.

Figure 4-1—maglev Suspension Concepts



SOURCE: U.S. Department of Transportation, Federal Railroad Administration, *Assessment of the Potential for Magnetic Levitation Transportation Systems in the United States* (Washington, DC: June 1990).

allow a 30-percent greater speed through curves than conventional trains, but the benefit for maglev of tilting vehicles or banking guideways depends on the particular alignment in question. Many see interstate highway right-of-way as desirable for maglev guideways or high-speed rail tracks because of its limited access and potential low cost compared with other rights-of-way, but even interstates, which were designed for 70 mph, are often too curvy for current maglev designs to approach top speed. It has been

Box 4-A—maglev Suspension Concepts

High-speed magnetically levitated (maglev) vehicles use one of two possible suspension technologies: electromagnetic suspension (EMS) or electrodynamic suspension (EDS). EMS maglev relies on magnetic attraction between the vehicle-mounted electromagnets and the underside of the guideway. The lower portion of the vehicle wraps under the guideway and is suspended by magnetic forces lifting it up toward the bottom of the guideway. EDS maglev relies on magnetic repulsion to keep the vehicle suspended from the guideway. For propulsion, all high-speed maglev designs use a linear synchronous motor, with power supplied to windings on the guideway ("active guideway"). With no physical contact between the vehicle and guideway at cruising speeds, and few moving parts, maglev produces no friction and has the potential for low maintenance compared to steel-wheel systems.

EMS maglev, used on the German Transrapid system, requires sophisticated control of the gap between the vehicle and guideway, which must be maintained at about 8 millimeters. EDS maglev, such as that used on the Japanese National Railways design, uses superconducting magnets for suspension, allowing a gap about 10 times greater than that for EMS maglev. Consequently, EDS maglev does not require guide way tolerances as precise, and may have lower construction costs than EMS systems (see later discussion of costs). Current EDS prototypes, however, have poorer ride quality than EMS systems and require further development of suspension systems.

The HSST EMS technology uses a linear induction motor (LIM) with power transmitted to the vehicle by means of a wayside third rail and a sliding pickup system. This passive guideway technology offers a lighter and less costly guideway, but is limited to a top speed in the 180 to 2OO mile per hour range, due to LIM inefficiencies and constraints on wayside power pickup.[1]

[1] Chris Boon, Canadian Institute of Guided Ground Transport, Queen's University at Kingston, Ontario, personal communication, June 21, 1991.

Box 4-B--Alternative Concepts

Among the many high-speed ground transportation concepts that have been proposed are several variations of magnetic levitation (maglev) vehicles. Others use fundamentally different technologies for guidance and propulsion.

The MIT Magneplane, a redueed-scale operational model of which was built in the 1970s, uses an electrodynamically suspended vehicle with a guideway consisting of an aluminum sheet trough. This design allows the vehicle to bank through curves, theoretically enabling high speeds and acceptable passenger comfort. The Magneplane concept takes advantage of the ability of maglev's synchronous motor propulsion to control accurately the position of every vehicle in the system.[1] Thus, vehicle intervals could be on the order of 1 minute or less. Using offline stations and single-vehicle operations, the Magneplane has been proposed for high-frequency, nonstop service between stations.

maglev concepts incorporating partially evacuated tubes have been proposed as a means of reducing aerodynamic drag and increasing fuel efficiency and speed. Since aerodynamic drag accounts for more energy consumption as speed increases, its elimination could enable speeds several times higher than conventional maglev, high-speed rail, or even passenger jets, with negligible energy consumption.[2]

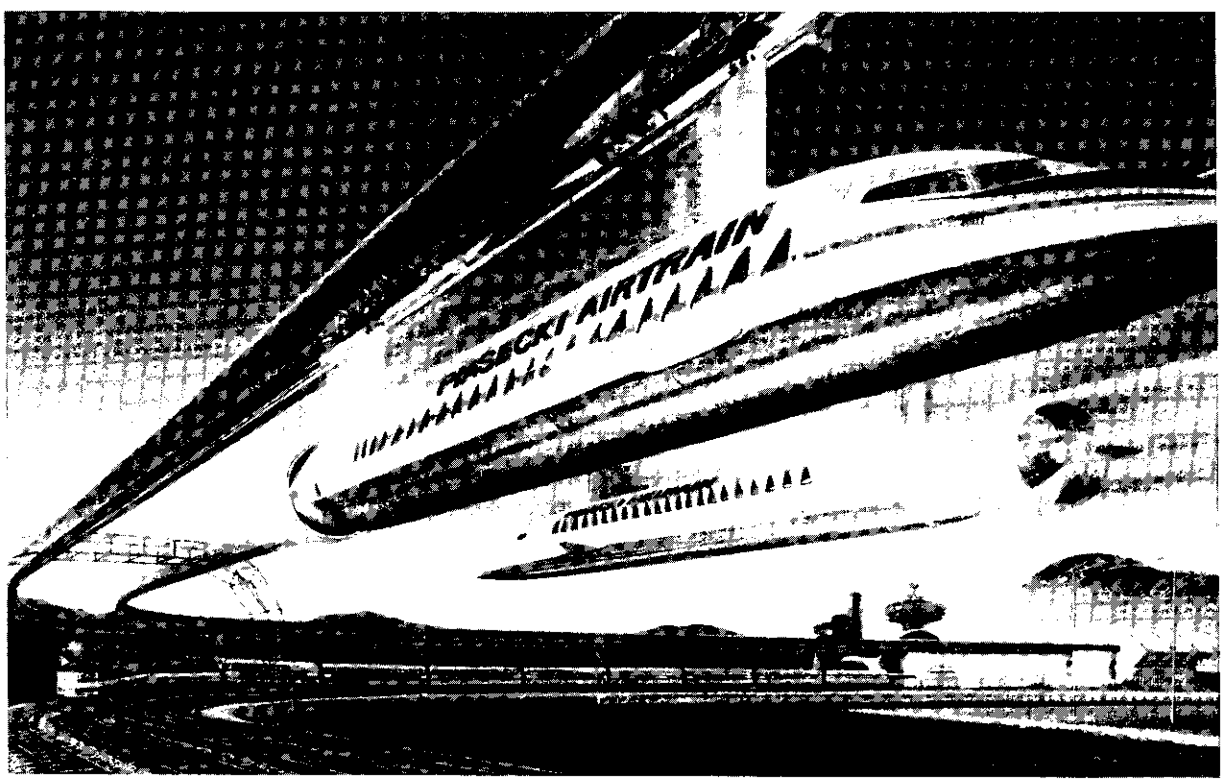


Photo credit.- Popular Mechanics

The Piasecki AirTrain concept uses aerospace technology for high-speed guided ground transportation.

[1] Henry Kolm, president, Magneplane International, Inc., personal communication, June 23, 1991.

[2] Gordon T. Danby, senior physicist, Brookhaven National Laboratory, personal communication, July 8, 1991.

Continued on next page

Box 4-B, continued

The Piasecki AirTrain design uses a powered turbofan for propulsion andbraking. The AirTrain concept entails light-weight passenger ears suspended from hinged links to rails in an elevated guideway, with propulsion and braking from a ducted air propeller powered by a gas or diesel turbine engine or an electric motor that takes current from an overhead rail in the guideway. Centrifugal forces would cause the passenger car to bank when it enters a high-speed turn, thus naturally compensating for lateral forces and improving passenger comfort. The rails would be enclosed to prevent derailment and debris on the track. Since the AirTrain design calls for a ducted propeller for propulsion and retardation, it does not need a heavy weight (typical for all conventional wheel-on-rail systems) to produce the necessary friction between wheel and rail. The low vehicle weight could permit a lighter and less expensive guideway. Small retractable wings reduce vibration levels and minimize guideway and suspension maintenance costs.[3]

3 Piasecki Aircraft Corp., *AirTrain High-Speed Ground Transport System,* report 99-X-21 (Essington, PA: Mar. 6, 1990).

estimated that for the right-of-way of the New York Thruway between New York and Buffalo, added banking capability could increase the average speed at which maglev can travel and still provide acceptable passenger comfort from 170 to 220 mph.[3] Box 4-C provides basic information on high-speed rail concepts.

Most maglev concepts call for elevated guideways, which can add significantly to initial infrastructure costs. However, an elevated structure provides more flexibility in dealing with vertical curvature constraints, is less susceptible to interference from foreign objects or vandalism, and does not interfere as much with agricultural or other ground activities as at-grade construction. It also adds a margin of safety, since grade crossings are eliminated.

State of the Technology

maglev technology has been developed primarily in Japan and Germany, where major, long-term, government-supported research programs arc under way. High-speed rail technology is most mature in Japan, France, and Germany, where early research was government-supported and where systems are now in revenue service. Table 4-2 gives a brief technical comparison between maglev and high-speed rail, and box 4-D describes the state of foreign high-speed rail systems.

maglev Systems in Operation

The only two maglev systems in revenue operation are relatively short, fully automated, slow-speed systems in Birmingham, England, and Berlin, Germany. The Birmingham Airport maglcv, in operation for over 10 years, is a shuttle that runs along a 620-meter-long guideway linking the airport and railway station. Although the short distance does not require high speeds, maglcv technology was chosen because it was thought to provide high reliability, low maintenance, and a high degree of automation. The system has not proven particularly reliable, and maintenance costs have been higher than expected because the system is unique and requires special parts. The Berlin system consists of a l-mile line, most of which has two tracks, connecting the Berlin Philharmonic concert hall to a nearby metro station. Supported by the West German Minister of Research and Technology and the Berlin Senator for Transport and Public Utilities, track construction began in 1983 and was completed in 1986. Operation of this demonstration line began shortly thereafter. Neither system exceeds 50 mph.

U.S. Research

The High Speed Ground Transportation Act, passed in 1965, established the Office of High Speed Ground Transportation under the Department of Commerce,

3 Richard Gran, Grumman Corp., personal communication, Apr. 2, 1991.

Box 4-C-High-Speed Rail Transportation

Although high-speed rail is similar to conventional electrified passenger rail, higher speeds are achieved through dedicated rights-of-way, lighter vehicle weight, more powerful propulsion, and more precise track tolerances. The Japanese Shinkansen and French TGVsteel-wheel systems operate at high speeds over exclusive track and have energy use and air quality benefits similar to those projected for magnetic levitation (maglev) systems. The TGV is also able to travel over high-quality conventional track, albeit at lower speeds, and thus its trains can penetrate city centers without extra right-of-way acquisition or construction. Existing TGV track has been built for anticipated cruising speeds of 250 miles per hour (mph), although speeds above the current 186 mph will require improvements in train technology. Still, some view regular speeds of greater than 200 mph as achievable by the end of the century.[1] Recent track tests of the TGV at 322 mph raise the possibility that such technology may become even more competitive with air travel or possible maglev systems.

High-speed rail shares certain characteristics with maglev (and interstate highways), including the need for total grade separation (at least along high-speed stretches of routes), expensive right-of-way construction (either new track or upgrading existing track), and tunneling or bridge work to avoid vertical and horizontal curves and maintain "fast" right-of-way and high ride quality. maglev is able to negotiate steeper grades than high-speed rail. Both maglev and high-speed rail use automated speed and interval control, limiting the responsibility of onboard operators during routine operations and providing automatic override in the event of operator error or incapacity.

[1] Barry James, "French Technology," *International Herald Tribune*, Oct. 31,1990, pp. 15-16.

Table 4-2—Comparison of maglev and High-Speed Rail

maglev	High-speed rail
Possible top revenue speeds of 300 mph.	180 mph speeds on straightaways, 200+ mph revenue speeds achievable before end of decade.
Totally new infrastructure required; higher initial construction cost; possibly low maintenance costs.	New right-of-way and tracks needed for high speed, but existing tracks might be used (at low speeds) for urban operations; lower construction cost.
Noise level equal to or lower than high-speed rail at identical speeds. Quieter at low speeds because no friction (EMS).	Noise level of 85 to 90 decibels at a distance of 25 meters (82 feet) from the track at train speed of 160 mph. At 185 mph, noise levels can be in the 90-to 100-decibel range.
No high-speed revenue experience.	Fatality-free revenue experience.
Less energy use at low speeds.	Consumes similar amounts of energy per seat-mile as projected for maglev at similar high speeds.
Faster acceleration than high-speed rail.	
Can climb steeper grades than high-speed rail.	

KEY: mph = miles per hour; EMS = electromagnetic suspension.

SOURCE: Office of Technology Assessment, 1991.

to explore advanced intercity ground transportation technologies. Although the stimulation of maglev research was not a major motivation behind this act, most early maglev work occurred around the time of its passage. The earliest U.S. work on maglev systems was carried out by Brookhaven National Laboratory, the Massachusetts Institute of Technology, Ford Motor Co., Stanford Research Institute, Rohr Industries, Boeing Aerospace Co., The Garrett Corp., Mitre Corp., and TRW Systems, Inc. maglev work in the United Slates--+ther than feasibility studies and technical assessments conducted by government, industry, and universities-essentially ended in 1975, with the

Box 4-D—High-Speed Passenger Rail Abroad

High-speed rail systems have been in successful commercial operation for several years. Two of the best known systems are the TGV in France and the Shinkansen in Japan. Germany has a prototype high-speed train, the Intercity Express (ICE), which is designed for speeds between 150 and 180 miles per hour (mph). More than 40 German trainsets are now being manufactured, and revenue service began in 1991 on the Hamburg-Frankfurt-Munich line. (The U.S. Amtrak Metroliner, which achieves speeds of 125 mph along some stretches between Washington, DC, and New York City of the Northeast Corridor, is the only US. rail service that approaches the speeds of foreign high-speed systems.)

In France: Train a Grand Vitesse (TGV)

The TGV, France's high-speed rail system, began operations in the early 1980s. Construction on the newest line of the TGV, the Atlantique, began in 1985. The line is Y-shaped and consists of a main line between Paris and Courtalain and two auxiliary branches. The western Paris-Le Mans branch was completed in 1989, and the southwestern Paris-Tours line was completed in 1990. Total estimated cost is 16 billion francs ($3 billion) for construction of 163 miles of track and rolling stock. The line includes 13 miles of tunnels, located mainly in Paris and the Loire Valley, and 2 miles of viaducts in the Loir, Cisse, Loire, and Cher Valleys. Maximum design speed is 300 kilometers per hour (km/hr) (186 mph), with turnout crossing speeds between 160 and 220 km/hr (100 and 136 mph).

Land belonging to the SNCF, the French national railway company, the government, or alongside existing rail or highway right-of-way was used for 60 percent of the Paris-Courtalain stretch. To avoid level crossings, there are more than 310 structures along the line, including 164 road bridges and 139 rail bridges. Continuous welded rail with reinforced concrete crossties is used throughout. The line is electrified and uses five power substations. A control center located at Paris-Montparnasse includes telemetry and remote control equipment for crossovers between the two tracks, spaced out along the line at approximately 14-mile intervals. It also controls electric power feed and can intervene via radio links with all trains on the line. Fifteen satellite stations house safety equipment for each crossover site. The track-to-locomotive transmission system sends signaling information to the cab, where the driver reads it on the control panel. The trainsets include 2 power cars, one at each end, and 10 trailers. The power car wheelsets use electric brakes, and the trailer wheelsets use antiskid disc brakes.[1]

The TGV's power and adhesion, and the dedication of the high-speed corridor to passenger service with its light loads, made possible a line with gradients of up to 3.5 percent (on the Paris to Sud Est line—the maximum grade on the Atlantique line is 2.5 percent) instead of the usual 0.5- to 0.8-percent gradient. As a result, the line could be routed over plateaus where large-radius curves could be easily laid out, and thus avoid valleys, which are often sinuous, densely populated, and furrowed by waterways and roadways—all of which increase construction costs. The TGV lines are compatible with existing track and thus the trains can penetrate city centers and serve all major stations on the line.[2]

In Japan: Shinkansen (Bullet Train)

The Shinkansen long-distance, high-speed railways include two groups, the Tokaido and Sanyo Shinkansen, which run southwest from Tokyo, and the Tohoku and Joetsu Shinkansen, which serve the regions to the northeast. The Tokaido Shinkansen began service between Tokyo and Osaka (515 km) in October 1964, just before the Tokyo Olympic games. In March 1972 the Sanyo Shinkansen began operating between Osaka and Okayama (161 km). The Tohoku Shinkansen, which runs north from Tokyo, began operation between Omiya and Morioka (465 km) in June 1982. The Joetsu Shinkansen runs across Honshu between the Sea of Japan and the Pacific Ocean, and began operation between Omiya and Niigata (270 km) in November of the same year. When the Japanese National Railways was privatized in 1987, these lines became the property of the new

[1] SNCF, Direction de la communication, "The TGV Atlantique: Construction of the New Line," informational document, June 1986.

[2] SNCF, Direction de la communication, "The Railways of France," brochure, n.d.

Continued on next page

Box 4-D, continued

Shinkansen HoIding Corp. Over 2-1/2 billion passengers have been carried on the Shinkansen without injury. The maximum speed for the Tohoku and Joetsu Shinkansen is now 150 mph. Five additional routes are scheduled for future construction, including extensions from Morioka to Aomori, Takasaki to Osaka, Fukuoka to Kagoshima, Fukuoka to Nagasaki, and Aomori to Sapporo.[3]

The Shinkansen Holding Corp. owns the four Shinkansen lines—Tohoku, Joetsu, Tokaido, and Sanyo—and leases them to three of the passenger railway companies: the East Japan Railway Co., Central Japan Railway Co., and West Japan Railway Co. The fees are calculated according to the traffic volume of each Shinkansen line and other factors. The Shinkansen's ability to take passengers directly from city center to city center makes it competitive with airline and expressway transportation.[4]

As with many other railway systems, Shinkansen tracks are equipped with snow-melting facilities to prevent railway switch points from freezing in cold weather. Additional measures are taken for lines that pass through areas with heavy snowfall. Measures to prevent snow from adhering to or penetrating the operating mechanisms of the cars include covering the lower parts of the cars and using centrifugal snow separators, which remove snow from the intake air.[5]

Trains operating in areas prone to earthquakes are protected by a combination of earthquake detection and control systems, including seismometers installed every 20 to 80 km along the line. If land cables are damaged by large earthquakes, a communications satellite system will be used to transmit information.[6]

Other High-Speed Rail Systems

The principles of tilting train technology are independently rotating wheels mounted on guided axles, a low center of gravity, light weight, and swivel coupling of car bodies. Development of one tilting train, the Spanish Talgo, began in the 1940s. The latest model, the Talgo Pendular, is designed for a maximum speed on straight track of 125 mph. It is designed to round curves safely and with no passenger discomfort at speeds 25 percent faster than that of conventional trains.[7]

The Talgo trainset is made up of a succession of rigid cars articulated to permit the train to negotiate curves but prevent vertical or transversal displacements between cars. When rounding a curve, acceleration felt by the passenger depends on the tilt of the car and is significantly reduced if the ear is tilted in toward the center of the curve. Thus, a tilting train can substantially increase its speed around curves compared with conventional trains. The Talgo system is based on raising the level of suspension above the center of gravity; the air springs of the main suspension behave elastically, allowing the ear to tilt naturally around curves as a result of centrifugal force. The Talgo train also features an automatic gauge-changing mechanism to accommodate different track gauges.[8] Other tilting train configurations are manufactured by Bombardier of Canada, Asea Brown Boveri, a Swedish-Swiss consortium, and Fiat of Italy.

The Swedish X-2000 and the Italian Pendolino use conventional track and employ active tilt technology, using powered actuators, to reduce passenger discomfort when traveling through curves and to enable curve speeds 25 to 40 percent faster than those of conventional trains. Tilt technology is being considered for the Northeast Corridor to reduce travel time between New York and Boston to under 3 hours (presently

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[3] East Japan Railway Co., Shinkansen brochure, n.d.

[4] Ibid.

[5] Ibid.

[6] 1bid.

[7] RENFE, "Talgo: An Up-to-date Train; A Long History," informational document, n.d.

[8] RENFE, "Talgo Pendular," informational brochure, n.d.

Continued *on next page*

Box 4-D, continued

4-1/2 hours) and between Washington and New York to under 2 hours, 15 minutes without having to acquire new rights-of-way.

Obstacles to Conventional High-Speed Passenger Rail

Most obstacles to conventional high-speed passenger rail systems center around the high cost of rights-of-way. Operating faster passenger trains would require in most cases a new roadbed and in some cases a separate right-of-way, because most of the track now used for passenger trains is also used by freight trains. Scheduling high-speed passenger trains on the same track with slower speed freight trains presents serious traffic and scheduling diffilculties. In addition, freight trains, because of their heavier weight, cause comparatively more track wear than passenger trains, and passenger trains tolerate less track wear. Furthermore, freight trains cause tracks to come out of alignment more quickly, and because passenger trains require more precise alignment, track maintenance is more expensive for track used for both passenger and freight transport. (However, TGV trains in France operate at speeds up to 136 mph on track shared with conventional freight and passenger trains.)

Since grade crossings of railroads and highways are where the highest percentage of fatal rail-related accidents occur in the United States, it is generally agreed that high-speed trains should not operate over highway grade crossings. However, the cost of eliminating grade crossings from existing mixed traffic lines is considerable. In a study of the proposed Houston-Dallas-Fort Worth corridor,[9] for example, the cost of grade separations for highways, which included 135 structures, represents 17 percent of the total right-of-way-related costs. Most European authorities have accepted higher speed service (up to about 100 mph) without the elimination of all existing grade crossings.

9 Texas Turnpike Authority, "Texas Triangle High Speed Rail Study," unpublished report, February 1989.

termination of Federal funding for high-speed ground transportation research. In fact, U.S. research activity for all mass transportation, as reflected by R&D outlays by the Federal Railroad Administration (FRA) and the Urban Mass Transportation Administration (UMTA)[4] declined steadily through the 1980s (see table 4-3).

The National maglev Initiative

As a result of legislative action in 1990,[5] directing the U.S. Army Corps of Engineers (the Corps) to prepare and implement a plan for a national maglev program, the Department of Transportation (DOT), the Department of Energy (DOE), and the Corps developed what is now known as the National Maglev Initiative (NMI). The NMI is a 2-year, $25-million program to assess the engineering, economic, environmental, and safety aspects of maglev. A major program

Table 4-3—Funding for Freight and High-Speed Ground Transportation Research

Years	Federal Railroad Administration R&D outlays (in millions of dollars)	Comments
1965-75	$15.0	On high-speed ground transportation
	2.3	On maglev
1980	63.0	Since 1980, these outlays have gone toward freight rail R&D.
1981	55.1	
1982	34.5	
1983	18.5	
1984	14.7	
1985	16.2	
1986	15.4	
1987	10.9	
1988	10.6	
1989	7.0	

SOURCE: Office of Technology Assessment, 1991, based on U.S. Department of Transportation data.

4 Both the Federal Railroad Administration and the Urban Mass Transportation Administration are part of the U.S. Department of Transportation.

5 Appropriations Conference report 101-235, for the Energy and Water Development Act of 1990.

report, planned for fall 1992, will include technical and economic assessments, options for developing U.S. capability to surpass existing foreign technologies, and recommendations on whether to pursue future development. Twenty-seven contracts, totaling $4 million, are currently being awarded to examine various subsystem technical issues, such as low-cost guideway construction, control systems, obstacle detection, and magnet design. One more set of contracts will be awarded shortly to examine various system concepts. Since the fiscal year 1993 budgets are now being prepared by the agencies and many of the results of the NMI are not expected until late 1992, it will be too late for the latter to influence the former.

Blending staff from three different cabinet-level departments has not been easy, and NMI team members have struggled to establish an effective working group. FRA has primary Federal responsibility for rail matters and has taken the lead role. FRA staff's technical expertise and experience in conventional rail safety and certification are transferable to some extent to high-speed rail and maglev. However, the tasks of developing guidelines and revised regulations for maglev and high-speed rail safety features and requirements have required reaching outside the agency for technical assistance.

Argonne National Laboratory (ANL) of DOE, which has substantial research experience in energy and propulsion systems, is playing the major role for the NMI in technical issues regarding levitation, guidance, and propulsion through its Center for Transportation Research. The Argonne Center is also studying vehicle-guideway interactions, developing requirements for test facilities, investigating superconductor applications, and conducting laboratory experiments on biomagnetic effects.[6] The Army Corps is providing expertise and assistance with guideway construction techniques and construction management.

FRA is depending heavily on staff from the Volpe National Transportation Systems Center (VNTSC) in Cambridge, Massachusetts, for support and administrative help for maglev research, in establishing safety testing requirements and, eventually, developing new standards. VNTSC is assisting FRA in conducting risk assessments, evaluating the safety of foreign systems, market and economic research, vehicle and guideway research, administering research contracts, and investigating the health effects of electromagnetic fields (EMF). Other portions of the EMF work are being performed by the Environmental Protection Agency (EPA) and ANL.

Other Research

DOT is also funding a study by the Transportation Research Board (TRB) to investigate possible use of maglev and high-speed rail technologies in U.S. corridors. In addition, a special committee on maglev transportation made up of technical experts has been created within TRB to review work of the NMI.

Status of German maglev

German Government-supported maglev research began in 1969,[7] when the Federal Minister for Transport commissioned a study on high-speed, trackbound, ground transportation. In the early 1970s, the firms AEG, Siemens, and Brown-Boveri commissioned a 150-mph EDS maglev vehicle in Erlangen, which used superconducting vehicle magnets to attain a 4-inch levitation height and used linear synchronous motor propulsion.[8] In 1977 the West German Federal Minister of Research and Technology decided to concentrate development work on attractive suspension (EMS) designs. A test facility with a 19.5-mile track was put into operation in Emsland in northwest Germany in 1983, where more than 62,000 miles of tests have been conducted to date.[9] Over $1 billion has been spent on what is called the Transrapid maglev project, and the vehicle has been developed to the preproduction prototype stage and tested extensively. Transrapid International was formed initially as a consortium of several German companies and institutes.

With Krauss Maffei, MBB, and Thyssen Henschel as the principal participants, and support from the German Federal Ministry of Research and Technol-

6 Donald Rote, Argonne National Laboratory, personal communication, July 3,1991.

7 The earliest research on electromagnetic suspension maglev was conducted by the German scientist Hermann Kemperin the early 1920s.

8 S. Kuznetsov, PSM Technologies, Inc., personal communication, July 2, 1991.

9 William Dickhart, consultant t. Transrapid International, personal communication, June 28,1991.

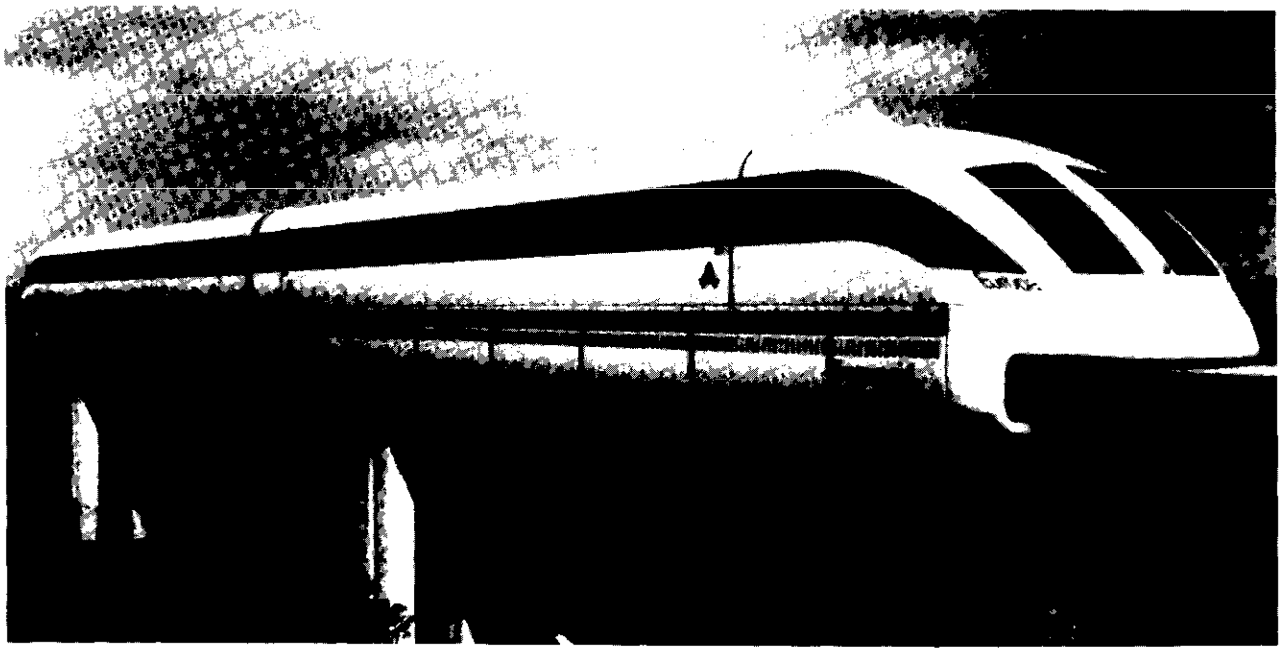

Photo credit: Magnetschnellbahn AG

The Transrapid maglev has been tested since the mid-1980s at a test track in Emsland, Germany.

ogy, the consortium has since been renamed Magnetschnellbahn and now includes Daimler-Benz, AEG, and Siemens. The Transrapid 07, the most recent vehicle prototype, has a top speed of between 250 and 310 mph and accommodates 80 to 100 seated passengers per section. Although Transrapid technology is presently the most advanced of maglev prototype systems, some experts believe its precise guideway tolerance requirements could lead to more costly construction and higher maintenance costs than would characterize other concepts.[10]

A short maglev route connecting Cologne/Bonn and Dusseldorf airports and the city of Essen has been approved by the government, but the Transrapid system has not undergone complete certification testing (travel through tunnels, two-way traffic), and the project lacks the necessary private sector funding. The German Government has stipulated that the estimated DM 3.6 billion in capital costs for the route must be shared by private industry, the airports and airlines, and the state of North Rhine-Westphalia, and it is not clear that this condition can be met.[11] Several intercity routes are currently being considered by the German Government, but there is no firm funding commitment yet.

Status of Japanese maglev

The Japanese Railway Technical Research Institute (RTRI), supported by the recently privatized Japanese National Railways, has developed an EDS maglev system that is some 7 years behind the Transrapid system in development. It is similar in concept to the early research conducted in the United States by Powell and Danby of Brookhaven National Laboratory. Work began in 1967, and R&D costs through 1990 exceeded $1 billion. The vehicle (MLU-002) has a design speed of about 300 mph and has been tested at a 7-km test facility in Miyazaki. It requires less sensitive tolerances between the vehicle and the guideway than does the German system, and thus may be less costly to construct and maintain. However, its ride quality is not satisfactory, and improvements are to be made in the

10 Richard A. Uher, director, High Speed Ground Transportation Center, Carnegie Mellon University, testimony at hearing before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Surface Transportation, Oct. 17, 1989.

11 *Spektrum der Wissenschaft*, February 1990, p. 32.

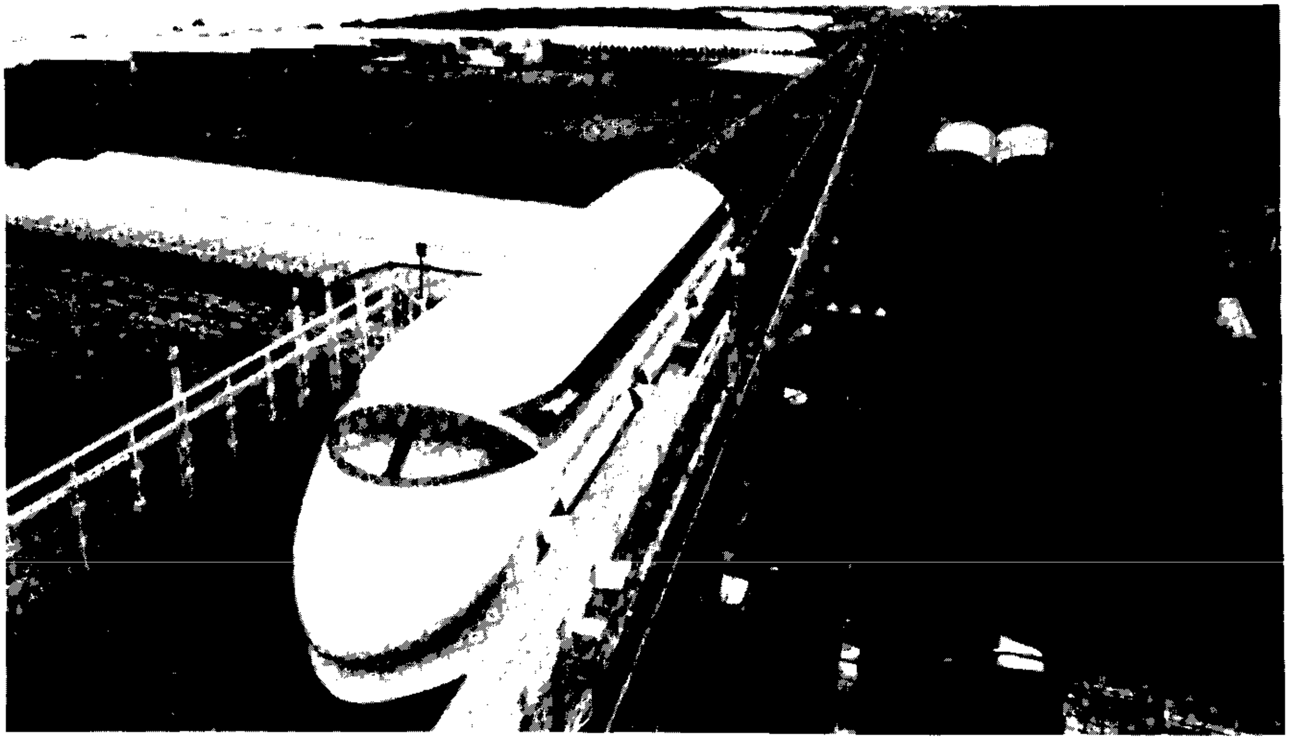

Photo credit: Railway Technical Research Institute

The Japanese MLU maglev vehicle uses electromagnetic (repulsive) suspension, which was invented in the United States.

suspension design. The JR system is the only maglev technology that uses high-temperature superconductors; this could bring modest gains in energy efficiency and reliability. Recent advances in developing high-temperature, superconducting materials are not likely to affect the overall feasibility of this technology.

A 27-mile test guideway is under development in Yamanashi prefecture for possible inclusion in a future revenue line between Tokyo and Osaka, and an extensive 4-year test of the system is expected to commence in 1993. The funding request for construction of the test track and for testing is approximately $3 billion, with the construction cost amounting to $2.3 billion.[12] RTRI receives funds from the Japan Railways Group, a consortium that includes six passenger railway companies, the Japan Freight Railway Co., and the Japanese Government (Ministry of Transportation). Construction of transportation facilities is handled by . the Ministry of Construction.[13]

The other major Japanese system is the HSST EMS design with an unpowered guideway. The existing prototype, the HSST-1OO, has a top speed of 60 mph, but the HSST-200 and HSST-300 design concepts could reach 125 and 186 mph, respectively. Development of this system began in 1975 by Japan Airlines (JAL); the technology was transferred to the HSST Corp. in 1985. Since 1981, the HSST system has received no government funding, and financial support has come mainly from JAL. As of mid-1988, over $40 million had been spent on the R&D program. The HSST-1OO maglev has been demonstrated extensively but has never realized its top design speed during these demonstrations because the tracks have been limited to lengths of less than 1 mile. It remains under development with no estimated completion date. Because

12 Canadian Institute of Guided Ground Transport, ***Update of Super-Speed Ground Transportation Technology Development Status and Performance Capabilities,*** report No. ***89-16*** (Kingston, Ontario, Canada: Queens University, May25, 1990), p. 4.7.

13 Uher, op. cit., footnote 10.

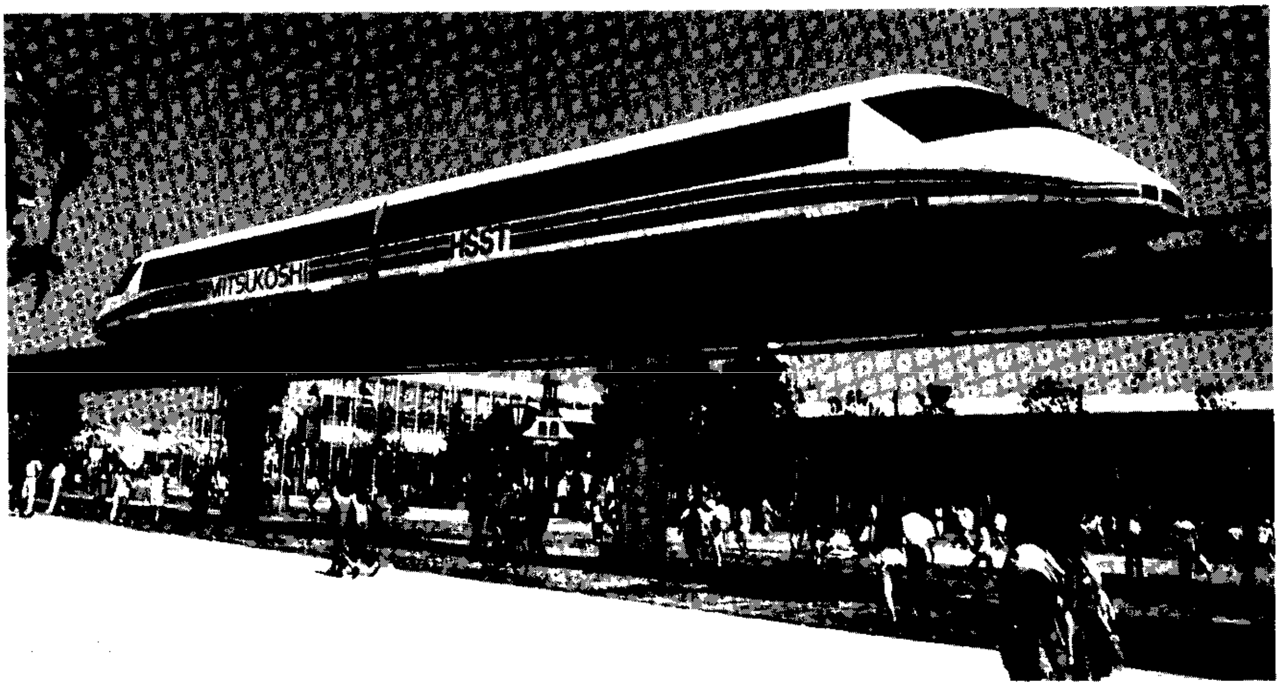

Photo credit: HSST Corp.

This low-speed maglev vehicle, the Japanese HSST, has carried visitors at expositions in Canada and Japan.

of its relatively low maximum speed in relation to other maglev designs, the HSST system will probably not compete with the RTRI system over longer routes. However, the technology is more mature, and because of its relative design simplicity and low guideway costs, it might find early applications in people mover and commuter service.[14]

maglev R&D Needs

Some maglev R&D needs are unique to either EMS or EDS systems, while others are shared by both. Some areas needing further development, like switching and low-cost guideway construction, will not preclude construction of short, simple maglev routes, whereas other areas, such as magnet refrigeration and control of EMF for EDS, must be adequately addressed before revenue operation can proceed.

Switching is an important subsystem that needs further development for both EMS and EDS. The Emsland test track in Germany uses moveable guideway segments, but other (nonmechanical) concepts for EMS and EDS maglev have been proposed, such as electromagnetic switching, that could possibly provide higher switching speed and reliability without moving guideway structural members.

Since guideway design and construction represent the majority of total system cost, it is important to minimize this cost component. Research is needed to develop optimal guideway shapes that make the most efficient use of materials and yet meet requirements for tolerance and low maintenance (see later cost discussion for tradeoffs associated with various guideway concepts). Construction and fabrication methods that minimize onsite time and labor requirements and thereby reduce cost are also needed.

Less developed than EMS maglev, the EDS maglev still requires considerable research and testing. Further development needs for EDS maglev include: negotiating curves while maintaining adequate stability, cooling the superconducting magnets, designing sus-

[14] Rote, op. cit., footnote 6.

pension systems for high ride quality, and limiting EMF in the passenger compartment (see EMF discussion later in this chapter). These areas must be adequately addressed before any system will be commercially feasible. Progress has been made in the last two areas by the latest Miyazaki test vehicle using niobium-titanium magnets and active shielding of the passenger compartment.[15]

High-speed rail, although a mature technology compared with maglev, needs further development, if it is to achieve speeds of 200 mph or more. R&D needs include braking capabilities, wheel/rail dynamics, and electric current collection techniques.

Economic Considerations

Since infrastructure costs make up the majority of upfront system costs, and routes are not easily changed once they are constructed, it is critical that both a need and an adequate ridership for maglev or high-speed rail are established before routes are approved. Extensive market research is needed for understanding of modal preferences, travel time needs, and door-to-door travel trends for maglev; better cost and pricing information is available for high-speed rail, making potential ridership easier to estimate.

In a 1983 study OTA found that the following characteristics are important for a high-speed surface transportation corridor:

- cities grouped along a route giving major passenger travel flows in the 100-to 300-mile trip range;
- cities with high population and high population densities;
- a strong "travel affinity" between cities; and
- cities with developed local transportation access to feed the high-speed rail line.[16]

Travel between city pairs with major passenger travel flows in the 100- to 300-mile range generally occurs by air or automobile, so for a maglev or high-speed rail service to be successful, significant shifts would have to be made away from air or automobile travel. Although connections are important if a maglev or high-speed rail system is to compete with automobiles, they are less critical if the system is designed to serve the air travel market.

Some projected shifts to maglev are likely to be opposed by private-sector transportation providers, such as some airlines and rental car companies, which have already attempted to block implementation of such new systems. In the Texas corridor (see table 4-1 again), for example, Southwest Airlines, which operates extensively between cities along the route, has lobbied successfully for legislation that prohibits public financing of high-speed rail. However, some airlines might be supportive of new surface transportation systems that were not direct market competitors. In addition, construction of the Orlando Airport-International Drive maglev route has encountered resistance from the airport authority, who feared a loss of rental car business to a new transportation mode that will also be a tourist attraction.

Market Potential

Of the U.S. corridors with the characteristics listed above, only the New York-Washington, DC, rail corridor of Amtrak, where speeds of 125 mph are reached, currently provides airline-competitive rail service. Indeed, Amtrak carries more passengers between these cities than does any single airline. At present, service on other rail corridors is too slow or too infrequent (or both) to compete successfully with airlines. Other city pairs may be strong candidates for intercity maglev or high-speed rail service, but independent, detailed ridership forecasts and cost-benefit analyses are needed to help determine whether public support is warranted.

Estimates of potential ridership are usually based on origin-destination data (or estimates thereof) for air, rail, automobile, and bus traffic, and on projections of future demographic trends. Reliable data for automobile travel and for all door-to-door trips are next to

15 Kuznetsov, op. cit., footnote 8.

16 U.S. Congress, Office of Technology Assessment, *U.S. Passenger Rail Technologies,* OTA-STI-222 (Washington? DC: U.S. Government Printing Office, December 1983), p. 29.

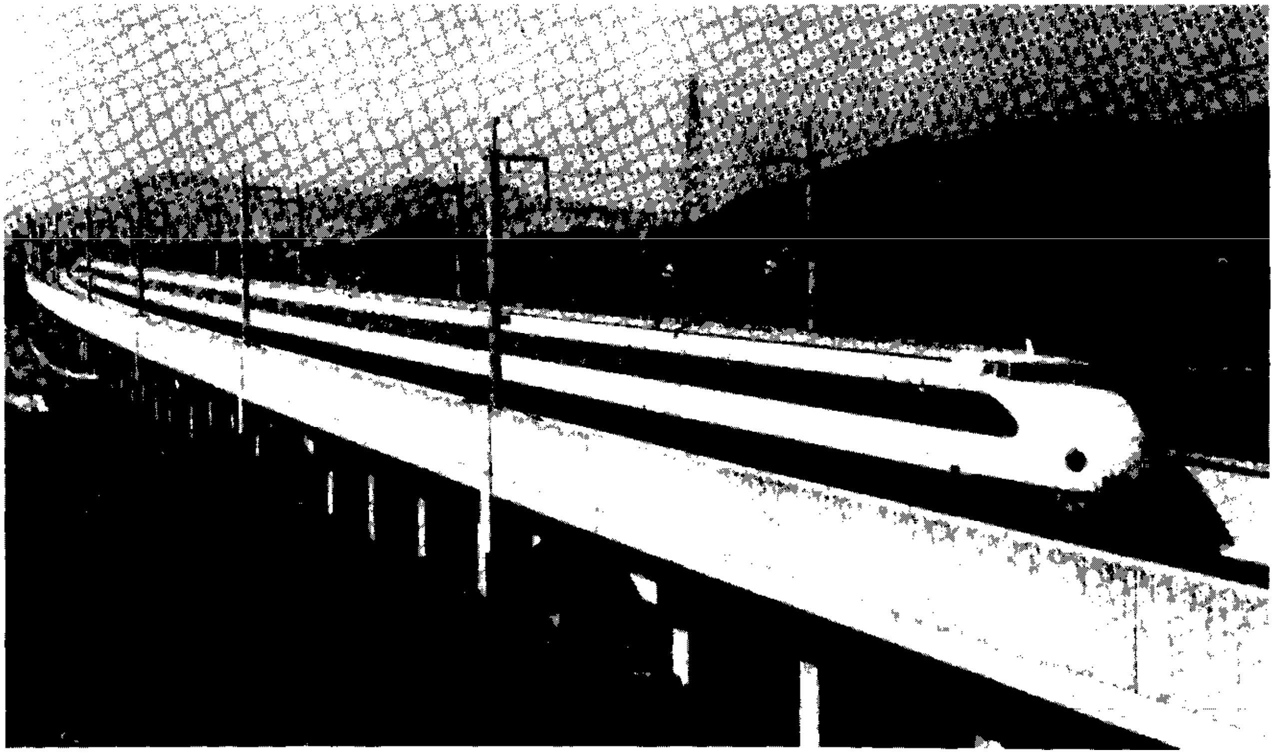

Photo credit: East Japan Railway Co.

The world's first high-speed rail service was provided by the Japanese Shinkansen (bullet train),

impossible to obtain, making intercity ridership for new maglev or high-speed rail systems extremely difficult to estimate. Uncertainties in forecasting and in projecting fare revenues are among the reasons that raising private capital for financing new systems has proven so difficult. (See chapter 2 for further details.)

Population and travel density determine the size of the potential market for maglev or high-speed rail service. The greater the population density, the more highly developed the transit system is likely to be, which can ease access to and egress from the high-speed line. For example, the ability of the Northeast Corridor to provide rail service is aided by the substantial local transit systems feeding the trains. Japanese experience with the Shinkansen, a high-speed railway, is similar; JR figures for 1982 indicate that the access to the Shinkansen from home to station is 75 percent by public transit, 20 percent by taxi, and 5 percent by automobile. Access from the train to final destination is 60 percent by public transit, 35 percent by taxi, and 5 percent by auto.[17] Comparable figures for New York and Washington, DC, confirm this pattern. Without convenient access to stations, some potential ridership for high-speed intercity rail or maglev is lost.

Other possible markets suggested for maglev are downtown-to-airport or suburban service. Speed requirements for such a system would not be as high as for intercity travel, so maglev system characteristics would be similar to those of conventional commuter rail lines. At speeds in the range of 50 to 60 mph, maglev could have some advantages over conventional rail in that it would probably be quieter and could require less maintenance.

costs

Guideways and tracks, including power and communication equipment, account for the majority (80

[17] Ibid., pp. 31-35.

Table 4-4-Comparative Economic Data for 250-mph maglev and 200-mph High-Speed Rail

Categories	maglev (EMS)[a] (200 seats)	High-speed rail (350 seats)
Vehicle cost	$7.2 million (2 sections)	$24 million
Guideway cost (per mile)	$10 million to $40 million: not firmly established and highly dependent on route and guideway parameters	$4 million to $20 million
Station costs (3 stations)	Comparable for both: $1 3,500/foot of platform; $3,000/parking space; $8.5 million/station for 500-foot platform and 600 parking spaces	
Vehicle operation and maintenance@	$0.028/seat-mile	$0.025/seat-mile
Fuel efficiency (seat-mile/gallon) . . .	Estimated at 440 depends on suspension	540

KEY: EMS = electromagnetic suspension.
[a]Comparable data for electrodynamic suspension were not available.
[b]A load factor of 0.65 is assumed-i.e., about 65 percent of the seats are filled.

SOURCE: Office of Technology Assessment, 1991.

percent or greater) of initial system costs for maglev and high-speed rail. Since no high-speed, revenue maglev systems exist, these costs can only be roughly estimated. Cost is affected by the degree of urbanization and system size. The major items are design and engineering studies, right-of-way acquisition, track or guideway construction, tunneling, station and facilities construction, purchase of vehicles and signal and control equipment, prerevenue testing, and modifications to existing roads, bridges, rail lines, or other structures. Estimates of guideway costs from maglev corridor studies range from $10.6 million (includes some single track sections) to $60.9 million per mile. Comparable cost estimates made by experts for high-speed rail, based on existing systems, range from $8 million to $32 million per mile of electrified double track, including land acquisition.

Day-to-day operating costs, which include wages, fuel, and maintenance, are the second major set of relevant factors. maglev operating costs are believed to be similar to current high-speed rail operating expenses because both systems consume similar amounts of energy, although personnel requirements may differ between the two systems. Maintenance for maglev depends on the system design and operating practices. Maintenance cost estimates range from appreciably lower than high-speed rail (because there are few moving parts) to appreciably higher (guideway tolerance and equipment needs may require frequent inspection and ongoing maintenance). See table 4-4 for a summary of cost data for maglev and high-speed rail.

maglev guideway costs could vary greatly, depending on the system design. Because EDS maglev would use a lighter vehicle and require less precise guideway tolerances, its construction costs are estimated to be lower than those for EMS. However, costs depend greatly on beam properties—such as cross-sectional area, material, and stiffness—so it is difficult to make general comparisons between EDS and EMS construction costs. For example, computer-integrated manufacturing can lower fabrication costs for all kinds of beams and make high EMS tolerance requirements less of a cost factor. On the other hand, some EDS concepts suggest box and circular beams, which could use less material than EMS beams and therefore be less costly. Since guideway costs make up a major portion of total system costs, all guideway options should be investigated. Generally, guideway costs for EDS do appear to be the same as or lower than for EMS guideways, all other factors being equal (guideway electronics, material costs, optimal shapes for beam) .18

18George Anagnostopoulos, Volpe National Transportation Systems Center, personal communication, Apr. 29,1991.

Regulations and Safety

Because neither maglevnor high-speed rail systems exist in this country, many issues related to these technologies are difficult to address within the existing regulatory and safety framework. Such issues include the institutional framework itself, safety certification, vehicle standards, guideway and system performance standards, emergency response procedures, and environmental impacts.

Institutional Framework

Two Federal agencies have jurisdiction over high-speed ground transportation: FRA and the Federal Highway Administration (FHWA). FHWA'S jurisdiction involves multiple right-of-way usage, including air rights, and grade crossings.[19] FRA has authority over all intercity passenger rail transportation and is charged with assuring the safety of maglev systems in the United States under the Rail Safety Improvement Act of 1988. All high-speed guided ground transportation systems (maglev, air-cushioned vehicles) have historically come under FRA authority, even though no such systems are currently operating in this country. Recognizing the inadequacy of the present framework to address maglev or high-speed rail safety issues, FRA embarked on a multiyear research program in 1989 to establish the appropriate safety measures that should be applied to these technologies.

FRA regulations relating to safety tend to be technology and component specific and were adopted from years of railroad operating experience. Although maglev systems consist of the same basic system elements as any guided ground or rail transport system, they use fundamentally different suspension and propulsion technologies. Therefore, most existing railroad regulations are not directly applicable, although the intent of some regulations is appropriate for maglev as well as railroads. Besides FRA standards, other Federal regulations could apply to maglev—Federal Aviation Administration (FAA) windshield strength standards and UMTA emergency preparedness procedures for rail transit, for example. FRA will have to modify its regulations and develop new ones to address maglev-specific safety issues. A number of foreign and other transportation industry safety standards and guidelines exist that could be applied to the proposed U.S. maglev systems (see box 4-E).[20]

Safety Certification

The only system for which even preliminary safety and certification guidelines have been proposed is Transrapid, which is the only high-speed maglev system advanced enough to be considered for revenue operation. Responsibility for safety assurance and proposing safety standards during technology development for Transrapid has rested on TUeV Rheinland (an independent certification authority), acting as an agent for the government of the Federal Republic of Germany. FRA will require Transrapid International to certify that the design, construction, and testing of the maglev system complies with TUeV's safety standards and with any construction plans and specifications submitted to FRA. Although no definite timetable has been set for issuing new regulations or guidelines, FRA does intend to establish testing requirements, including a list of safety-related tests to be performed by the operator of any maglevsystem prior to commercial operation of the system, and at regular intervals thereafter. The Orlando line could operate under a special demonstration waiver, if FRA requirements have not been issued by the time testing of that system begins.

At present, TUeV requirements state that the vehicle levitation and guidance functions will not be lost under any sequence of system failures, and that the vehicle will maintain its own suspension until it is brought to a stop by either central control or its own internal control system. This "safe hovering" concept requires that the vehicle come to a stop only at guideway locations where auxiliary power and evacuation means are provided. The vehicle must be able to reach the next allowable stop location independent of the wayside power system (i.e., relying solely on momen-

[19] 23 CFR 646.

[20] For further information see U.S. Department of Transportation, Federal Railroad Administration, *Safety of High Speed Magnetic Levitation Transportation Systems: Preliminary Safety Review of the Transrapid Maglev System*, DOT/FRA/ORD-90/09 (Washington, DC: November 1990); and Robert M. Doer et al., *Safety Relevant Observations on the X2000 Train as Developed for the Swedish National Railways* (Cambridge, MA: U.S. Department of Transportation, Volpe National Transportation Systems Center, December 1990).

Box 4-E—High-Speed Rail Safety Standards

High-speed steel-wheel-on-rail systems include all the technologies of conventional rail systems, but because vehicle and track standards for high-speed rail are more stringent, more and newer safety equipment must be in place. For instance, overhead bridges are commonly equipped with intrusion detection devices to provide warning if a vehicle breaks through a bridge railing and could fall onto the track area. At European grade crossings, where some high-speed trains routinely cross highways at 125 miles per hour (mph), on-train closed-circuit television, gates, and warning sounds are used. All routes on which trains exceed 125 mph have been grade separated. Other safety and route protection measures for high-speed rail include fencing to protect against intrusion on the right-of-way, induction loops, interlocking signaling, and speed monitoring. Automatic train detection, which uses the rail as an electrical conductor and senses trains when they close the circuit, activates warning and control systems to warn motorists—a technique that is standard grade-crossing protection for freight systems in North America.

European high-speed rail uses concrete crossties and elastic fasteners, which provide a more stable structure than the wood ties and cut spikes traditionally used in North America and are projected to have a life of 40 to 50 years under light-weight, high-speed trains. Amtrak's high-speed tracks between Washington, DC, and New York City use primarily concrete crossties.

Current U.S. rail operating practices, vehicle and track standards, and communication and signal system practices differ in many respects from pertinent foreign high-speed rail practices recommended by the International Railway Union (Union Internationale des Chemins de Fer), and from those of foreign railway companies presently operating trains at speeds of 130 mph or more. Design practices for tracks, roadways, bridges, and other structures in the United States are standardized in the recommended practices of the American Railway Engineering Association (AREA) and incorporated in 49 CFR 200-268. The passenger equipment interchange rules of the Association of American Railroads (AAR) were canceled effective Jan. 1,1984, and republished as recommended industry practices. U.S. industry design standards are embodied in the recommended practices of AAR, AREA, and Amtrak specifications, but not all are enforced under the U.S. code.

Federal Railway Administration (FRA) vehicle crashworthiness regulations are based on the assumption of mixed freight-passenger traffic. They stipulate that vehicles be able to withstand certain compressive loads without permanent deformation and led to heavier trains than those on European or Japanese high-speed systems. Foreign high-speed rail systems are generally dedicated to passenger service and assume a greater need for collision avoidance and energy absorption during collisions. For high-speed power cars in Europe, the relatively low buff strength is compensated for by the varying use of energy-absorbing, or collapsible, structures at the cab ends to provide protection to the crew in the event of collisions. This protection is less than that provided by locomotives and self-propelled cars in North American service. This aspect is partially offset on high-speed lines, however, by severely limiting access to the tracks to reduce significantly the probability of collisions.[1]

Track standards also differ between U.S. and foreign systems. FRA categories track quality in six classes. Maximum permissible train speed is restricted to a specified limit for each class—the poorest quality track is class 1 and the best is class 6. Class 6 maximum permissible passenger train speed is 110 mph, and to exceed this, a railroad must petition FRA for a waiver of the rules. Europeans have established track standards in some areas for safe speeds of up to about 200 mph.

To provide for maintenance activities and unforeseen contingencies, virtually all lines handling high-speed trains are equipped with complete high-speed crossover tracks and bi-directional signals. Tunnels and other problem areas are provided with repeaters or auxiliary antennas to ensure reception and continuous voice communication.[2]

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[1] John Bachman, Bachman Associates, "Federal Law and Regulations Relevant to High Speed Rail Systems,'' working paper prepared for The Florida High Speed Rail Transportation Commission, September 1986.

[2] Transportation Research Board, "Safety Factors Related to High-Speed Rail Passenger Systems," *Transportation Research Circular 351* (Washington, DC: National Research Council, July 1989).

Continued on next page

Box 4-E, continued

The primary function of a signal system is to provide a warning early enough to permit a train to stop safely, and signal spacing is based on calculated stopping distances. Because stopping distance increases proportionally to the square of the speed, high-speed trains would require very long stopping distances, if conventional braking systems were used. (In an emergency, trains can change speed only, not direction.) After stopping distances have been determined for a particular type of vehicle's braking system on a specific line profile, European regulations add a 10-percent factor of safety to allow for poor adhesion, improperly adjusted brakes, low air pressure, and other variables. TypicaI American industty practice has been to add **15 to 25** percent as a safety factor. The automatic train control systems in Europe normally allow for 4 to 8 seconds (similar to U.S. practice) for the train operator to react and apply the brakes before the system applies an automated brake. The distance traveled during this reaction time must also be added to the stopping distance to determine the proper signal spacing (an additional 1,760 feet at 150 mph). In summary, the stopping distances for European high-speed trains that are used to determine signal spacing are appreciably shorter than those of typical American practice because of the additional braking capacity of the high-speed trains (dynamic and track brakes).[3]

[3]1bid.

turn or an onboard energy supply). The vehicle must also be able to bring itself to a safe stop without any input or guidance from the central control system.[21]

maglev Vehicle Safety Standards

maglev vehicles have both a primary and a secondary braking system, which function independently of each other and provide controlled braking. The primary brake is initiated by the central control system, which controls the propulsion motor (drive) to reverse vehicle thrust. Secondary braking is accomplished using longitudinal vehicle magnets to induce eddy currents in the track guide rails. Since the eddy current brake force decreases sharply with speed, the final emergency braking requires the vehicle to come to a stop on landing skids (in the case of Transrapid).[22]

There is concern that passengers cannot exit the vehicle safely in an emergency unless it is at a preestablished exit location. Evacuation chutes, like those on aircraft, and a walkway on the guidcway leading to evacuation ladders are options that could alleviate this concern.

The structural design of the maglev vehicle is similar to that of aircraft, and the vehicle is not designed to withstand the buff forces railcars are required to withstand. Buff strength is defined as the amount of longitudinal compressive load a ear body can take without permanent deformation. **In-depth evaluation of crashworthiness is essential.** FAA window glazing requirements might be considered for use in modifying existing FRA regulations.[23] maglev vehicles might have pressure-sensitive doors similar to those required by European high-speed rail standards. U.S. standards also do not address the impact of lightning on maglev safety and operation.[24]

Guideways

A maglev guideway consists of bearings, beams, footings or foundations, and piers or columns spaced approximately every 80 feet. The guideway must have

21 Federal Railroad Administration, op. cit., footnote 20, p. 3-5.
[22]1 bid., p. 3-8.
[23]49 CFR 223.
24 Federal Railroad Administration, op. cit., footnote 20, p. 7-1.

sufficient stability and stiffness to transmit all static and dynamic loads to the subgrade while meeting alignment requirements and a service life commensurate with other system components. The guideway must withstand many forces and conditions over time: repeated vehicle loadings, high winds, erosion, oxidation, extreme thermal conditions, and other environmental factors.

Standards

Tolerances for guideways vary according to the maglev concept, but are typically more precise than normal construction tolerances for transportation structures in this country. One of the NMI staff's challenges is to consider developing structural standards for guideways and guidelines for how inspection and maintenance will be performed.[26]

Eliminating the possibility of or detecting the presence of people or objects on the guideway is crucial if casualties or collisions are to be avoided. Requirements for an intrusion detection system or a physical barrier are likely to be necessary to ensure the security of the guideway, especially in areas where the guideway is easily accessible.

Right-of-Way

If interstate highway rights-of-way are to be used for maglev, a number of issues must be addressed, including legality, construction and maintenance on limited access highways, safety impacts, and environmental impacts. Federal-aid highways and their associated rights-of-way are owned, operated, and maintained by the States, but both State and Federal Governments must approve their use. FHWA decisions on the use of Federal-aid rights-of-way are made on a case-by-case basis; there are no set guidelines. Current Federal law has a fair market value provision stipulating that a State must receive reimbursement for use of the right-of-way unless the right-of-way is owned by a publicly owned transit authority. (This may change; the 1991 surface transportation bill proposed by DOT eliminates the stipulation.) States may, however, charge for use of their right-of-way, as is commonly done with utilities.

State and local governments can acquire additional rights-of-way through the power of eminent domain in judicial condemnation proceedings. States vary in the extent to which they permit multiple uses of highway rights-of-way. Condemnation procedures often strictly limit the purposes for exercising eminent domain, including restricting use of the condemned land to specific purposes. Issues of whether and how State or local government rights-of-way can be used must be resolved, especially if maglev is built and operated by the private sector.

Since allowing the use of a Federal-aid right-of-way for maglev is a major Federal action requiring FHWA involvement, the compliance of a maglev system with provisions of the National Environmental Policy Act must be satisfied. The level of environmental analysis and documentation required to ensure compliance depends on the extent of the encroachment and the nature and extent of project impacts. The approval action may be either a categorical exclusion, an environmental assessment finding of no significant impact, or a request for an environmental impact statement.[27]

Safety Impacts

Present highway policy maintains the desirability of a clear zone, or unobstructed recovery area, in the median strip and along the edges of highways to allow room for vehicles leaving the road either to recover and return to the pavement or to run a reasonable distance before colliding with an object (see box 4-F). If maglev systems use elevated guideways in highway medians, questions must be resolved about the safety of the piers for vehicles and drivers, the impact of road vehicles on the piers, and the safety of the maglev vehicles. The potential for the crash of an 80,000-pound or heavier truck traveling at 55 mph or more into a concrete pier must be taken into account in guideway design if the piers are located near the roadway.

25 For Transrapid these are 0.1 inch per 32.8 feet, since its suspension system requires close tolerances.
26 Federal Railroad Administration, op. cit., footnote 20, p. 7-1.
27 Letter from the Federal Highway Administration (FHWA) Executive Director to FHWA San Francisco Regional Administrator, Apr. 4, 1990.

Box 4-F—Mukiple Uses of Highway Rights-of-Way

The American Association of State Highway and Transportation Officials (AASHTO) has long been active in matters of highway policy and engineering. AASHTO'S policy on highway rights-of-way states:

> A recovery area clear of unyielding objects should be provided. When provision of such an area is not practicable, any unyielding objects within its limits are to be made breakaway or are to be shielded by installation of crashworthy barriers or attenuators. Similarly, to the extent practicable, the pier and abutment supports for another highway or for a railroad overpass structure should be designed to provide a lateral clearance equal to the clear recovery area. The width of the recovery area is to be commensurate with the selected design speed and roadside conditions. The width is to be determined through application of currently accepted procedures. In restrictive areas, it may be necessary to construct barriers, walls, piers, abutments or other unyielding objects nearer to the traveled way than the width required for a clear recovery area. The minimum lateral clearance from the edge of the through lanes to the face of such objects shall be the shoulder width with appropriate crashworthy barriers and attenuators.[1]

Although AASHTO authority is not binding, most States and the Federal Highway Administration use these guidelines, and clear zones and recovery areas must be taken into account in decisions about maglev or high-speed rail route alignments. The Department of Transportation has recently begun a 6-month study, entitled "Shared Right of Way and Safety Issues for High Speed Guided Ground Transportation," which is examining the operation of maglev and high-speed rail along highway rights-of-way.

[1] Francis B. Francois, executive director, American Association of State Highway and Transportation Officials, testimony at hearings relating to the development of high-speed transportation corridors, before the House Committee on Public Works and Transportation, Subcommittee on Surface Transportation, May 3,1991.

Another area of possible conflict is the effect of the maglev or high-sped rail power systems, if any, on vehicle and highway electronics. Electronic fuel injection equipment and computers in automobiles and trucks are increasingly common. Also, sensor and communication technologies related to intelligent vehicle/highway systems must be taken into account in maglev system analyses.[28] Federal Communications Commission requirements related to electromagnetic emissions must be considered.

Emergency Procedures

Provisions must be made to allow passengers and employees to leave the vehicle and allow emergency response personnel to enter the vehicle at any location where an emergency can occur. In existing European high-speed rail systems and Amtrak, train crews are instructed and given practical training in routine and emergency public address system announcements as well as hands-on practice to protect, evacuate, and rescue passengers. This type of training is also provided by the railroad and car builders to fire departments and other emergency organizations located along the routes. Some railroads furnish detailed local maps to regional fire and rescue groups to expedite their access to train accident sites.[29] **At present, FRA has no guidelines, regulations, or standards addressing this issue.** An emergency equipment and facilities response plan that addresses emergency response training and preparedness is needed.

[28] Francis B. Francois, executive director, American Association of State Highway and Transportation officials, testimony at hearings relating to the development of high-speed transportation corridors, before the House Committee on Public Works and Transportation, Subcommittee on Surface Transportation, May 3, 1990.

[29] Transportation Research Board, "Safety Factors Related to High-Speed Rail Passenger systems," *Transportation Research Circular 351* (Washington, DC: National Research Council, July 1989).

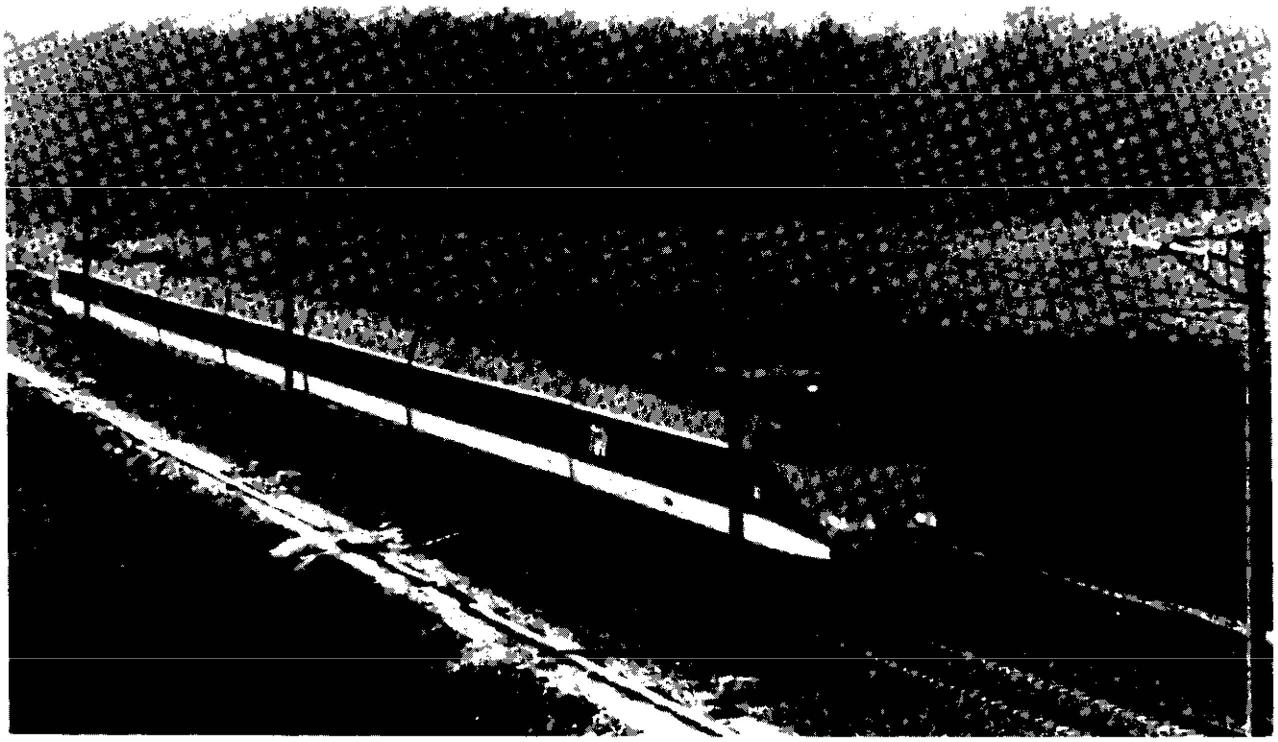


Photo credit: SCNF

The Train a Grand Vitesse (TGV) currently operates at high speeds along 1,100 miles of track in France.

Health and Environmental Issues

maglev and high-speed rail systems face **a** number of potential health and environmental hurdles **affect**ing their public acceptability, including electromagnetic fields and noise. Resolution of these issues is just as important **as** technical performance.

Electromagnetic Fields

One of maglev's consistent selling points has been its power source. Electrical power, the reasoning goes, provides a clean, efficient, and safe energy source. But as attention has focused recently on the possible harmful effects of EMFs, this selling point for maglev could turn out to be a major roadblock, depending on which suspension technology is used. The fields encountered in passenger cabins and along the wayside of an EMS system are on the same order of magnitude **as** ambient Earth levels and about the same as or below the field levels associated with common household appliances, such as microwave ovens, refrigerators, and hair dryers. With current EDS designs, however, DC magnetic field levels can significantly exceed acceptable limits, and measures will have to be taken to reduce these levels or to shield passengers and bystanders from their effects. In addition, existing Department of Health and Human Services rules regarding electromagnetic emissions must be considered in any maglevsystem. Appendix A describes what is currently known about EMF levels and their impacts on human health.

Air Quality and Noise

Neither maglev nor high-speed rail systems depend on petroleum for power and consequently do not de-grade air quality where the vehicles operate. Moreover, they are projected **to** be four or more times as energy efficient as wide-body airliners.[30] Air pollution in the form of carbon dioxide emissions generally depends on power requirements. For electrified systems such as maglev, these emissions would have point sources rather than mobile sources and would probably not occur in areas where air quality is a concern.

maglev and high-speed rail produce noise levels that increase with speed. Aerodynamic factors are the principal noise contributors for maglev. High-speed rail noise is affected by those factors plus wheel/rail interaction, the propulsion system, and a high-speed pantograph-catenary interaction.[31] Above about 150 mph, aerodynamic noise exceeds other sources of noise for high-speed rail. At speeds in this range and above, the vehicle can be heard many hundreds of feet from the right-of-way, and in populated areas, a reduction in speed for noise reasons alone (accompanied by sound barriers or other measures) may be necessary. At speeds above 170 mph, the TGV produces noise levels in the 90- to 100-decibel (dB) range.[32] By comparison, noise from a heavy truck traveling on the highway measures about 90 dB, while that from a jet takeoff measures 105 dB 2,000 feet away from the source. Table 4-5 summarizes the noise impacts of various transportation modes. Federal agencies, including DOT, EPA and the Department of Housing and Urban Development, are involved in regulating noise impact. In addition, many municipalities have noise ordinances that must be complied with during construction and operation.

Table 4-5-Noise Characteristics of Transportation and Other Activities

Activity	Sound level in decibels
Whispering	30
Light auto traffic at 100 ft	50
Conversational speech	60
Vacuum cleaner at 10 ft.	69
Freight train at 50 ft	75
Shinkansen at 150 mph at 82 ft.....	80
Alarm clock at 2 ft	80
Riding inside a city bus	83
Trensrapid at 185 mph at 82 ft......	84
Heavy truck at 50 ft	90
TGV at 185 mph at 82 ft..	91
Jet takeoff at 2,000 ft.	105
Jet takeoff at 200 ft.	120
Threshold of physical pain	130

SOURCE: Office of Technology Assessment, 1991, based on U.S. General Accounting Office data.

Institutional and Financing Issues

No matter how developed the technology, many institutional issues surround the approval, construction, and operation of new high-speed ground transportation systems, including who will operate them, on whose land they will be built, and who will finance them. The choice of potential operators, which depends on who owns the system and right-of-way, includes airlines, public transportation authorities, railroads, or other private providers. Careful consideration must be given to where these new systems are built, who will operate them, and whether more than one operator can use the same guideway or right-of-way.

Community Acceptance

Objections on grounds of noise, EMFs, traffic congestion near new station sites (particularly in urban areas), and aesthetics are likely to be the major obstacles to gaining community acceptance. Intense public education, combined with adequate environmental protections, will be required before any system gains widespread popular support. Even with privately owned rights-of-way, which may not require as much official review, States would probably not proceed without full environmental compliance. Efforts to shorten the environmental impact assessment process could create public distrust, as was the case in the Los Angeles-San Diego project sponsored by the American High Speed Rail Corp.

30 U.S. Department of Transportation, Volpe National Transportation Systems Center, "Innovative Technology for Intercity Passenger Systems," unpublished draft report, Aug. 24,1990, p. 37.

31 A catenary is an overhead wire from which electrical current is drawn. A pantograph draws current from the catenary.

32 The Canadian Institute of Guided Ground Transport, Queen's University at Kingston, Ontario, "Characterization of High-Speed Ground Transportation Technology Alternatives for U.S. Applications and Discussion of Key Issues and Questions,'' unpublished report, Nov. 28,1990, p. 5-15.

Proposals calling for the construction of entirely new rights-of-way will require public agreement on land-use questions. Permission to use or buy a right-of-way in the United States would have to be sought from any number of organizations that could include States, municipalities, transit properties, airports, Amtrak, freight and commuter railroads, toll and turnpike authorities, utilities, and private citizens and organizations. The support for maglev or high-speed rail by local governments, institutions, environmentalists, and citizen groups will be influenced by projections of demand for the service, by the amount of urban land and areas of natural beauty through which the line must travel, and by the perceived need to reduce congestion elsewhere. Ironically the areas where maglev or high-speed rail are most likely to be successful are so densely populated that establishing new high-speed lines is difficult and costly. In constructing the TGV, high capital costs and environmental opposition were avoided by using existing, state-owned rights-of-way into and out of Paris. The line between Paris and Lyon encountered relatively little opposition because of the low population density between the cities.

If government subsidies are used to finance a new system, political disputes may occur over which areas should host it and what the appropriate site selection criteria would be. Local government support may well depend on whether a local stop is included in the new route. If a number of intermediate stops are made to satisfy local interests, travel time between large urban centers would increase, and the new system would be less competitive with other modes.

Intergovernmental and Financing Issues

Governments have played a strong role in transportation infrastructure development because relying on private funding is often not feasible (see chapter 2). Government support has been essential to the development of new transportation technologies—Germany has invested around $1 billion in the Transrapid; Japan is planning to spend $3 billion over the next decade on maglev development and testing; the TGV and Shinkansen systems were supported significantly by their respective national governments or railroads; the United States spent approximately $15 million on the High Speed Ground Transportation program from 1965 to 1975, roughly $2.3 million of which went toward maglev research.

Even if foreign-developed vehicle technologies are used, financing for construction of new infrastructure remains a huge obstacle. Financing for high-speed rail projects in this country was encouraged by a Federal law enacted in 1988 exempting from Federal income tax those revenues received on bonds issued for high-speed, intercity rail facilities. Choice of operator will affect labor regulations and costs and the amount of competition encountered from other modes. It is unclear, for example, how existing railroad labor statutes will apply to high-speed rail or maglev. Finally, acquiring the right-of-way, particularly in congested corridors, could prove to be a major obstacle.

Of the many high-speed ground transportation corridors that have been proposed, a few (Los Angeles-San Diego, Miami-Tampa-Orlando) have reached the stage where project financing has been seriously considered. Although most States have established policies that any high-speed rail or maglev project must be privately funded, no private entity has ever expressed willingness to bear the full costs of any proposed system. All projects have proceeded from assumptions (sometimes unstated) that the public sector will facilitate or financially support such activities as land acquisition for right-of-way, guideway or track construction, station construction, environmental mitigation, grade separation, and so forth.

Funding for major transportation projects typically comes from taxes or passenger fares, regardless of whether the project is publicly or privately financed. Mechanisms suggested for aiding high-speed rail/maglev projects include sales taxes, motor vehicle fuel tax revenues, bond issues, station development cost-sharing, developer fees, “capturing” increases in value of the land surrounding stations, tax-free status for project bonds, exemption or special status regarding environmental approval and fees, Federal loan and investment guarantees, special taxes, and diversion of funds from other public sources. Timely payment of interest during construction also appears to be very important in determining project profitability.

Other financing options include establishment of special taxing districts to allow projects to be financed by property taxes on local businesses, benefit assessments, tax increment financing, development impact fees, equipment leasing, and joint public-private development. DOT has proposed legislation permitting States to provide available highway rights-of-way at little or no cost to high-speed rail projects, including maglev. The current provisions for market-rate compensation of highway rights-of-way drive up the costs of high-speed rail and maglev projects, although there are good policy reasons, in many cases, for encouraging the co-location of transportation facilities. Another proposal under consideration would permit States to use Federal-aid highway funds to make highway facility adjustments to accommodate other modes, including high-speed rail and maglev. Such improvements might include alignment modifications, fencing, drainage, structural work, grade crossing elimination, and construction of modal separation barriers.[33]

Conclusions

maglev and high-speed rail systems show considerable technical promise as high-volume, intercity passenger modes in selected corridors up to about 500 miles, However, any system would require substantial infrastructure investment initially, although high-speed rail and probably maglev systems have low operating costs relative to other modes. maglev requires further development and local demonstration before it could enter intercity service in this country. Intercity high-speed rail systems are already highly developed and operating in Europe and Japan.

Economics and Market Potential

U.S. demographics and geography and the construction costs of implementing maglev or high-speed rail raise difficult financial and policy issues which must be addressed before any intercity system can go forward. Only a few U.S. corridors have population and travel densities comparable to the European and Japanese corridors currently enjoying high ridership. Thorough, independent market research, including analyses of current door-to-door travel trends, intermodal connections, modal preferences, and modal competition, must be undertaken to assess the potential ridership and benefits of new maglev or high-speed rail connections and determine which corridors are most likely to benefit from high-speed ground service.

Guideways and Right-of-Way

Right-of-way alignment must include long, straight sections or large-radius curves if maglev vehicles or high-speed trains are to achieve average travel speeds approaching maximum vehicle speeds. Existing interstate rights-of-way, which were designed for 70 mph, are not adequate for current maglev or high-speed rail concepts to achieve sustained high (150 mph+) speeds in many areas. Acquiring rights-of-way in all corridors where maglev or high-speed rail could be used effectively would be both difficult and costly.

Guideway design and construction represent the majority of total system cost. Further work is needed in developing optimal guideway shapes that make most efficient use of material and yet meet requirements for tolerance and low maintenance. Concepts that employ banking of the track or guideway as well as tilt of the vehicle could enable higher speeds through curves while still maintaining high passenger comfort levels. Construction and fabrication methods that minimize onsite time and labor requirements and thereby reduce cost are also needed.

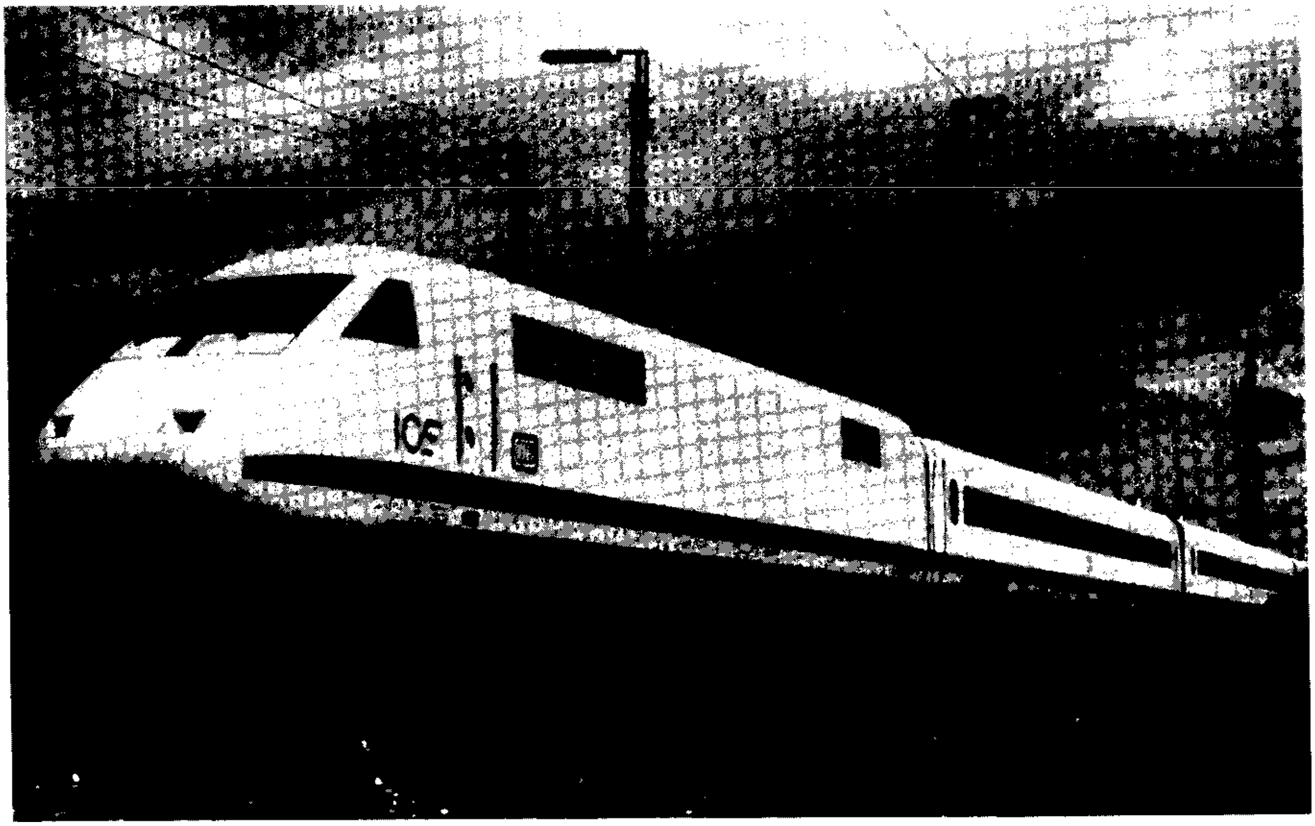
Research and Development

The National maglev Initiative marks renewed U.S. interest in maglev and will provide useful input regarding how or whether to pursue this technology. While results from the NMI are not yet in, it is clear that several technical issues need further work before maglev systems can begin revenue service.

EMF health effects are still unknown, but exposure levels from EMS maglev and high-speed rail are believed to be on the same order as those emanating from common appliances. EDS maglev produces higher DC magnetic fields, however, and will require design strategies and magnetic shielding for minimizing passenger exposure.

Further development needs for EDS maglev include: negotiating curves while maintaining adequate stability, cooling the superconducting magnets, limiting EMF in the passenger compartment, and cost re-

[33] Elaine L. Chao, deputy secretary of transportation, U.S. Department of Transportation, remarks at Washington High Speed Rail Forum, Washington, DC, Nov 9, 1990.



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ductions for superconducting magnets and magnetic shielding. High-speed maglev concepts that incorporate many branch lines will require further development of switching technology. High-speed rail R&D issues include braking capabilities, wheel/rail dynamics, and economically acceptable techniques for collecting current at speeds over about 200 mph.

Institutional Issues

Intergovernmental Arrangements

Should the decision be taken to develop maglev technology, careful consideration must be given to how the development should proceed and who should undertake it. Different areas of technical expertise reside in various government agencies, private firms, and universities. A **lead organization must be chosen or created to coordinate research on areas critical to maglev systems, ensure compatibility between system components, and, when appropriate, develop a strategy for testing prototypes (including selection of test sites).** At some point, a decision may have to be made regarding suspension and guideway configurations, since different maglev designs are mutually incompatible for network operations. It is estimated that full-scale maglev development costs would range from a minimum of $750 million to somewhat over $1 billion, most of which would go toward prototype and test facility design and construction.

Safety and Certification

Operational safety features of existing maglev prototypes as well as the zero-fatality rate of existing high-speed rail systems indicate that these technologies could potentially operate more safely than all other passenger modes. However, the current U.S. safety and regulatory framework for railroads cannot be directly applied to maglev and high-speed rail, and **needs major reformulation. FRA must ensure that it has sufficient technical and administrative expertise for this task** At present, for example, track standards for steel-wheel technology cover only speeds up to 110 mph. Current FRA and Association of American Railroads practices governing traffic control, track standards, and crashworthiness are based on the assumption of mixed passenger and freight traffic. Dedicated rights-of-way for passenger traffic, which are practically a necessity for high-speed systems, require a rethinking of current regulations. A new total system safety approach must be developed for high-speed rail and maglev. A separate safety evaluation process for different types of vehicles (transit mixed passenger/freight, dedicated, passenger-only high-speed rail), somewhat like the case in aviation, may be warranted.

No matter how developed the technology, maglev or high-speed rail systems must gain public acceptance and be publicly financed in order to be built. Atypical line could fall under many different State and local jurisdictions, complicating the regulatory and finance picture considerably. Siting the right-of-way, noise, and electromagnetic fields are the factors likely to cause the greatest concern, and each must be effectively mitigated if new systems are to stand any chance of being built. Technology demonstration and validation will be crucial in gaining public acceptance of a new system. Since private backing for new systems has been inadequate to cover initial costs fully, some combination of financial and institutional public support will be necessary for capital costs. Public sector support is essential if substantial R&D is to be conducted domestically.[34]

[34] For further information, see Arthur D. Little, Inc., *An Industry Perspective on Maglev*, DOT/FRA/ORD-90/07 (Washington, DC: U.S. Department of Transportation, June 1990).