Final Report on

The National Maglev Initiative

September 1993

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16. Abstract

High-speed magnetically levitated ground transportation (maglev) is a new surface mode of transportation in which vehicles glide above their guideways, suspended, guided, and propelled by magnetic forces. Capable of traveling at speeds of 250 to 300 miles-per-hour or higher, maglev would offer an attractive and convenient alternative for travelers between large urban areas for trips of up to 600 miles. It would also help relieve current and projected air and highway congestion by substituting for short-haul air trips, thus releasing capacity for more efficient long-haul service at crowded airports, and by diverting a portion of highway trips.

This report presents the findings and recommendations of the NMI, a unique interagency cooperative effort of the Federal Railroad Administration (FRA) of the DOT, the USACE, and the DOE, with support from other agencies. The purpose of the report is to recommend future Government action regarding maglev. The recommendation is based on private sector and Government information generated during the past 3 years concerning the viability of maglev as an intercity transportation alternative for the United States. The information includes the projected technical and financial performance of maglev in intercity markets in competition with other modes of travel, the anticipated external benefits such as reduction in pollution and congestion in other modes, and other national-level impacts. The report considers the potential of a new United States Maglev (USML) system compared with that of alternatives using existing maglev technology or high-speed rail (HSR).

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Maglev, High-Speed Ground Transportation, Intercity Transportation, magnetic levitation, high-speed rail, German maglev system, TGV, maglev economics, maglev technology

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (ml) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq ml, ml^2) = 2.6 square kilometers (km^2)
1 area = 0.4 hectares (hs) = 4,000 square meters (m^2)

MASS – WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.95 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y°C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (ml)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq ml, ml^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS – WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

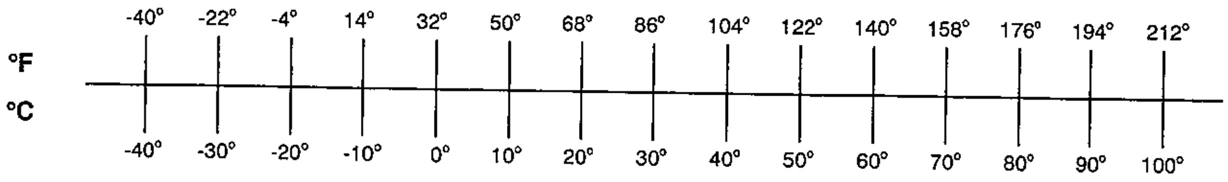
1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x°F

QUICK INCH-CENTIMETER LENGTH CONVERSION

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION



For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50, SD Catalog No. C13 10286.

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Preface

In June 1990, the Department of Transportation (DOT), responding to a directive from Congress, submitted a preliminary report on the technical and economic feasibility of constructing high-speed, intercity maglev transportation systems in the United States. At the same time, the U.S. Army Corps of Engineers (USACE), also in response to Congress, submitted a preliminary implementation plan for the development of a U.S. designed maglev system. In its report, the Department's preliminary conclusion was that some maglev routes could be built and run at a profit and that public benefits could justify public sector support on other routes. Although there was some indication of the opportunity for significant technological advances, the limited nature of the study was insufficient to develop recommendations for initiating a maglev program in the United States. Further technical and economic investigation was recommended.

In April 1990, the DOT, USACE, the Department of Energy (DOE), and other agencies formed the National Maglev Initiative (NMI) to conduct and coordinate further research and evaluation. The goals of the NMI were to continue the analysis conducted earlier in evaluating maglev's potential for improving intercity transportation in the United States and also to determine the appropriate role for the Federal Government in advancing this technology. About $26.2 million was spent through FY 1992 on maglev technology research and economic analysis. In FY 1993, an additional $9.8 million was appropriated to complete the NMI and conduct high priority research. Also, in December 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) authorized a $725 million maglev prototype development program but no funding has been appropriated for FY 1992 or 1993, pending the results of the NMI.

The purpose of this report is to recommend future Government action regarding maglev. The recommendation is based on private sector and Government information generated during the past 3 years concerning the viability of maglev as an intercity transportation alternative for the United States. The information includes the projected technical and financial performance of maglev in intercity markets in competition with other modes of travel, the anticipated external benefits such as reduction in pollution and congestion in other modes, and other national-level impacts. The report considers the potential of a new United States Maglev (USML) system compared with that of alternatives using existing maglev technology or high-speed rail (HSR).

The report discusses three options for acquiring maglev technology for the United States. The first option is to acquire maglev technology currently being developed in Germany or Japan. The second option is to undertake advanced maglev development in partnership with Germany or Japan. The third option is to invest in an advanced USML development program. Based on a comparison of the three options, the report recommends a program that is appropriate to and consistent with the Federal role in a national transportation strategy.

High-speed magnetically levitated ground transportation (maglev) is a new surface mode of transportation in which vehicles glide above their guideways, suspended, guided, and propelled by magnetic forces. Capable of traveling at speeds of 250 to 300 miles-per-hour or higher, maglev would offer an attractive and convenient alternative for travelers between large urban areas for trips of up to 600 miles. It would also help relieve current and projected air and highway congestion by substituting for short-haul air trips, thus releasing capacity for more efficient long-haul service at crowded airports, and by diverting a portion of highway trips.

Strategic economic goals of job creation, technological advancement, international competitiveness, and petroleum conservation would be supported by the development and building of maglev systems.

Conclusions

This report presents the conclusions and findings of the NMI, a unique interagency cooperative effort of the Federal Railroad Administration (FRA) of the DOT, the USACE, and the DOE, with support from other agencies. The findings are based on a series of comprehensive studies conducted over a 36-month period to evaluate the potential for maglev in the future U.S. transportation system and the role of the Federal Government in achieving that potential. The principal conclusions of these studies are:

- U.S. industry can develop an advanced U.S. Maglev (USML) system.
- A USML system has the potential for revenues to exceed life cycle costs in one corridor, and to cover operating costs and a substantial portion of capital costs in others. The high initial investment will require substantial public assistance.
- A USML system would provide an opportunity to develop new technologies and industries with possible benefits for U.S. businesses and the work force.
- A USML system is not likely to be developed without significant Federal Government investment.

U.S. Industry Can Develop an Advanced USML System

With an adequately funded program, U.S. industry would have a high probability of success in developing a U.S.-designed and built magnetic levitation system with physical performance capabilities better than those of existing maglev or high-speed rail (HSR) systems. This conclusion is based on results of studies of critical technologies under 27 contracts sponsored by the NMI and on the evaluations and independent analyses of four system concepts defined under major contracts awarded by the NMI. Findings from these studies are as follows:

- A U.S. 300-mph maglev system is feasible.
- In locations where land is too costly or unavailable, following existing rights-of-way (ROW) can be an acceptable

option. A USML system can be designed to include tilting mechanisms and high-powered propulsion systems that would allow vehicles to follow existing ROW at very high speeds. Tilt angles up to 30° and turning rates involved in following existing ROW at high speed will be acceptable to most travelers.

- There are many cases where following existing ROW would not be cost-effective. A limited sharing (LS) alignment with shared use limited to urban areas permits higher operating speeds, reduced guideway length, and shorter trip times. Extensive Sharing (ES) ROW alignments tend to be inferior to the LS alignments in ridership, costs, and overall financial performance.

- A USML system can be designed so that magnetic fields are attenuated to normal urban levels without severe weight or cost penalties.

- A new USML system can be designed with new composite materials and innovative vehicle components to reduce weight and energy consumption.

At the same time, promising innovations for further technological improvement were identified. If proved effective, they would reduce the cost and improve performance of a USML system. Most prominent among these potential innovations are:

- Local commutation or individual control and activation of each guideway propulsion coil for a linear synchronous motor (LSM) will lower capital costs while enhancing propulsion performance.

- Use of the same coil system to transfer auxiliary power from the guideway onto the vehicle, as a spin-off of the locally commutated LSM, will reduce on-board battery requirements and associated vehicle weight.

- Applying the rapid advances in power semiconductor technology, in which the United States has a lead, will reduce both capital and operating costs. The savings result from substantial reductions in size and weight as well as improved efficiencies of power conditioning equipment for both vehicle and wayside systems.

- Electronic vehicle switching to replace current movable mechanical switches in the guideway will result in higher vehicle speeds and reduced headways, reducing trip time and increasing system capacity.

Although none of these improvements are considered to "leap frog" the existing maglev designs, taken together, they represent a significant opportunity for U.S. industry to participate in the maglev competition.

Synthesis of the above NMI findings gives rise to what would be expected in a USML. Table ES.1 below compares a USML technology that could result from a development program, with existing high-speed ground transportation (HSGT) technologies. The costs shown on the first 2 rows of Table ES.1 include only distance-related costs of guideway structure, electric power supply, propulsion, and control systems. They do not include vehicle costs, the costs of major facilities, such as stations and

Table ES.1
Cost and Performance of Different Systems

Parameter	TGV[1]	TR07[3]	U.S. Maglev
Elevated Guideway ($ millions/mi)[2]	22.3	19.6	17.6
At Grade Guideway ($ millions/mi)[2]	3.3	17.4	13.0
Range of Initial Capital Costs ($ millions/mi)[4]	17.2 - 33.4	30.4 - 49.3	26.6 - 45.4
Cruise Speed (mph)	200	311	300
Maximum Grade (%)	5.0	10	10
Acceleration Time(s) with Full Thrust (sec)			
0-186 mph	408	107	36
0-300 mph	---	240	58
Total Bank Angle (°)	7	12	30

Note:
(1) Modified *Train a Grand Vitesse* (TGV) proposed for the Texas HSR System.
(2) Includes only distance-related technology costs.
(3) German Maglev System.
(4) A construction financing cost is included in these estimates using the 7 percent discount rate.

maintenance or control centers, land acquisition, site preparation, earth moving, tunneling or long span bridges, program management, and contingencies. These factors are, however, appropriately covered in the economic analysis described below and in the third row of Table ES.1, which presents the spread of capital costs per mile for each technology over the corridors analyzed in the NMI studies.

It should be pointed out that the estimated costs for TGV are supported by significant operational experience in France and for TR07, significant test experience in Germany. For USML, the cost estimates were derived from analytical studies by system contractor teams and are considered reasonable; yet, until a U.S. maglev system is built and operated in the United States, there is uncertainty regarding these estimates.

A USML System Has the Potential for Revenues to Exceed Life Cycle Costs in One Corridor, and to Cover Operating Costs and a Substantial Portion of Capital Costs in Others

If a USML system with the characteristics shown in the above table were installed in the 10 top U.S. corridor markets, its revenues would cover operating costs, with substantial contribution to capital costs in all corridors. In the Northeast Corridor, its revenues would cover total life cycle costs. In the other corridors significant public investment would be required. These projected results reflect the ability of the technology to offer the best door-to-door travel time for distances up to 300 miles and very competitive trip times even up to 600 miles. They also, however, reflect the high cost of building such systems, $27 million to $46 million per mile, including site preparation and other costs that depend on terrain, degree of urbanization, and other factors.

The detailed economic results depend on the discount rate used in the calculations. A 7 percent discount rate with constant dollar prices was used as the baseline rate for this report. When translated into market terms (where inflation is taken into account), it would be about 10 to 11 percent. The 7 percent rate is required to be used by the Office of Management and Budget for making economic decisions regarding all Federal Government sponsored or assisted projects. It is intended to reflect the average return to capital investments in all sectors of the economy and, thus, the social opportunity cost of using resources for maglev investments. With a 7 percent rate USML revenues would be slightly higher than life cycle costs in the Northeast Corridor, but would cover only about 30 to 50 percent of life cycle costs in the other nine corridors. Under more favorable assumptions about future travel growth, congestion, and cost of competing modes, two of the corridors would cover life cycle costs and the others would cover about 50 to 80 percent.

A 4 percent discount rate was also used for the same calculations as a sensitivity analysis. When translated into market terms, this is representative of the type of financing that could be available to sponsors of high-speed ground-transportation projects using tax exempt bonds. In this case, in the Northeast Corridor, a U.S. Maglev system would produce a surplus of revenues about 47 percent above life cycle costs. In the other nine corridors, revenues would cover about 50 to 80 percent of the life cycle costs. Under the more favorable assumptions, six corridors would cover total costs, with the other three covering about 75 percent.

Generally, revenue-to-cost ratios would be higher for USML versus both TR07 and TGV at both discount rates; however, outside the Northeast Corridor, where revenues are less than life cycle costs, USML would require higher public investment than TGV, though lower than for TR07. In the Northeast Corridor, the revenue-to-cost ratio for USML would be about the same as for TGV at the 7 percent discount rate, but higher than for TR07, while at the 4 percent rate it would be higher than for both TGV and TR07. The advantages for USML are more pronounced when it is compared to other systems using existing ROW, because of the superior ability of USML to operate on curves at high speed.

USML produces public benefits of reduced environmental pollution, petroleum consumption, and congestion at airports because of its ridership diversion from highways and air systems. Generally, these public benefits are also larger for the USML than for TR07 or TGV because of its comparative attractiveness as an alternative to air and auto travel.

A USML System Would Provide an Opportunity to Develop New Technologies and Industries with Possible Benefits for U.S. Businesses and the Work Force

The development of a USML system would enhance U.S. competitiveness in HSGT, increase the Nation's productivity in related fields, and generate both high technology and construction jobs. U.S. businesses would develop a competitive advantage in building the maglev systems in the United States and possibly abroad. There are a number of elements of the USML system that have significant potential for applications in other fields, giving U.S. business further advantages. Finally, the technology development process itself would require an estimated 15,500 person years of direct and secondary labor–much of it consisting of high technology white collar jobs–at a time when the United States faces less than full employment of these resources because of decreased defense spending.

A USML System is not Likely to be Developed without Significant Federal Government Investment

The technical and financial risk associated with development of maglev and the long-term payback involved are significant, and it is unlikely that private investors would finance a significant share of the development costs. The major development costs will be associated with the vehicle/guideway interaction and propulsion/levitation/ guidance and control issues. These are small relative to the high guideway construction costs encountered in an implementation phase. The industry partners involved in these intricate development activities will not be the ones with the largest potential return. The likelihood of industry supporting significant cost sharing is very low. If maglev were implemented, the ultimate sponsors (i.e., the state and local governments) would be expected to share in the construction costs because they are the ones to ultimately benefit and at that stage, the payback period would be much reduced relative to the development timeframe.

The above principal conclusions suggest that, with significant Federal support, a high probability exists that U.S. industry can develop a maglev system that is superior to existing maglev and HSR technology. This USML would be faster than existing HSGT systems and less expensive to build and operate than the German maglev system. Recommendations related to such a development program are discussed below.

Options for USML

Options for developing a maglev system for the United States fall into several categories, including:

1. Reliance on existing maglev systems developed abroad.

2. Further development of existing maglev technology through joint venture with Germany or Japan.

3. A program to develop a new USML.

Relying on existing maglev systems developed abroad has the advantage of lower development costs, but it also has the significant disadvantage of older technology that was not designed for U.S. markets. The study has shown that there are significant opportunities in the United States for the application of HSGT technologies and that a U.S.-developed maglev system would perform better than existing HSGT technologies in some U.S. markets, in terms of costs versus revenues and public benefits. Option one is not recommended.

Allowing joint ventures has advantages because it would enable the development program to benefit from the experiences and advances of established efforts. However, a joint venture would be more acceptable if the principal efforts for redesign, test, and upgrading were carried out in the United States.

A program to develop a new USML system would have several advantages. In addition to the possible development of an alternative for fast and convenient transportation between cities up to 600 miles apart, such a program would also do much to enhance the technological competitiveness of U.S. industry. The disadvantages of such a development program are its costs and associated development risks.

Recommendations

The NMI has concluded that the potential benefits from a U.S. maglev system are sufficient to justify initiation of a development program. During such a program, the remaining technological, economic, and environmental questions must be fully addressed so that maglev's full potential in an integrated transportation system can be understood. Thus, it is recommended that the Federal Government initiate the first phase of a competitive-based USML development program to develop an advanced maglev system. To benefit fully from recent maglev development abroad, joint ventures between U.S. companies and foreign companies should be permitted to the extent that development activities take place substantially in the United States.

It is further recommended, with select exceptions, that the maglev development program be implemented within the general framework of Section 1036 of the Intermodal Surface Transportation Efficiency Act of 1991. The following modifications are recommended:

- First, the time allowed for each of the phases should be increased.
- Second, the new system should be tested at full-scale at a Government test site.
- Third, the option for U.S. companies to involve foreign partners in the new U.S. development effort should be clarified.

Finally, because of the estimated development expense (about $800 million) and the technological and financial risks of such a development program, it is recommended that during the life of the program there be formal milestones. These milestones will occur in December 1994 in addition to the end of each phase of the program, at which time the benefits and costs of the program can be reevaluated. The first such milestone, in December of 1994, will be based in part on information available from the study of the commercial feasibility of high-speed ground transportation mandated under ISTEA.

A full description of the recommended approach is found in Chapter 6.

1.1 WHAT IS MAGLEV?

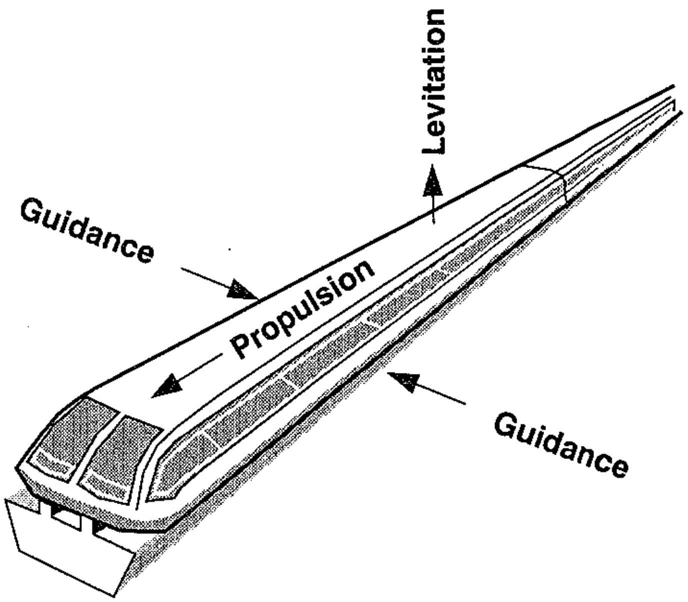
Magnetic levitation (maglev) is a relatively new transportation technology in which noncontacting vehicles travel safely at speeds of 250 to 300 miles-per-hour (112 m/s[1] to 134 m/s) or higher while suspended, guided, and propelled above a guideway by magnetic fields. The guideway is the physical structure along which maglev vehicles are levitated. Various guideway configurations, e.g., T-shaped, U-shaped, Y-shaped, and box-beam, made of steel, concrete, or aluminum, have been proposed.

Figure 1.1 depicts the three primary functions basic to maglev technology: (1) levitation or suspension; (2) propulsion; and (3) guidance. In most current designs, magnetic forces are used to perform all three functions, although a nonmagnetic source of propulsion could be used. No consensus exists on an optimum design to perform each of the primary functions.

1.1.1 Suspension Systems

The two principal means of levitation are illustrated in Figures 1.2 and 1.3. *Electromagnetic suspension (EMS)* is an attractive force levitation system whereby electromagnets on the vehicle interact with and are attracted to ferromagnetic rails on the guideway. EMS was made practical by advances in electronic control systems that maintain the air gap between vehicle and guideway, thus preventing contact.

Figure 1.1
The Three Primary Functions Basic to Maglev Technology



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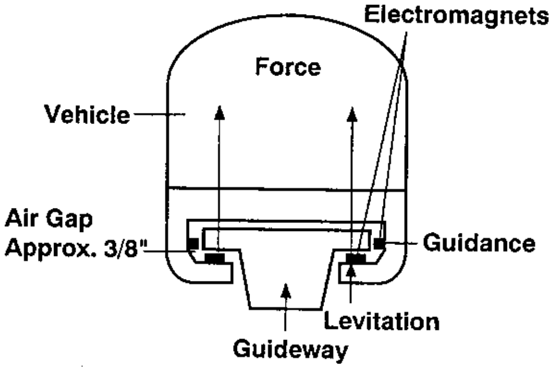
[1] To convert from feet to meters, multiply by 0.3048.

Figure 1.2
Electromagnetic Maglev



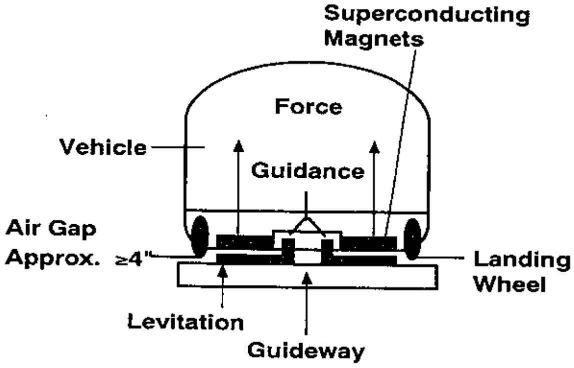
Variations in payload weight, dynamic loads, and guideway irregularities are compensated for by changing the magnetic field in response to vehicle/guideway air gap measurements.

Electrodynamic suspension (EDS) employs magnets on the moving vehicle to induce currents in the guideway. Resulting repulsive force produces inherently stable vehicle support and guidance because the magnetic repulsion increases as the vehicle/guideway gap decreases. However, the vehicle must be equipped with wheels or other forms of support for "takeoff" and "landing" because the EDS will not levitate at speeds below approximately 25 mph. EDS has progressed with advances in cryogenics and superconducting magnet technology.

1.1.2 Propulsion Systems

"Long-stator" propulsion using an electrically powered linear motor winding in the guideway appears to be the favored option for high-speed maglev systems. It is also the most expensive because of higher guideway construction costs.

Figure 1.3
Electrodynamic Maglev



"Short-stator" propulsion uses a linear induction motor (LIM) winding onboard and a passive guideway. While short-stator propulsion reduces guideway costs, the LIM is heavy and reduces vehicle payload capacity, resulting in higher operating costs and lower revenue potential compared to the long-stator propulsion. A third alternative is a nonmagnetic energy source (gas turbine or turboprop) but this, too, results in a heavy vehicle and reduced operating efficiency.

1.1.3 Guidance Systems

Guidance or steering refers to the sideward forces that are required to make the vehicle follow the guideway. The necessary forces are supplied in an exactly analogous fashion to the suspension forces, either attractive or repulsive. The same magnets on board the vehicle which supply lift can be used concurrently for guidance or separate guidance magnets can be used.

1.1.4 Maglev and U.S. Transportation

Maglev systems could offer an attractive transportation alternative for many timesensitive trips of 100 to 600 miles in length, thereby reducing air and highway congestion, air pollution, and energy use, and releasing slots for more efficient long-haul service at crowded airports. The potential value of maglev technology was recognized in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

Prior to passage of the ISTEA, Congress had appropriated $26.2 million to identify maglev system concepts for use in the United States and to assess the technical and economic feasibility of these systems. Studies were also directed toward determining the role of maglev in improving intercity transportation in the United States. Subsequently, an additional $9.8 million were appropriated to complete the NMI Studies.

1.1.5 Why Maglev?

What are the attributes of maglev which commend its consideration by transportation planners?

- Faster trips – high peak speed and high acceleration/braking enable average speeds three to four times the national highway speed limit of 65 mph (30 m/s) and lower door-to-door trip time than high-speed rail or air (for trips under about 300 miles or 500 km). And still higher speeds are feasible. Maglev takes up where high-speed rail leaves off, permitting speeds of 250 to 300 mph (112 to 134 m/s) and higher.

- High reliability – less susceptible to congestion and weather conditions than air or highway. Variance from schedule can average less than one minute based on foreign high-speed rail experience. This means intra- and intermodal connecting times can be reduced to a few minutes (rather than the half-hour or more required with airlines and Amtrak at present) and that appointments can safely be scheduled without having to take delays into account.

- Petroleum independence – with respect to air and auto as a result of being electrically powered. Petroleum is unnecessary for the production of electricity. In 1990, less than 5 percent of the Nation's electricity was derived from petroleum whereas the petroleum used by both the air and automobile modes comes primarily from foreign sources.

- Less polluting – with respect to air and auto, again as a result of being electrically powered. Emissions can be controlled more effectively at the source of electric power generation than at the many points of consumption, such as with air and automobile usage.

- Higher capacity – than air. At least 12,000 passengers per hour in each direction with potential for even higher capacities at 3 to 4 minute headways. Provides sufficient capacity to accommodate traffic growth well into the twenty-first century and to provide an alternative to air and auto in the event of an oil availability crisis.

- High safety – both perceived and actual, based on foreign experience.

- Convenience – due to high frequency of service and the ability to serve central business districts, airports, and other major metropolitan area nodes.

- Improved comfort – with respect to air due to greater roominess, which allows separate dining and conference areas with freedom to move around. Absence of air turbulence ensures a consistently smooth ride.

In contrast to the above attributes, there are other key issues that need to be considered, such as noise, electromagnetic fields, and right-of-way. These issues, along with the above attributes, are addressed in the following chapters of this report.

1.2 U.S. TRANSPORTATION ENVIRONMENT

The transportation system in the United States has been much admired around the world. Its extensive highway and air systems have facilitated business and leisure travel and contributed to a high quality of life for many Americans. In 1990, 429 million passengers traveled 342 billion passenger miles on commercial airlines. Americans traveled 2 trillion passenger miles by car, truck, bus, and public transit and 6.1 billion passenger miles on Amtrak. The majority of these riders, however, traveled by car or airplane, often on overcrowded highways and through congested airports. As population growth and shifts have occurred and travel has increased, these systems have become stressed.

On the highways, development trends and travel patterns in metropolitan areas are causing congestion on intercity routes. Intercity highway travelers are now subject to delays that are local in origin, especially during peak travel hours. A 1989 General Accounting Office report on highway congestion estimated that by the year 2000, 70 percent of peak-hour travelers will experience highway congestion delays with costs to the Nation exceeding $100 billion annually. Approximately 91 percent of all urban freeway delay occurs in 37 metropolitan areas with populations greater than 1 million people. Many of these are the same urban areas suffering from air pollution. A 1991 Federal Highway Administration (FHWA) report, "The Status of the Nation's Highways and Bridges," stated:

By all performance measures of highway congestion and delay, performance is declining. Congestion now affects more areas, more often, for longer periods and with more impacts on highway users and the economy than any time in the nation's history.

Congestion pricing and other management strategies, including the implementation of Intelligent Vehicle/Highway Systems (IVHS), which will allow electronic communication between roads and vehicles to ease traffic problems, will provide some congestion relief, particularly in metropolitan areas in the near term. However, longer term strategies must be developed that address the problems of through traffic.

Commercial air traffic has increased by 56 percent between 1980 and 1990 as consumer demand for fast intercity travel and deregulation brought more competition with lower fares in the airline industry. To meet travel demand, airlines have used regional hubs to achieve more efficient use of aircraft and to offer more varied and frequent service. This practice has accentuated traffic peaking as flights from several origins are brought together within a short period of time at a single airport. If peaking and adverse weather conditions converge, delays at one airport can cause backups to ripple throughout the air travel system. Moreover, commuter/regional carrier growth strains the airport and airways system, contributing to congestion and delay by using up valuable landing slots that could be reserved for larger planes on more profitable, long-haul flights.

In 1987, 21 major airports experienced more than 20,000 hours of flight delays in air carrier operations at a cost of $5 billion annually to American businesses and the aviation industry. By the end of this century, if relief strategies are not developed, 18 additional U.S. airports could experience the same congestion at a cost of over $8 billion per year, even with some planned capacity improvements in place. The public is likely to encounter greater costs, diminished convenience and quality of service, and possibly diminished safety if strategies are not planned now that take account of developing domestic and international travel needs.

Congestion on highways and airports wastes time and fuel and increases pollution. It can constrain mobility to the extent that economic growth and productivity could be adversely affected. Although system management and capacity improvements may provide some relief, adding more highway lanes and building new airports in or near the larger cities is becoming increasingly difficult. Land is costly and scarce. Adding new highway capacity in urban areas typically costs more than $15 million per lane-mile. The new Denver airport is estimated to cost about $3 billion. There is growing concern that a continuation of the nearly exclusive reliance on flying and driving, particularly in the most densely traveled intercity corridors, will exacerbate environmental problems and constrain capacity even further, causing the transportation system to be more gridlocked and winglocked during the next several decades.

Moreover, current intercity aviation and highway transportation technologies are petroleum-dependent, accounting for 64 percent of total petroleum use. Transportation-related petroleum use is expected to remain high and at a level 38.5 percent above U.S. petroleum production – contributing to the U.S. trade deficit and dependence on oil imports with national security implications. It will be important to develop transportation alternatives that reduce petroleum dependency.

Added capacity can be provided in dense intercity corridors with a new High-Speed Ground Transportation (HSGT) alternative –maglev, which is capable of approaching the high speed of the airplane, while offering some of the flexibility of the automobile. Maglev, the fastest form of (HSGT), is more likely than high-speed rail to attract medium-distance travelers from air, as well as some drivers from the highway. Maglev has the potential to complement existing transportation systems and help meet transportation demand with few environmental impacts. Electrically powered, it would be virtually independent of petroleum-based fuels. It would connect to the air and highway networks, smoothing their operations while reducing air and highway congestion, air pollution, and energy use. Maglev can contribute to meeting the transportation needs of the future while improving the efficiency and lengthening the life of existing highway and air facilities. Investment in maglev development can invigorate U.S. technological expertise and facilitate the conversion of defense industry skills towards the solution of infrastructure problems.

1.3 MAGLEV EVOLUTION

The concept of magnetically levitated trains was first identified at the turn of the century by two Americans, Robert Goddard and Emile Bachelet. By the 1930s, Germany's Hermann Kemper was developing a concept and demonstrating the use of magnetic fields to combine the advantages of trains and airplanes. In 1968, Americans James R. Powell and Gordon T. Danby were granted a patent on their design for a magnetic levitation train.

Under the High-Speed Ground Transportation Act of 1965, the FRA funded a wide range of research into all forms of HSGT through the early 1970s. In 1971, the FRA awarded contracts to the Ford Motor Company and the Stanford Research Institute for analytical and experimental development of EMS and EDS systems. FRA-sponsored research led to the development of the linear electrical motor, the motive power used by all current maglev prototypes. In 1975, after Federal funding for high-speed maglev research in the United States was suspended, industry virtually abandoned its interest in maglev; however, research in low-speed maglev continued in the United States until 1986.

Over the past two decades, research and development programs in maglev technology have been conducted by several countries including: Great Britain, Canada, Germany, and Japan. Germany and Japan have invested over $1 billion each to develop and demonstrate maglev technology for HSGT.

The German EMS maglev design, Transrapid (TR07), was certified for operation by the German Government in December 1991. A maglev line between Hamburg and Berlin is under consideration in Germany with private financing and potentially with additional support from individual states in northern Germany along the proposed route. The line would connect with the high-speed Intercity Express (ICE) train as well as conventional trains. The TR07 has been tested extensively in Emsland, Germany, and is the only high-speed maglev system in the world ready for revenue service. The TR07 is planned for implementation in Orlando, Florida.

The EDS concept under development in Japan uses a superconducting magnet system. A decision will be made in 1997 whether to use maglev for the new Chuo line between Tokyo and Osaka.

1.4 THE NATIONAL MAGLEV INITIATIVE (NMI)

Since the termination of Federal support in 1975, there was little research into high-speed maglev technology in the United States until 1990 when the National Maglev Initiative (NMI) was established. The NMI is a cooperative effort of the FRA of the DOT, the USACE, and the DOE, with support from other agencies. The purpose of the NMI was to evaluate the potential for maglev to improve intercity transportation and to develop the information necessary for the Administration and the Congress to determine the appropriate role for the

Federal Government in advancing this technology.

To achieve these goals, the NMI has conducted technical and economic analyses and market feasibility studies of maglev concepts, as well as research on associated energy, environmental, health, and safety issues. In addition, four contracts were funded to define new or improved maglev system concept designs. Total funding for the NMI activities through Fiscal Year (FY) 1993 is $36 million. More than a hundred Government employees with appropriate expertise have been supporting the program in addition to another hundred contract personnel.

The challenge of the NMI was to integrate economic and technical findings to provide a basis for recommendations on the prospects for maglev in the United States. Clearly, it is important to plan, analyze, and assess now in order to have an option that will be available some 15 to 20 years hence.

To initiate a new untried transportation system entirely through the private sector involves high capital costs and high risk that few, if any, investors are willing to take. Government institutional support and innovative financing strategies would be necessary for maglev development. Such public support would be consistent with other past and current innovative transportation systems. In fact, from its inception, the U.S. Government has aided and promoted innovative transportation for economic, political, and social development reasons. There are numerous examples. In the nineteenth century, the Federal Government encouraged railroad development to establish transcontinental links through such actions as the massive land grant to the Illinois Central-Mobile Ohio Railroads in 1850. Beginning in the 1920s, the Federal Government provided commercial stimulus to the new technology of aviation through contracts for airmail routes and funds which paid for emergency landing fields, route lighting, weather reporting, and communications. Later in the twentieth century, Federal funds were used to construct the Interstate Highway System and assist States and municipalities in the construction and operation of airports. In 1971, the Federal Government formed Amtrak to ensure rail passenger service for the United States.

1.5 ISSUES ADDRESSED IN THIS REPORT

Each chapter in this report addresses a different set of issues aimed at determining the potential for maglev in the United States and the Federal role in its technological development:

Chapter 2:	The likely physical performance and cost characteristics of a new maglev system designed and built in the United States.
Chapter 3:	The economic performance of such a system in competition with other modes in specific intercity corridor markets, in terms of costs, revenues, and public benefits. Other national level impacts of maglev, including effects on U.S. technological competitiveness, both inside and out of the transportation field, construction jobs, and other macroeconomic effects.

Chapter 4: The economic performance and public benefits of the U.S. system compared with existing HSGT technology such as the German TR07 maglev and French high-speed rail (HSR) *Train a Grande Vitesse* (TGV) systems. Whether the added cost of developing a U.S. system is justified by economic performance.

Chapter 5: Comparison of the economic and national impacts of the following three options for acquiring HSGT technology:

- Acquire and install existing foreign systems.
- Improve new systems through a joint venture with foreign developers.
- Develop a new U.S. designed system.

Chapter 6: The future role of maglev and recommendations on the role of the U.S. Government in its development.

Chapter 2: Assessment of Maglev Technology

2.1 ANALYSIS PROCESS

In order to determine the technical feasibility of deploying maglev in the United States, the NMI Office performed a comprehensive assessment of the state-of-the-art of maglev technology. The process included:

- Determining and analyzing relevant critical technologies.
- Defining conceptual maglev systems that reflected the ideas and talent of U.S. industry.
- Assessing maglev concepts defined by U.S. industry and comparing these concepts with foreign HSGT systems.
- Estimating the cost of constructing and installing a maglev system, using U.S. technology concepts.

2.1.1 Investigation of Critical Technologies

The NMI office initiated the critical technology investigation in September 1990 by soliciting proposals from industry and academia through a Broad Agency Announcement (BAA). There were over 250 responses to the BAA leading to the award of 27 contracts totaling $4.4 million. The contracts addressed innovative approaches for improving performance and reliability and for reducing costs of maglev systems. Among the topics addressed by the contract work were: maglev route alignment and ROW; guideway sensor systems; noise of high-speed rail and maglev; aerodynamic forces on maglev vehicles; power transfer to high-speed vehicles; measurement and analysis of magnetic fields; application of cable-in-conduit conductors for maglev; safe speed enforcement; and parametric studies of suspension and propulsion subsystems.

In addition, since little data are available about passenger acceptance of the motions associated with advanced HSGT systems, the NMI funded an experimental investigation of ride quality criteria. An airplane was used to simulate rapid banking, turning, acceleration, and braking of a maglev vehicle traversing a route through the grades and curves typical of an interstate highway.

2.1.2 Development of U.S. Maglev (USML) Concepts

The NMI initiated an assessment of U.S. industry's maglev development potential in November 1991 by awarding four System Concept Definition (SCD) contracts totaling $8.6 million. The contract work was completed by September 1992. Each of the four contractor teams defined a system concept by combining the key elements of maglev technology (i.e., vehicle, guideway, suspension, propulsion, braking, and control) into a total transportation system. The systems were described in terms of conceptual design detail, performance, cost, safety, and other measures in order to illustrate their merit for application to a next-generation 300 mph (134 m/s) maglev for U.S. deployment.

2.1.3 Assessment of Technology

An independent Government Maglev System Assessment (GMSA) team made up of scientists and engineers from the DOT, DOE, Army Corps of Engineers, and experts from other Government organizations, evaluated technology aspects of the SCDs. They also reviewed and compared foreign HSGT alternatives.

The evaluation process consisted of two steps. The first step was to obtain or develop mathematical models of vehicle/guideway interaction, propulsion and power supply, magnet force relationships, and system performance over various trial routes. The second step was to use these models to evaluate the various technologies in terms of system, vehicle, and guideway requirements such as speed, capacity, ride comfort, magnetic field effects, safety, structural integrity, and power systems.

2.1.4 Cost Estimating

USACE staff, experienced in estimating the costs of large civil construction projects, examined the SCD contractor cost estimates for the guideway structure and associated distance-related costs. The USACE staff modified the contractor estimates where necessary to put each technology on a common basis, e.g., standardizing the guideway height and the contingency factors for overhead and profit. Each SCD concept was evaluated in terms of five major components: 1) guideway structure; 2) guideway magnetics; 3) power distribution; 4) wayside control and communications; and 5) power stations.

The Government staff used a standard method to estimate the costs for each component of the U.S. baseline designs in the SCD final reports as well as for the French TGV high-speed rail system and the German Maglev TR07. Additional information on this methodology is provided in Appendix A. The data used for estimating TGV costs were taken primarily from the Texas TGV proposal, while the TR07 costs were taken from the Transrapid International/Bechtel proposal to build a maglev system between Anaheim, CA and Las Vegas, NV. Cost estimates are not available for the Japanese high-speed Maglev system. The results of the Government cost analysis are presented in Section 2.4.

2.2 OVERVIEW OF SYSTEM CONCEPTS

The four SCDs that the GMSA team evaluated were developed by teams led by Bechtel, Foster-Miller, Grumman, and Magneplane as examples of potential U.S. systems. The HSGT alternatives to which the SCD concepts were compared were the French TGV steel-wheel-on-rail system and the German TR07 Maglev system. The Japanese high-speed Maglev system is also described in this section, but is not included in Table 2.1 due to lack of performance information. Table 2.1 summarizes the general performance results of the GMSA team evaluation. The section that follows briefly describes the alternative foreign HSGT systems and the SCD concepts.

2.2.1 Existing HSGT Systems

Because there is no U.S.-based HSGT system in operation or under test, the GMSA team compared the SCD concepts

Table 2.1
General Performance Parameters

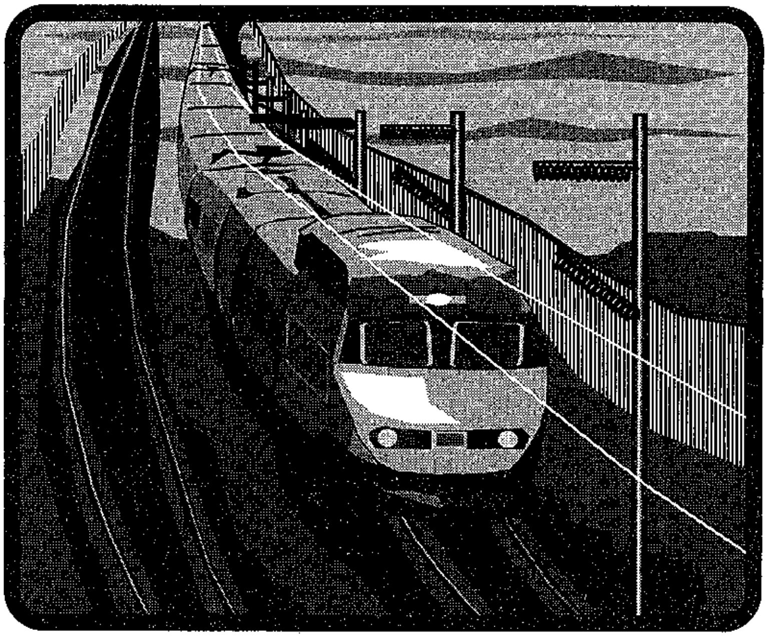
Parameter	TGV-Atlantique	TR07	Bechtel	Foster-Miller	Grumman	Magne-plane
Concept	Steel wheel-on-rail	EMS, separate lift & guidance	EDS, ladder levitation	EDS, sidewall null-flux	EMS, common lift & guidance	EDS, sheet levitation
Vehicles/ Consist	1-10-1	2	1	8	2	1
Seats/Consist	485	156	120	600	100	140
Cruise Speed (mph)	186*	311	300	300	300	300
Switch Design Speed (mph)	143	125	72	112	145	224
Air Gap (inches)	N/A	.4	2.0	3.0	1.6	5.9

* *In order to maximize TGV performance, the 200 mph Texas TGV was used for calculations of trip time in Chapter 4 of this report.*

to foreign technology. Over the past two decades various ground transportation systems have been developed overseas, having operational speeds in excess of 150 mph (67 m/s), compared to 125 mph (56 m/s) for the U.S. Metroliner. Several steel-wheel-on-rail trains can maintain a speed of 167 to 186 mph (75 to 83 m/s), most notably the Japanese Series 300 Shinkansen, the German ICE, and the French TGV. The German Transrapid Maglev train has demonstrated a speed of 270 mph (121 m/s) on a test track, and the Japanese have operated a maglev test car at 321 mph (144 m/s). The following are descriptions of the French, German, and Japanese systems used for comparison to the U.S. Maglev (USML) SCD concepts.

2.2.1.1 French *Train a Grande Vitesse* (TGV)

Figure 2.1
Artist Conception of French *Train a Grande Vitesse* HSR System



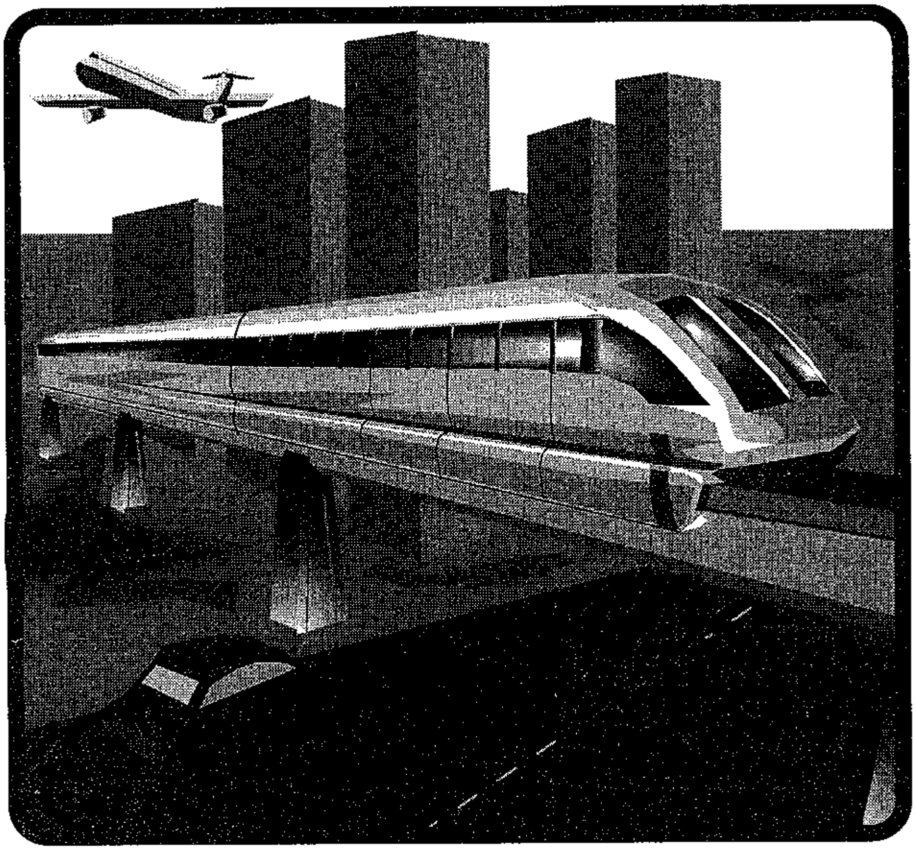
The French National Railway's TGV is representative of the current generation of high-speed, steel-wheel-on-rail trains. The TGV has been in service for 12 years on the Paris-Lyon (PSE) route and for 3 years on an initial portion of the Paris-Bordeaux (*Atlantique*) route.

The *Atlantique* train consists of ten passenger cars with a power car at each end. The power cars use synchronous rotary traction motors for propulsion. Roof mounted pantographs collect electric power from an overhead catenary. Cruise speed is 186 mph (83 m/s). The train is nontilting and, thus, requires a reasonably straight route alignment to sustain high speed. Although the operator controls the train speed, interlocks exist including automatic overspeed protection and enforced braking. Braking is by a combination of rheostat brakes and axle-mounted disc brakes. All axles possess antilock braking. Power axles have anti-slip control.

The TGV track structure is that of a conventional standard-gauge railroad with a well engineered base (compacted granular materials). The track consists of continuous-welded rail on concrete/steel ties with elastic fasteners. Its high-speed switch is a conventional swing-nose turnout. The TGV operates on pre-existing tracks, but at a substantially reduced speed. Because of its high speed, high power, and antiwheel slip control, the TGV can climb grades that are about twice as great as normal in U.S. railroad practice and, thus, can follow the gently rolling terrain of France without extensive and expensive viaducts and tunnels.

2.2.1.2 German TR07

Figure 2.2
Artist Conception of the German TR07 Maglev System



The German TR07 is the high-speed Maglev system nearest to commercial readiness. If financing can be obtained, ground breaking will take place in Florida in 1993 for a 14 mile (23 km) shuttle between Orlando International Airport and the amusement zone at International Drive. The TR07 system is also under consideration for a high-speed link between Hamburg and Berlin and between downtown Pittsburgh and the airport.

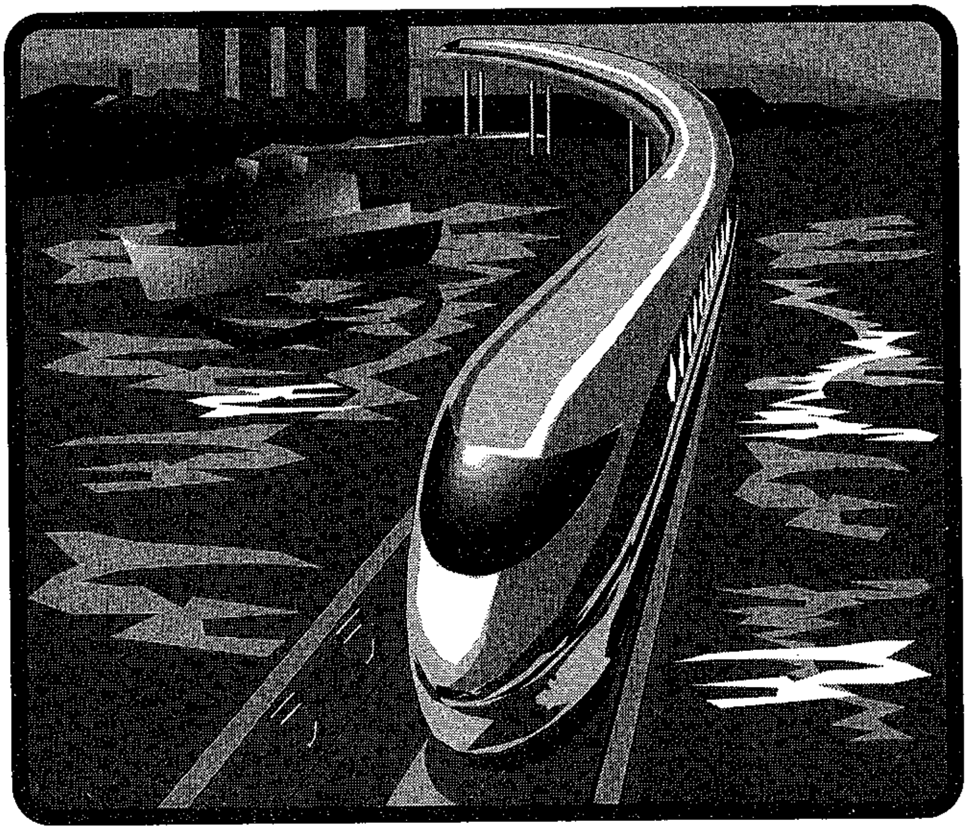
As the designation suggests, TR07 was preceded by at least six earlier models. In the early seventies, German firms, including Krauss-Maffei, MBB and Siemens, tested full-scale versions of an air cushion vehicle (TR03) and a repulsion maglev vehicle using superconducting magnets. After a decision was made to concentrate on attraction maglev in 1977, advancement proceeded in significant increments, with the system evolving from linear induction motor (LIM) propulsion with wayside power collection to the linear synchronous motor (LSM), which employs variable frequency, electrically powered coils on the guideway. TR05 functioned as a people-mover at the International Traffic Fair Hamburg in 1979, carrying 50,000 passengers and providing valuable operating experience.

The TR07, which operates on 19.6 miles (31.5 km) of guideway at the Emsland test track in northwest Germany, is the culmination of nearly 25 years of German Maglev development, costing over $1 billion. It is a sophisticated EMS system, using separate conventional iron-core attracting electromagnets to generate vehicle lift and guidance. The vehicle wraps around a T-shaped guideway. The TR07 guideway uses steel or concrete beams constructed and erected to very tight tolerances. Control systems regulate levitation and guidance forces to maintain a ⅜-inch gap (8 to 10 mm) between the magnets and the iron "tracks" on the guideway. Attraction between vehicle magnets and edge-mounted guideway rails provide guidance. Attraction between a second set of vehicle magnets and the propulsion stator packs underneath the guideway generate lift. The lift magnets also serve as the secondary or rotor of a LSM, whose primary or stator is an electrical winding running the length of the guideway.

TR07 uses two or more nontilting vehicles in a consist. TR07 propulsion is by a long-stator LSM. Guideway stator windings generate a traveling wave that interacts with the vehicle levitation magnets for synchronous propulsion. Centrally controlled wayside stations provide the requisite variable-frequency, variable-voltage power to the LSM. Primary braking is regenerative through the LSM, with eddy-current braking and high-friction skids for emergencies. TR07 has demonstrated safe operation at 270 mph (121 m/s) on the Emsland track. It is designed for cruise speeds of 311 mph (139 m/s).

2.2.1.3 Japanese High-Speed Maglev

Figure 2.3
Artist Conception of the Japanese Maglev System



The Japanese have spent over $1 billion developing both attraction and repulsion maglev systems. The HSST attraction system, developed by a consortium often identified with Japan Airlines, is actually a series of vehicles designed for 100, 200, and 300 km/h. Sixty miles-per-hour (100 km/h) HSST Maglevs have transported over two million passengers at several Expos in Japan and the 1989 Canada Transport Expo in Vancouver. The high-speed Japanese repulsion Maglev system is under development by Railway Technical Research Institute (RTRI), the research arm of the newly privatized Japan Rail Group. RTRI's ML500 research vehicle achieved the world high-speed guided ground vehicle speed record of 321 mph (144 m/s) in December 1979, a record which still stands, although a specially modified French TGV rail train has come close. A manned three-car MLU001 began testing in 1982. Subsequently, the single car MLU002 was destroyed by fire in 1991. Its replacement, the MLU002N, is being used to test the side wall levitation that is planned for eventual revenue system use. The principal activity at present is the construction of a $2 billion, 27-mile (43 km) maglev test line through the mountains of Yamanashi Prefecture, where testing of a revenue prototype is scheduled to commence in 1994.

The Central Japan Railway Company plans to begin building a second high-speed line from Tokyo to Osaka on a new route (including the Yamanashi test section) starting in 1997. This will provide relief for the highly profitable Tokaido Shinkansen, which is nearing saturation and needs rehabilitation. To provide ever improving service, as well as to forestall encroachment by the airlines on its present 85 percent market share, higher speeds than the present 171 mph (76 m/s) are regarded as necessary. Although the design speed of the first generation maglev system is 311 mph (139 m/s), speeds up to 500 mph (223 m/s) are projected for future systems. Repulsion maglev has been chosen over attraction maglev because of its reputed higher speed potential and because the larger air gap accommodates the ground motion experienced in Japan's earthquake-prone territory.

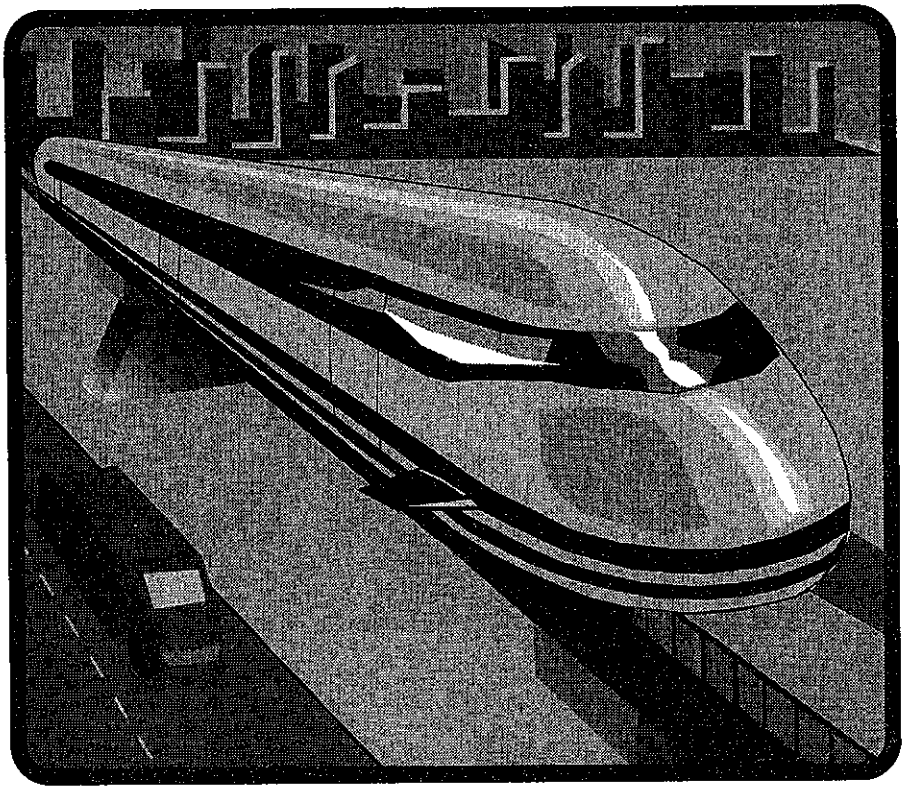
The design of Japan's repulsion system is not firm. A 1991 cost estimate by Japan's Central Railway Company, which would own the line, indicates that the new high-speed line through the mountainous terrain north of Mt. Fuji would be very expensive, about $100 million per mile (8 million yen per meter) for a conventional railway. A maglev system would cost 25 percent more. A significant part of the expense is the cost of acquiring surface and subsurface ROW. Knowledge of the technical details of Japan's high-speed Maglev is sparse. What is known is that it will have superconducting magnets in bogies with sidewall levitation, linear synchronous propulsion using guideway coils, and a cruise speed of 311 mph (139 m/s).

2.2.2 U.S. Contractors' Maglev Concepts (SCDs)

Three of the four SCD concepts use an EDS system in which superconducting magnets on the vehicle induce repulsive lift and guidance forces through movement along a system of passive conductors mounted on the guideway. The fourth SCD concept uses an EMS system similar to the German TR07. In this concept, attraction forces generate lift and guide the vehicle along the guideway. However, unlike TR07, which uses conventional magnets, the attraction forces of the SCD EMS concept are produced by superconducting magnets. The following individual descriptions highlight the significant features of the four U.S. SCDs.

2.2.2.1 Bechtel SCD

Figure 2.4
Artist Conception of the Bechtel SCD Maglev System

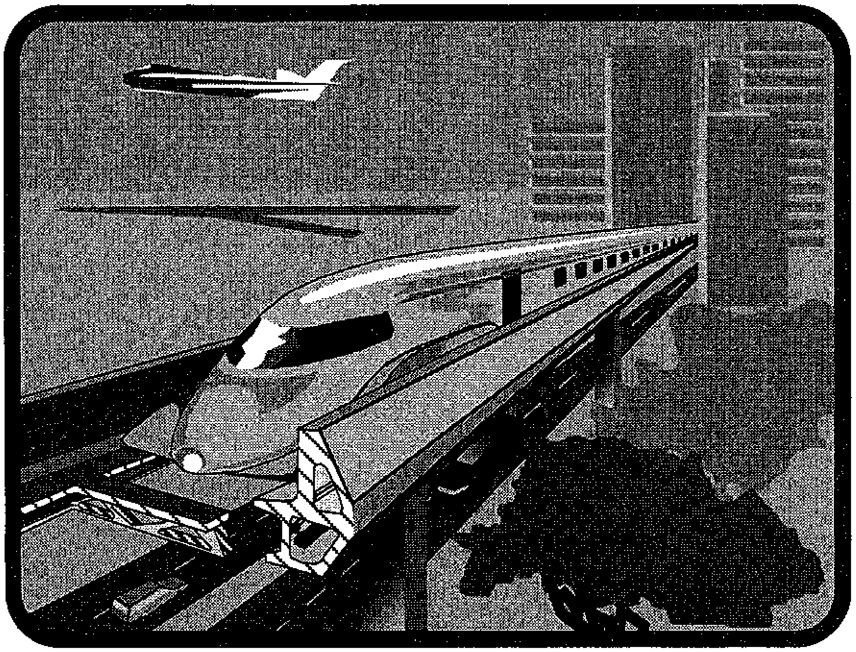


The Bechtel concept is an EDS system that uses a novel configuration of vehicle-mounted, flux-canceling magnets. The vehicle contains six sets of eight superconducting magnets per side and straddles a concrete box-beam guideway. Interaction between the vehicle magnets and a laminated aluminum ladder on each guideway sidewall generates lift. Similar interaction with guideway mounted null-flux coils provides guidance. LSM propulsion windings, also attached to the guideway sidewalls, interact with vehicle magnets to produce thrust. Centrally controlled wayside stations provide the required variable-frequency, variable-voltage power to the LSM.

The Bechtel vehicle consists of a single car with an inner tilting shell. It uses aerodynamic control surfaces to augment magnetic guidance forces. In an emergency, it delevitates onto air-bearing pads. The guideway consists of a post-tensioned concrete box girder. Because of high magnetic fields, the concept calls for nonmagnetic, fiber-reinforced plastic (FRP) post-tensioning rods and stirrups in the upper portion of the box beam. The switch is a bendable beam constructed entirely of FRP.

2.2.2.2 Foster-Miller SCD

Figure 2.5
Artist Conception of the Foster-Miller SCD Maglev System

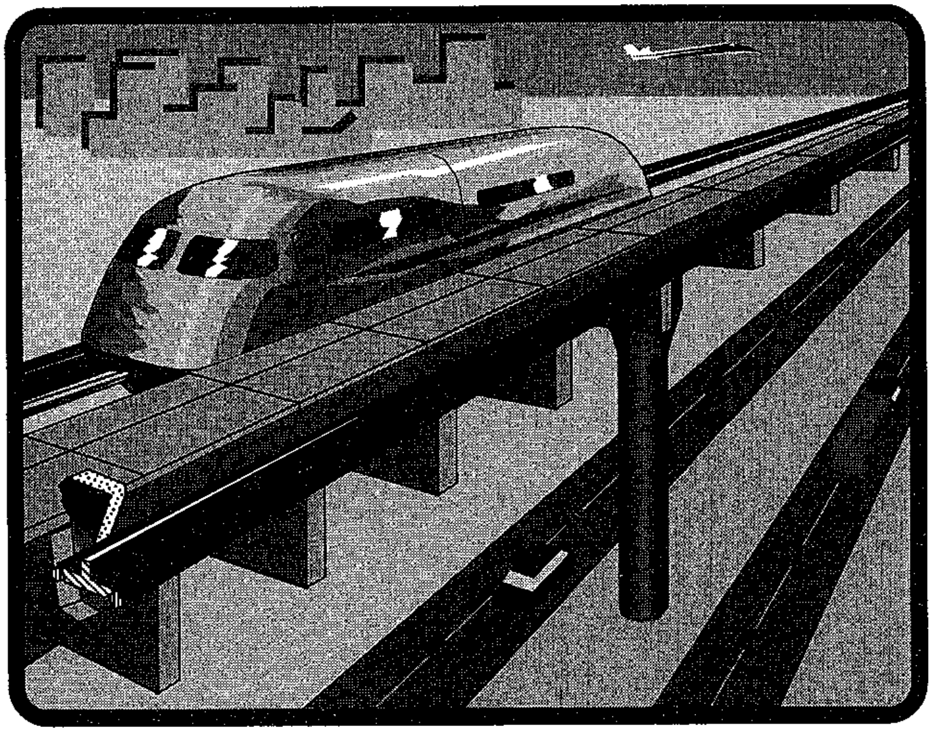


The Foster-Miller concept is an EDS similar to the Japanese high-speed Maglev, but has some additional features to improve potential performance. The Foster-Miller concept has a vehicle tilting design that would allow it to operate through curves faster than the Japanese system for the same level of passenger comfort. Like the Japanese system, the Foster-Miller concept uses superconducting vehicle magnets to generate lift by interacting with null-flux levitation coils located in the sidewalls of a U-shaped guideway. Magnet interaction with guideway-mounted, electrical propulsion coils provides null-flux guidance. Its innovative propulsion scheme is called a locally commutated linear synchronous motor (LCLSM). Individual "H-bridge" inverters sequentially energize propulsion coils directly under the bogies. The inverters synthesize a magnetic wave that travels along the guideway at the same speed as the vehicle.

The Foster-Miller vehicle is composed of articulated passenger modules and tail and nose sections that create multiple-car "consists." The modules have magnet bogies at each end that they share with adjacent cars. Each bogie contains four magnets per side. The U-shaped guideway consists of two parallel, post-tensioned concrete beams joined transversely by precast concrete diaphragms. To avoid adverse magnetic effects, the upper post-tensioning rods are FRP. The high-speed switch uses switched null-flux coils to guide the vehicle through a vertical turn-out. Thus, the Foster-Miller switch requires no moving structural members.

2.2.2.3 Grumman SCD

Figure 2.6
Artist Conception of the Grumman SCD Maglev System

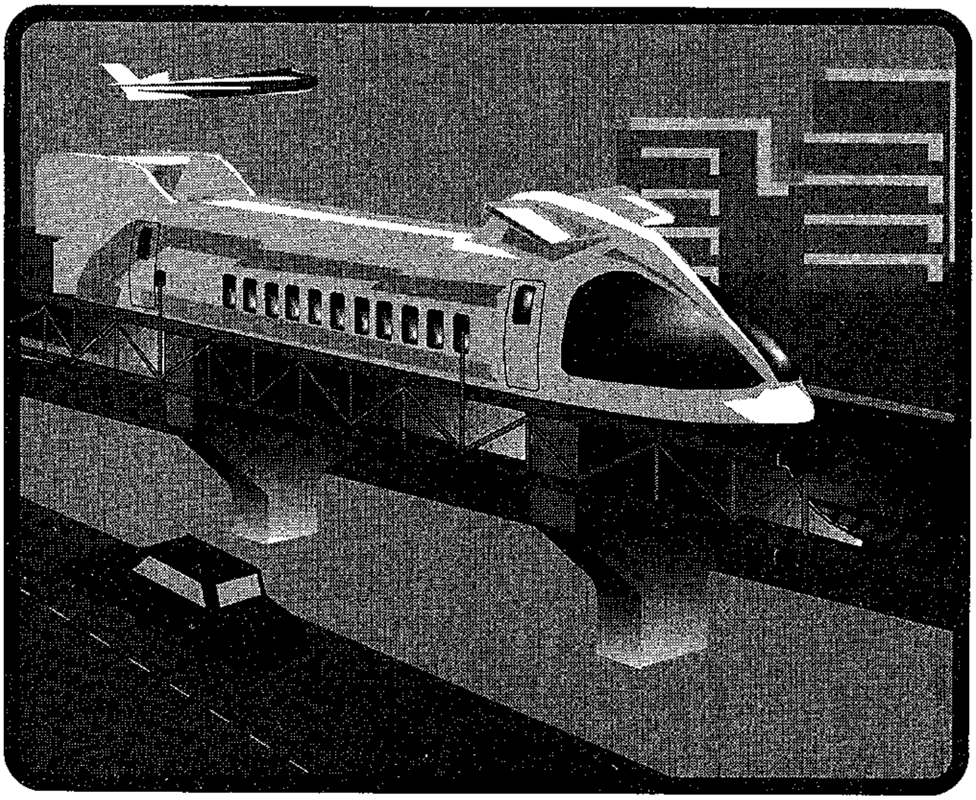


The Grumman concept is an EMS with similarities to the German TR07. However, Grumman's vehicles wrap around a Y-shaped guideway and use a common set of vehicle magnets for levitation, propulsion, and guidance. Guideway rails are ferromagnetic and have LSM windings for propulsion. The vehicle magnets are superconducting coils around horseshoe-shaped iron cores. The pole faces are attracted to iron rails on the underside of the guideway. Nonsuperconducting control coils on each iron-core leg modulate levitation and guidance forces to maintain a 1.6 inch (40 mm) air gap. No secondary suspension is required to maintain adequate ride quality. Propulsion is by conventional LSM embedded in the guideway rail.

Grumman vehicles may be single- or multi-car consists with tilt capability. The innovative guideway superstructure consists of slender Y-shaped guideway sections (one for each direction) mounted by outriggers every 15-feet to a 90-foot (4.5 m to a 27 m) spline girder. The structural spline girder serves both directions. Switching is accomplished with a TR07-style bending guideway beam, shortened by use of a sliding or rotating section.

2.2.2.4 Magneplane SCD

Figure 2.7
Artist Conception of the Magneplane SCD Maglev System



The Magneplane concept is a single-vehicle EDS using a trough-shaped 0.8 inch (20 mm) thick aluminum guideway for sheet levitation and guidance. Magneplane vehicles self-bank up to 45 degrees in curves. Earlier laboratory work on this concept validated the levitation, guidance, and propulsion schemes. Superconducting levitation and propulsion magnets are grouped in bogies at the front and rear of the vehicle. The centerline magnets interact with conventional LSM windings for propulsion and also generate some electromagnetic "roll-righting torque" called the keel effect. The magnets on the sides of each bogie react against the aluminum guideway sheets to provide levitation.

The Magneplane vehicle uses aerodynamic control surfaces to provide active motion damping. The aluminum levitation sheets in the guideway trough form the tops of two structural aluminum box beams. These box beams are supported directly on piers. The high-speed switch uses switched null-flux coils to guide the vehicle through a fork in the guideway trough. Thus, the Magneplane switch requires no moving structural members.

2.3 FINDINGS

2.3.1 Opportunities for Technology Improvements

A major factor leading to the creation of the NMI was the myriad claims by USML proponents regarding opportunities for technological improvements relative to foreign maglev systems. The NMI critical technology investigation focused on these claims. Some have been verified, while others appear to be unfounded or exaggerated. The following are some of the significant findings from the technology investigation:

- A U.S. 300-mph (500 km/h) maglev system is feasible. U.S. industry and academia have the capability to compete with foreign maglev developments. Assessment of the four conceptual designs elicited from U.S. firms concludes there are many areas where improvements can be made with systems more suited to U.S. geography and demographics.

- Tilting mechanisms have been designed for maglev vehicles that allow them to follow existing ROW at speeds substantially higher than the design speed of existing maglev technologies. In those cases where land is unavailable or too costly, this will provide an acceptable alternative route.

- In connection with the above finding, it has also been established by experiment that most people do not suffer ill effects from the large tilt angles and rates of turn involved in following existing ROW at high speed.

- Magnetic fields created by a maglev system can be attenuated to normal urban levels without severe weight or cost penalties. Measurements of magnetic fields aboard existing transportation systems reveal that fields substantially in excess of ambient occur in and around certain electrically powered systems, just as is the case with many home and office appliances. However, the steady magnetic fields measured aboard the Transrapid Maglev vehicle are no greater than the earth's field. Although the magnetic fields generated by superconducting magnets are greater than the Transrapid values, design approaches exist to maintain the fields in the passenger compartment to acceptable levels.

- Procedures have been identified for the use of new composite materials and innovative vehicle and component designs, which can reduce the weight of maglev vehicles and energy consumption. In addition, the application of sophisticated manufacturing and erection techniques to guideway construction may greatly reduce the transportation and site preparation costs associated with building in or near existing ROW.

- Overcoming aerodynamic drag on vehicles is the dominant factor in energy consumption at 300 mph (134 m/s). Research shows there are ways of reducing drag which provides a fruitful area for additional research.

- Maglev systems can offer significant energy savings relative to air and auto when configured in multiple-car consists due to less than the proportional increase in aerodynamic drag. However, there appears to be no energy advantage for single or dual car consists.

- Maglev has the potential for being quieter than conventional trains at speeds below 155 mph (69 m/s), which is an important consideration when traveling in urban areas where speed restrictions will most likely be in place. At speeds above 155 mph (69 m/s), most of the noise produced by a vehicle is of aereodynamic origin, whether it is on rail or levitated. As in other transportation modes, methods exist to alleviate noise where necessary.

- The power semiconductors that are required to regulate the propulsion currents in the guideway will require improvements in the state of the art, particularly in regard to bringing costs down. U.S. manufacturers are in a favorable position to accomplish this and improve their market position with respect to allied products as well.

- Developments in high temperature superconductors have made such progress in the past 2 years that it is prudent to consider designs for superconducting magnets and cryostats which incorporate this new technology. Avoiding very low temperatures would reduce complexity, weight, and operating and maintenance costs for cryogenic systems.

- Innovative operational strategies, such as single-car, nonstop, point-to-point service, can provide faster travel between suburban stations, making the maglev system more competitive relative to the automobile.

- Maglev systems can take advantage of existing infrastructure to provide access to city centers and intermodal facilities. In many cities, existing bridges, tunnels, and transportation corridors are not being used to full capacity and could be inexpensively modified to accommodate maglev. Techniques exist for coupling maglev vehicles to, or mounting them on, rail vehicles to provide near term access to rail terminals until maglev facilities can be built in these congested areas.

- The large air gaps made possible with superconducting magnets do not appear to lead to any significant guideway cost savings compared to small gap EMS systems. Ride quality, rather than gap control, is the significant factor in setting guideway precision and rigidity requirements. However, large air gaps do enhance the safety of the system by increasing the tolerance to nondesign irregularities arising from damage, earthquakes, or improper maintenance.

- In order to take full advantage of a large air gap, a suspension with sophisticated characteristics, such as some combination of feedback, preview, and adaptive control, is needed. Such a suspension may allow lower guideway fabrication and maintenance tolerances, consequently reducing associated costs. While the current SCD designs are capable of traversing a single large perturbation of guideway geometry, these suspensions cannot traverse repeated guideway irregularities and offer a comfortable ride. Research to determine the optimum suspension force-control characteristic is ongoing.

In addition to the preceding findings, several worthwhile innovations surfaced as a result of the SCD work. Examples are:

- An advanced, high power, efficient propulsion system and a 30-degree tilt capability would allow maglev to negotiate existing highway or railroad ROW, where that is the preferred option, at much higher average speeds than is possible with the existing German Transrapid and Japanese systems.

- The individual control and activation of each guideway propulsion coil for the LSM, known as local commutation, was once regarded as impractical. Millions of silicon switching devices would be required for an intercity route, but if the trend of reduced costs with volume applies here as it has with other semiconductor devices, the LCLSM will lower cost while enhancing propulsion performance. Research is in progress to further assess this concept which could provide an important strategic advantage for American competitiveness in semiconductor technology.

- A spinoff of the locally commutated LSM is the capability to use the same coil system to transfer auxiliary (hotel) power from the guideway onto the vehicle, with an attendant reduction in on-board battery requirements. The advantage is reduced vehicle weight and improved safety.

- Applying the rapid advances in power semiconductor technology, in which the United States has a lead, will enable substantial reductions in size, weight, and cost. Also, improvement in the efficiencies of power conditioning equipment for both vehicle and wayside systems will be provided.

- Some of the SCD concepts allow maglev vehicles to make use of completely electronic switches (turnouts). These switches have no moving parts and, therefore, could substantially reduce the costs of achieving the tolerances required for rapid activation. Higher vehicle speeds through the switch and reduced headways improve trip time and increase system capacity.

- Novel helical winding designs for LSM may allow operation at higher voltages with improved electrical efficiency, better power factor, and no component and installation cost penalty.

2.3.2 Safety

Studies have been underway for the last 2½ years in the FRA's Office of Research and Development on the subject of high-speed guided ground transportation safety. The key areas that may be of concern as any maglev technology moves towards implementation in the United States are:

- High-speed collision avoidance (automation, guideway integrity, shared ROW).

- Adequate protection for high mass low speed collisions and low mass high-speed collisions.

- Emergency response plans and procedures (fire safety, evacuation methods, training).

- Electromagnetic field generation and effects (passengers, workers, public).

- Operational issues (weather, automation and human factors, etc.).

Included in the overall assessment of maglev technology are the safety concepts from both design and operational view points. Current safety studies do not indicate any safety-related issues that cannot be accommodated through system safety design considerations in an appropriate development program.

As with aircraft, the high speed of maglev appears to make it infeasible to design a practical system that could withstand a high-speed collision. Accordingly, the proper approach is to ensure that collisions do not occur. Although this approach has not been used in U.S. railroad practice in the past, the fact is that foreign high-speed rail has a flawless record.

The Japanese Shinkansen has been in operation for 30 years, has carried 3.5 billion passengers, and has never had a high-speed collision nor caused a passenger fatality. Likewise, the French TGV has operated for 12 years, carrying a quarter billion passengers. There has never been a passenger fatality on the grade-separated French high-speed line. Thus, it is possible to reduce the probability of collisions to an acceptable level. This must be the focus of the design for maglev safety as contrasted with crash survivability.

The overall safety of a USML system must be reviewed and analyzed from the start of the design phase right through and including the operational phase in an ongoing and systematic manner. Keeping the overall safety of a maglev system within acceptable levels as the technology proceeds to the deployment stage will reduce the potential for unplanned design modifications or prohibitive operational restrictions or procedures that could threaten the basic viability of the maglev system.

2.4 SYNTHESIS OF A U.S. MAGLEV SYSTEM

The purpose of the SCD exercise was to provide an opportunity to show what U.S. industry was capable of doing relative to foreign maglev competition, educating the industry itself and the Government in the process. It was not the intention to select a winner at this stage. Instead, the NMI has attempted to employ all the information collected from the technology assessment process, take the best features therefrom, and synthesize them into performance capabilities of a USML. (Obviously, care must be taken to ensure that the components of such a USML system are compatible.)

For example, it is now clear that the structural properties of a maglev guideway, such as beam rigidity and accuracy of alignment, need to be the same for all maglev systems, because they derive from ride quality considerations which are the same for all passenger carrying systems. Some of the SCD contractors arrived at more efficient girder designs, which are applicable to the other concepts. We have incorporated appropriate associated cost savings in the economic model.

An economic model requires only a general description of a maglev system in order to predict costs, ridership, revenue, and the like. Accordingly, the USML system which is incorporated into the economic model consists only of performance and cost data and does not include, for instance, a depiction of the system. Specifically, the USML is defined in terms of maximum speed, acceleration, banking capability, grade and curving capability, and guideway and related costs as specified in Figure 2.8 and Table 2.2. The principal features of the USML were chosen on the basis of reducing trip time on existing ROW, which appeared to be the intent of Congress, and is important to making maglev competitive with short haul air. This was accomplished by providing a 30° banking capability and a high performance propulsion system. (Had other objectives prevailed, the USML could have been less energy intensive, less costly or even more comfortable, but only at the expense of some other objective.) It should be noted when referring to Figure 2.8 that the NMI work defined normal maximum ride comfort during acceleration to be 0.16g[1]. The additional acceleration capacity depicted for the USML represents potential power to maintain 0.16g, climbing steep grades and powering through turns such as might be required when following existing U.S. ROW for highways and railroads.

The estimated guideway cost for USML, TR07 and TGV are shown in Table 2.2. TR07 and TGV costs were obtained by analyzing published data, and the cost of the USML was based upon Government

Table 2.2
Technology Cost and Performance

Parameter	TGV[1]	TR07[3]	U.S. Maglev
Elevated Guideway ($ millions/mi)[2]	22.3	19.6	17.6
At Grade Guideway ($ millions/mi)[2]	3.3	17.4	13.0
Range of Initial Capital Costs ($ millions/mi)[4]	17.2 - 33.4	30.4 - 49.3	26.6 - 45.4
Cruise Speed (mph)	200	311	300
Maximum Grade (%)	5.0	10	10
Acceleration Time(s) with Full Thrust (sec)			
0-186 mph	408	107	36
0-300 mph	---	240	58
Total Bank Angle (°)	7	12	30

Note: (1) Modified *Train a Grand Vitesse* (TGV) proposed for the Texas HSR System.
(2) Includes only distance-related technology costs.
(3) German Maglev System.
(4) A construction financing cost is included in these estimates using the 7 percent discount rate.

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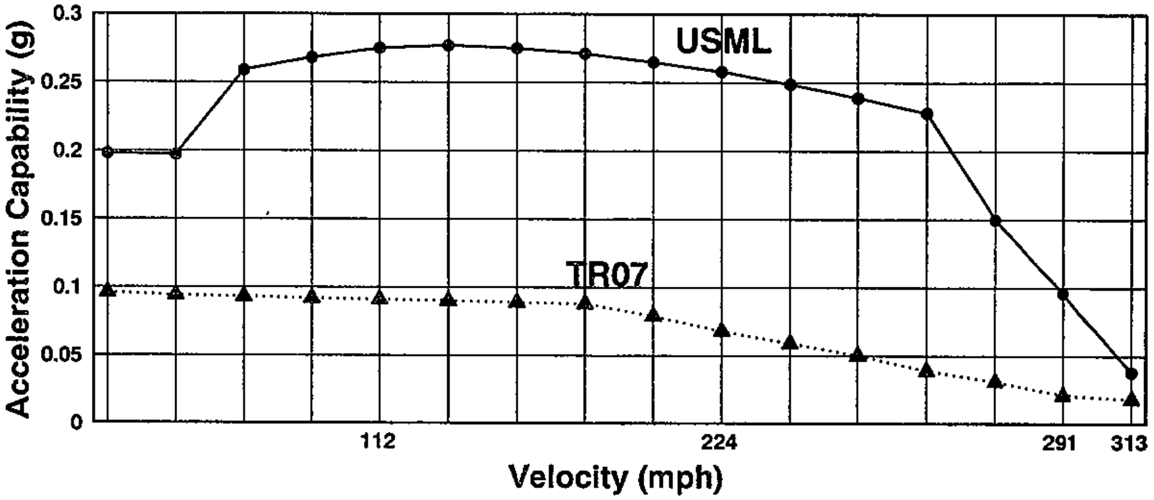
[1] g is acceleration due to earth's gravity, 32.2 ft/sec^2 (9.8 m/sec^2).

Figure 2.8
U.S. Maglev/German TR07 Maximum Available Acceleration



estimates and data provided by the SCD contractors (see Appendix A). The costs in the first two rows of Table 2.2 include only distance-related costs of the guideway structure, electric power supply, propulsion, and control systems. They do not include vehicle costs, the costs of major facilities, such as stations and maintenance or control centers, site preparation, earth moving, tunneling or long span bridges, land acquisition, program management, and contingencies; however, all of these costs are included in the third row of Table 2.2 and in the economic analysis in Chapters 3 and 4 of this report. These latter costs are site specific, but can add $9 million to $27 million per mile ($6 thousand to $17 thousand per meter) beyond the technology cost.

Examination of Table 2.2 reveals several interesting features of the hypothetical USML. If an elevated system is desired for reasons of safety, ROW access or other operational considerations, USML could offer some advantages. It could provide the best performance (quicker accelerations leading to lower trip times) and the lowest technology cost. For systems constructed mostly at-grade, the situation becomes more complicated. TGV offers the lowest technology cost, but at significantly reduced performance. However, as shown in Chapters 3 and 4, the increased ridership and revenue resulting from the USML's anticipated higher performance offsets its higher costs. Thus, even for at-grade systems, the USML could offer an overall advantage. The USML also could offer a decided cost advantage over the TR07 at-grade. The current design of the TR07 requires that a guideway be supported by short piers, even at-grade, which precludes the full cost advantage of a continuously-supported structure.

Chapter 3: The Potential for Maglev Application in U.S. Intercity Transportation

3.1 OVERVIEW

This chapter explores how well a USML system, as defined in Section 2.4, would perform economically, in terms of revenues, costs, and public benefits, if such a system were built in specific intercity corridors. Principal findings are that:

- Maglev revenues would cover operating costs and contribute to the payment of capital costs in all but one of 16 corridors studied.
- Using a 7 percent discount rate, maglev revenues would cover total operating and capital costs in one corridor under the baseline scenario*, but, for most of the other 15 study corridors, revenues would cover only about 40 percent of total costs. The high initial investment will require substantial public assistance.
- With a 4 percent discount rate one corridor's revenue would exceed total costs by a wide margin for the baseline scenario*, and for most of the other study corridors, revenues would cover about 55 percent of total costs.
- Under a more favorable economic scenario*, financial performance would be improved; 2 of the study corridors would cover total costs at the 7 percent discount rate and 6 at the 4 percent discount rate. Intercorridor system effects could further improve financial performance.
- Maglev has positive social benefits from congestion, petroleum and emission reductions and from improvements to passenger safety which may justify the expenditure of public funds.

3.2 ANALYTICAL APPROACH AND METHOD

3.2.1 General Approach

Initially 26 corridors were identified where High-Speed Ground Transportation (HSGT) would be most likely to perform well. This identification was based primarily on the number of current air trips of less than 600 miles, since trips diverted from air travel have been shown to be the largest source of revenue. Sixteen of these corridors were chosen for detailed analysis of maglev performance under various conditions. These 16 corridors are shown on a map in Figure 3.1 and listed in Table 3.1. A listing of all 26 corridors is provided in Table 3.10.

In each corridor the revenues, operating costs, and capital costs associated with a USML system were estimated for two different types of route alignments and two different "scenarios" using 1991 dollars. Thus, it was possible to evaluate the performance in each corridor in purely financial terms (i.e., revenue versus cost) using measures such as the ratio of revenue-to-costs or the excess (or deficit) of revenues over costs. In addition, public benefits attributed to maglev were

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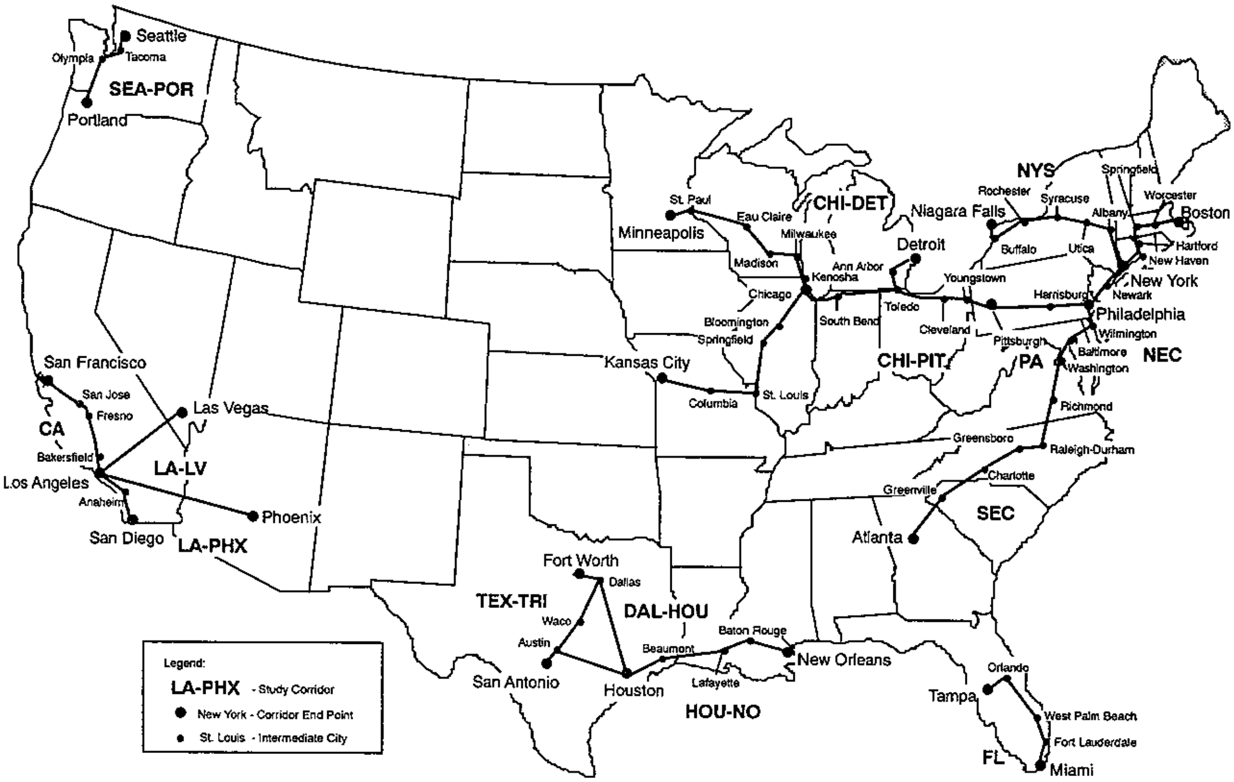
* See Page 3-4, Table 3-2 for definition.

Figure 3.1
U.S. Map of Study Corridors



estimated and, where possible, given a monetary value to determine the extent to which public benefits could compensate for revenue deficiencies.

3.2.2 Routes and Scenarios

Two types of maglev alignments were considered:

- An alignment with extensive sharing (ES) of existing highway and railroad ROW, with the shared portion amounting to about 80 percent of its length.

- A mainly new alignment with limited sharing (LS) of existing highway and railroad ROW with the shared portion occurring mainly in urban areas and amounting to about 35 percent of its length.

The lengths for the ES and LS alignments in the 16 study corridors are provided in Table 3.1. The LS ROW for a corridor has fewer and less severe curves than the ES ROW and is usually shorter. This permits higher maglev operating speeds, resulting in shorter trip times.

Two socioeconomic scenarios were considered: a "baseline" scenario using conservative assumptions, and a "favorable" scenario using less conservative assumptions.

The assumptions for each scenario are listed in Table 3.2.

Table 3.1
Corridor Identification for Maglev Analysis

Code	Name	Corridor End Point Cities	Length of ROW	
			Limited Sharing (miles)	Extensive Sharing (miles)
NYS	New York	New York Buffalo	447	452
CHI-DET	Chicago-Detroit	Chicago Detroit	315	334
CA	California	San Diego San Francisco	540	538
NEC	Northeast Corridor	Boston Washington	467	477
PA	Pennsylvania	Philadelphia Pittsburgh	311	333
CHI-PIT	Chicago-Pittsburgh	Chicago Detroit Pittsburgh	575	585
CHI-MSP	Chicago-Minneapolis	Chicago Minneapolis	431	433
CHI-KC	Chicago-Kansas City	Chicago Kansas City	539	559
DAL-HOU	Dallas-Houston	Dallas-Fort Worth Houston	279	291
TEX TRI	Texas Triangle	Dallas-Fort Worth San Antonio Houston	704	728
FL	Florida	Miami Tampa	297	318
LA-LV	Los Angeles-Las Vegas	Los Angeles Las Vegas	285	300
LA-PHX	Los Angeles-Phoenix	Los Angeles Phoenix	398	401
SEA-POR	Seattle-Portland	Seattle Portland	169	177
HOU-NO	Houston-New Orleans	Houston New Orleans	341	351
SEC	Southeast Corridor	Washington Atlanta	661	655

Table 3.2
Summary of Differing Assumptions under Each Scenario

Item	Baseline Scenario	Favorable Scenario
Auto trip growth	1.5 percent per year overall; sharply declining rate after 2010.	2.0 percent per year overall.
Air trip growth	2.4 percent per year overall; growth rate declines over time.	2.8 percent per year overall.
Air trip diversion	Calculated by model, assuming air competition.	Calculated by model, but at least 90 percent of air trips divert if trip time similar to air and city pair has a congested air hub.
Air transfer trip diversion	Calculated by model if airport served by maglev station, but lower diversion than for true origin/destination.	Calculated by model, but at least 90 percent of air trips divert if trip time similar to air and city pair has a congested air hub.
Air congestion	Minimal increase in 2000, increasing to 2-20 minutes in 2030.	Ten minutes total trip delay above baseline.
Auto congestion	Estimates for 1988 used for all future years.	Baseline trip time increased by 4 percent.
Rail trip diversion	Calculated by model assuming competition, but adjusted upward because conventional Amtrak service would be replaced.	Same as baseline.
Air and auto fare or operating cost	Estimates of 1991 fare or cost.	Add 20 percent to baseline.
Induced travel	10 percent of diverted.	20 percent of diverted.

3.2.3 Trip Times

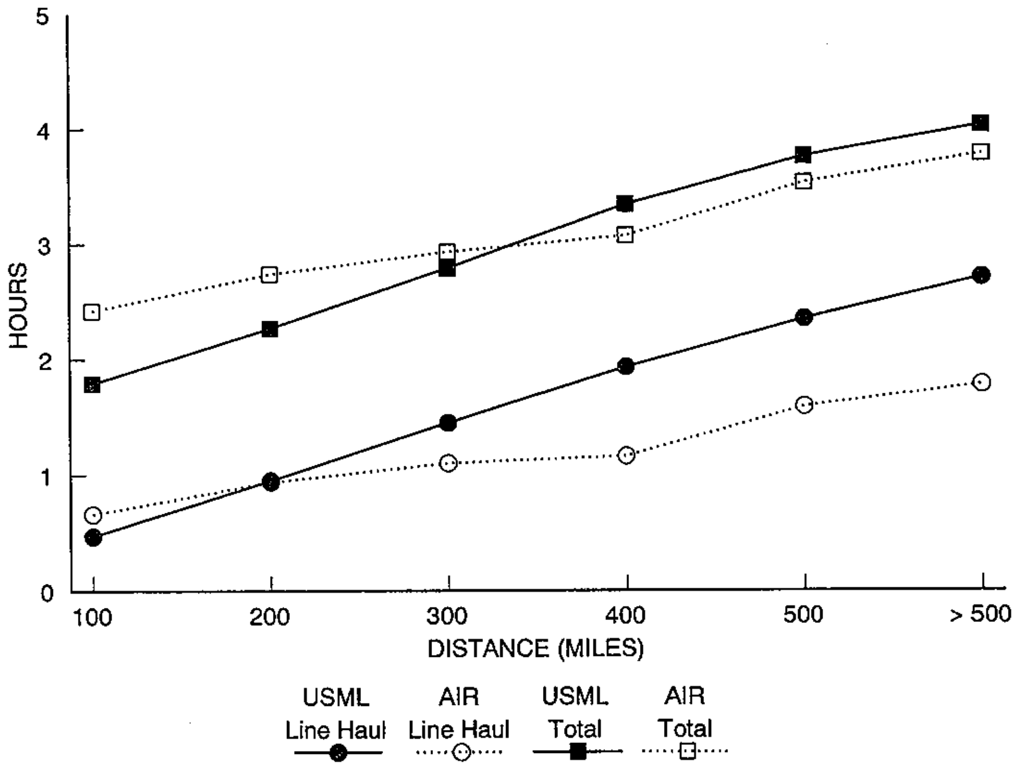
Trip times for maglev and competing modes of travel were estimated under a consistent set of assumptions regarding their respective operating environments, and these trip times were used in estimating the percentage of trips diverted to maglev. Trip times included estimates for terminal access and egress times at either end of the trip and time spent in terminals. The time on the maglev line itself between each pair of stations was obtained by simulating the operation of a USML vehicle with a particular pattern of intermediate stops, urban speed limits, and technical characteristics such as top speed, rates of acceleration and deceleration, and bank angles when rounding curves. The routes were generated based on maps and geographic information systems and made use of highway location and topographic information.

Figure 3.2 provides a comparison of maglev and air trip times. Maglev has a line haul trip time advantage over air up to about 200 miles, and a total trip time advantage over air up to about 300 miles. Maglev's total trip time disadvantage is relatively small even at 600 miles suggesting that some air passengers in such markets would divert to maglev.

Demand for maglev is strongest in markets where its trip times compare favorably to those of other competing modes. Table 3.3 compares line haul and total (including terminal access, etc.) trip times for the maglev, auto, and air modes between end point metropolitan areas for 16 study corridors in the year 2000. These are estimates of trip times travelers would actually experience for both air and maglev.

As illustrated in Table 3.3, the line haul trip time for maglev is greater than air

Figure 3.2
Comparison of Air and Maglev Trip Times by Distance



Notes:
(1) Maglev line haul trip time based on use of the LS alignment.
(2) Data are averages for city pairs from the 16 study corridors in each distance range.
(3) Total trip time includes in-terminal processing time and time for local access and egress to terminals.
(4) Trip time estimates include appropriate adjustments for congestion delays, stops, speed restrictions, etc.

Table 3.3
Comparison of Line Haul and Total Trip Times by Mode for Selected Corridor City Pairs (Hours)

CORRIDOR	TRIP ENDPOINTS		LINE HAUL TRIP TIME			TOTAL TRIP TIME		
	City 1	City 2	Maglev	Air	Auto	Maglev	Air	Auto
NEC	Boston	Washington	2.48	1.60	9.60	3.52	3.08	9.77
CAL	San Diego	San Francisco	2.60	1.63	9.62	3.70	3.09	9.78
LA-PHX	Los Angeles	Phoenix	1.55	1.31	7.40	2.77	2.91	7.65
DAL-HOU	Dallas	Houston	1.12	1.17	4.65	2.16	2.60	4.82
LA-LV	Los Angeles	Las Vegas	1.19	1.05	5.05	2.46	2.49	5.30
TEX TRI	Dallas	San Antonio	1.26	1.18	4.93	2.17	2.51	5.10
SEC	Washington	Atlanta	2.71	1.79	11.12	3.67	3.26	11.28
CHI-PIT	Chicago	Pittsburgh	2.51	1.70	9.30	3.68	3.34	9.55
CHI-MSP	Chicago	Minneapolis	1.72	1.71	7.93	2.91	3.37	8.18
CHI-DET	Chicago	Detroit	1.38	1.45	5.33	2.47	3.09	5.58
CHI-KC	Chicago	Kansas City	2.17	1.70	10.13	3.23	3.21	10.38
NYS	New York	Buffalo	1.77	1.30	8.28	2.81	2.74	8.53
FL	Miami	Tampa	1.36	1.11	4.63	2.50	2.60	4.80
HOU-NO	Houston	New Orleans	1.36	1.19	6.87	2.35	2.52	7.03
PA	Philadelphia	Pittsburgh	1.35	1.29	7.05	2.27	2.78	7.22
SEA-POR	Seattle	Portland	0.79	0.91	3.20	1.77	2.29	3.37

unless the short distance gives maglev a slight advantage. This table also shows, however, that when total trip time is considered, the air mode's advantage over maglev is generally reduced or eliminated because of the maglev mode's usual advantage in terminal access and processing time. Most other city pairs in the study corridors are closer together than those listed in these tables, thus having maglev trip times that are more favorable relative to air than those listed. The maglev's trip time advantage relative to the auto mode is also evident, especially for city pairs that are separated by long distances.

3.2.4 Fares

Regarding fares and auto operating costs, maglev competes primarily with air, consequently, maglev fares are expressed as a percentage of the air fare calculated for each market. A value of 90 percent was used, but lowered in markets where the maglev mode had a large trip time disadvantage. The fare used for the USML design was at or close to the net revenue-maximizing fare.

3.2.5 Ridership and Revenues Estimation

Estimating maglev revenue involved five steps. First, 1988 trips by mode (air, auto, and rail) were estimated for each origin/destination (OD) market and allocated between business and nonbusiness purposes. Second, these trips were forecast for the years 2000 to 2030 at 10-year intervals. Third, maglev diversions from each mode/purpose category were estimated using a mathematical model of predicted passenger behavior. Relative trip times, fares, and frequencies of service of the competing modes were used to estimate the percentage of trips that would be diverted to maglev. Fourth, the maglev trips in each category were multiplied by the maglev fare. Fifth, the totals were increased by 10 or 20 percent to reflect induced travel. The process included adjustments for special circumstances associated with intercity markets under 85 miles and the air passenger transfer market.

A key step in the process is the projection of trips over the study period. While growth rates differ by mode and city pair, the overall pattern is summarized for the 16 corridors in Figure 3.3. The growth rate for air is higher than for auto, averaging 2.4-percent per year. This is considerably below the air 5.2 percent growth rate from 1978 to 1988, but it leads to 2030 air trips increasing to about 2.7 times their 1988 levels.

3.2.6 Cost Estimation

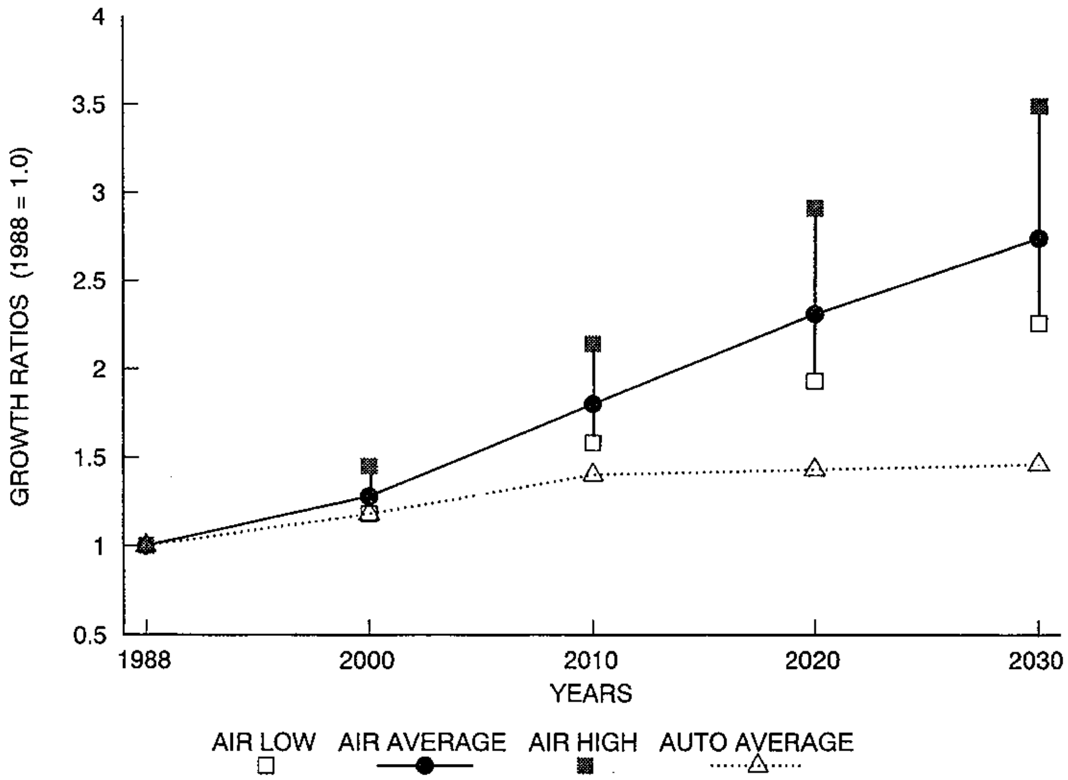
Estimating the cost of constructing the USML system took into account not only the "technology costs" discussed in Section 2.4, but also nontechnology costs elements such as ROW preparation, surveying, fencing, access roads, land acquisition, traffic control, and demolition/reconstruction of existing buildings, roads, and utilities. Costs were estimated for combinations of terrain and degree of urbanization, taking into account whether existing ROW was to be used, the percentage of the maglev guideway estimated to be at grade or elevated, and regional construction cost variations.

Estimates of operating costs were based on providing a full-service organization to run the system in each separate corridor. Personnel levels were estimated according to the size and length of the system and the amount of service provided, assuming an average load factor of 65 percent. Costs of energy and materials were also included.

3.2.7 Financial Assessment

Most of the financial assessment in this section involves the use of either the revenue-to-cost ratio or the difference between revenues and costs associated with building and operating a USML system. These values are developed by first discounting future revenues for the years 2000 to 2040 back to the year 2000, a hypothetical year when operations might begin. It is intended to reflect the average return to capital investments in all sectors of the economy and thus, the social opportunity cost of using resources for maglev investments. It should be considered that initial capital costs would occur on average 1.5 years before opening. Therefore, instead of using a discount factor, a 1.5-year premium was added to the cost.

Figure 3.3
Trip Growth Rates for Air and Auto Modes



Notes:
(1) Corridor and overall averages are weighted using city pair trips as weights.
(2) Underlying growth rates estimated from regional demographic and economic trends.
(3) Average annual growth rate for air is 2.4 percent and auto is 1.5 percent.
(4) The "high" and "low" figures for air represent the fastest (Florida) and the slowest (Chicago-Detroit) growth corridors, respectively.

A discount rate of 7 percent with constant dollar values was used. This is the equivalent of 10.5 or 11 percent in market terms (where inflation is taken into account instead of using constant dollars) and is required to be used by the Office of Management and Budget for making economic decisions regarding all Federal Government sponsored or assisted projects. It is intended to reflect the average return to capital investments in all sectors of the economy and, thus, the social opportunity cost of using resources for maglev investments. It should be considered as a "baseline" discount rate for the purpose of this report.

In addition, a discount rate of 4 percent with constant dollar values was also used as sensitivity analysis, to reflect the type of bond financing that is likely to be available to sponsors of HSGT projects in the future. When translated into market terms, 4 percent is the equivalent of 7.5 or 8 percent. The market yield of tax exempt interest state and municipal bonds is now about 6 percent and the Administration has supported making available such tax-free interest financing, without annual limits, to sponsors of HSGT projects. Therefore, the rate used is somewhat higher than the tax-free bond rate and would allow a slight margin for risk and/or higher prevailing rates in the future. Nevertheless, the 7-percent constant dollar rate should be used as the primary basis in benefit/cost analysis for Government decision making.

3.2.8 Public Benefits

Estimates were made of benefits from the relief of air congestion, reductions of petroleum usage and emissions of airborne chemicals, and safety improvements. The procedure for air congestion relief was to estimate the reduction in the future growth of traffic at key airports due to diversion to maglev and to estimate the effect of this on the average delay for people who continue to use the airports. Reduced levels of petroleum usage and emissions and safety impacts were estimated from the altered modal distributions of passenger miles and the projected petroleum usage and emission and safety rates of those modes.

3.3 ESTIMATES OF MAGLEV RIDERSHIP, REVENUE, AND COSTS

Revenue and cost estimates are derived from corridor-specific estimates of trip time and other factors affecting costs and trip-making rates. The maglev system analyzed is the U.S. technology as defined by the NMI, using the operational performance and cost estimates described in Section 2.4. The analysis focuses on the baseline scenario using the LS alignment as defined in Section 3.2, but some information regarding the favorable scenario and the ES alignment cases is provided also.

3.3.1 Corridor Financial Feasibility Results

Comparisons of revenue and cost estimates developed for 16 corridors indicate that:

- For the Northeast Corridor (NEC) maglev revenues cover all costs using a 7 percent discount rate, and considerably exceed costs with a 4 percent discount rate.

- For 14 of the 15 other corridors, revenues would cover operating costs, but only a portion of capital costs, using either discount rate.

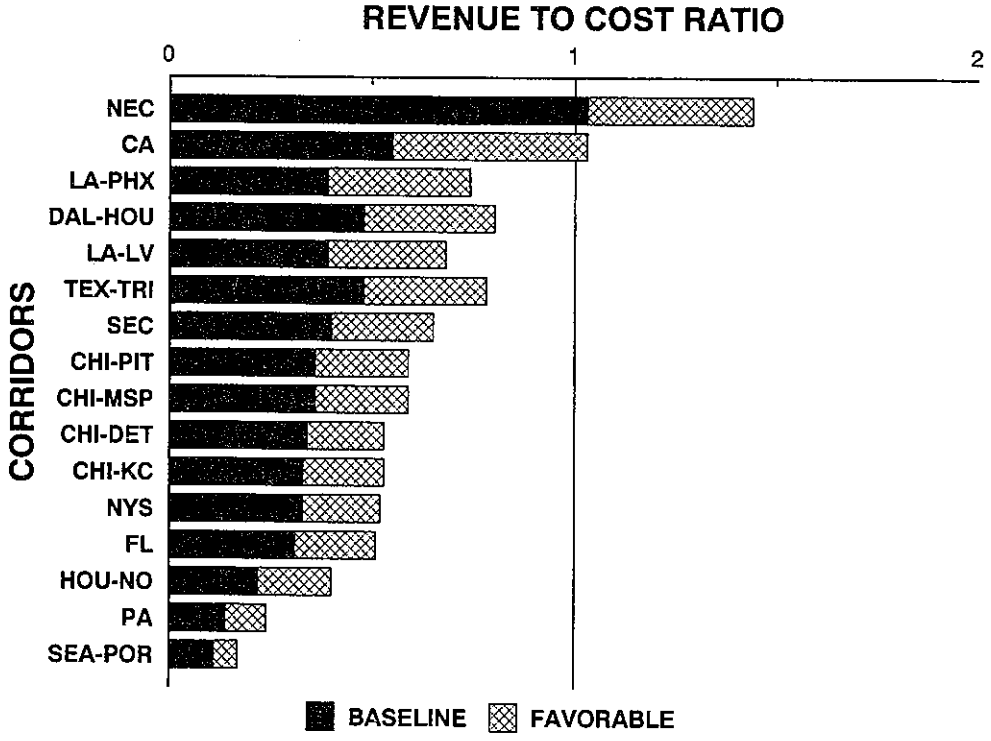
- If more favorable assumptions are made, revenues cover all costs in 2 of the 16 corridors studied using a 7 percent discount rate, and 6 of the 16 corridors with the 4 percent discount rate.

- Alternative discount rates and project starting dates can result in sizable changes to the revenue-cost comparisons.

Figure 3.4A provides estimated corridor revenue-cost (R/C) ratio information using a 7 percent discount rate for the 16 study corridors on the alignment that uses only LS of existing ROW. A value of 1.0 indicates a break even condition and the full bar widths are R/C values for the favorable scenario. The dark portion of the bar indicates a corridor's R/C value for the baseline scenario.

The positive financial positions of the NEC under the baseline scenario and for the California corridor in the favorable scenario are evident. These estimates also

Figure 3.4A
Estimates of Maglev Revenue-to-Cost Ratios for Baseline and Favorable Scenarios by Corridor Using a 7 Percent Discount Rate



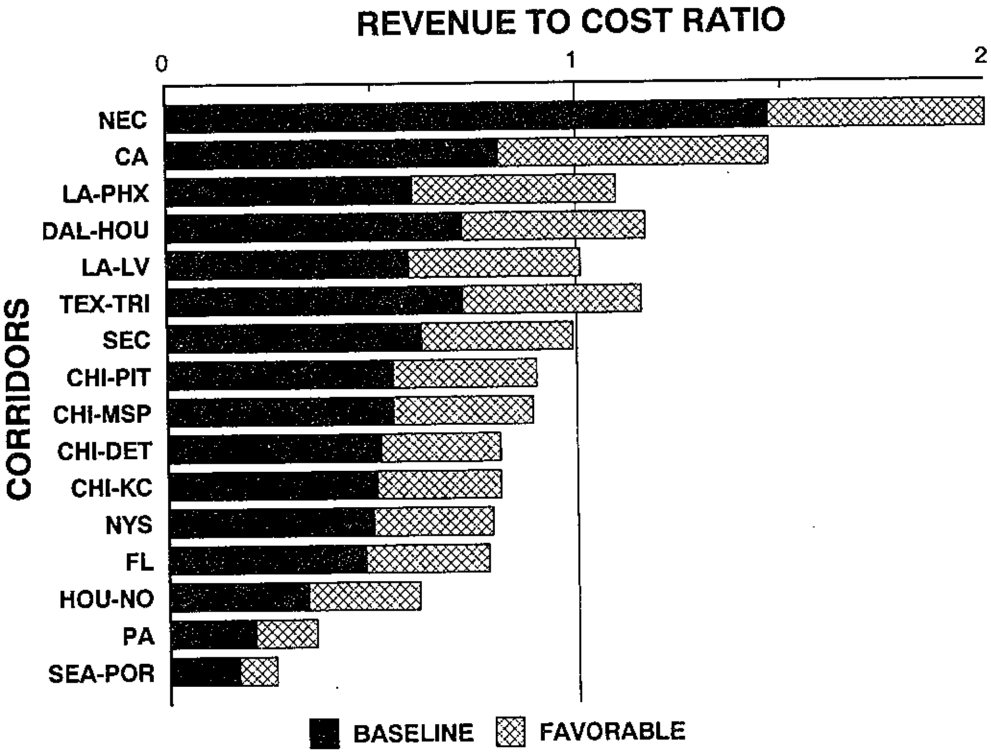
Notes: (1) Estimates based on present values to year 2000 using a 7 percent discount rate.
(2) Revenues and operating costs estimated for 40 years.
(3) Costs include initial construction, initial vehicles, and future vehicle replacement and fleet growth.
(4) Corridor alignments based on limited sharing ROW case.

reveal, however, that 3 corridors have significantly lower economic performance even under this study's favorable scenario. Still, as will be seen in later sections, even some of these corridors can be significant links in a larger maglev system or network.

The R/C ratios of Figure 3.4A are computed using a discount rate of 7 percent. A lower discount rate would raise these values. For example, using a 4 percent discount rate for the NEC changes its R/C ratio from 1.03 to 1.47 and for the Dallas-Houston (Dal-Hou) corridor, the ratio changes from 0.48 to 0.72. Results using the 4 percent discount rate for all 16 corridors and both scenarios are provided in Figure 3.4B.

Some corridors might not begin operations until after the year 2000, and this factor would also affect a corridor's estimated R/C ratio because of higher passenger demand. For example, if 2010 were used as the starting date for the California corridor, its R/C ratio would increase from 0.55 to 0.69 (7 percent discount rate) or from 0.81 to 1.00 (4 percent discount rate).

Figure 3.4B
Estimates of Maglev Revenue-to-Cost Ratios for Baseline and Favorable Scenarios by Corridor Using a 4 Percent Discount Rate



Notes:
(1) Estimates based on present values to year 2000 using a 4 percent discount rate.
(2) Revenues and operating costs estimated for 40 years.
(3) Costs include initial construction, initial vehicles, and future vehicle replacement and fleet growth.
(4) Corridor alignments based on limited sharing ROW case.

While the R/C ratios summarize the financial performance of maglev in individual corridors, the dollar value of the revenue and cost estimates (as discussed below) are also important to the evaluation of the maglev technology as a potential intercity transportation system. In particular, these estimates reflect:

- Very substantial costs involved in building and operating maglev systems in all corridors.
- High levels of ridership attracted to maglev for many of the corridors.

These cost and ridership estimates are at the high end, but in the general range of those used in previous studies of HSGT.

Finally, the analysis in this report, even though it considered factors particular to specific corridors, was designed to help reach conclusions about maglev applicability across the United States. In some cases, more detailed surveys of potential ridership and more detailed cost analysis of routes have been undertaken to support decisions on specific HSGT projects. The analysis in this report should not be considered a substitute for such studies of particular geographic areas.

3.3.2 Corridor Costs

The cost estimates used in the overall evaluation of corridor financial performance are discounted (present value) totals of all capital and operating costs over 40 years. The key results in the cost area are:

- Initial capital costs for each corridor are substantial, ranging from $5.7 billion to $21.4 billion (7 percent discount rate) or $5.5 billion to $20.5 billion (4 percent discount rate).
- Technology-driven guideway costs are only about half of the initial construction cost; costs for vehicles, stations and other required ancillary facilities, civil reconstruction, environmental mitigation measures, contingencies, and program management make up the rest.
- Vehicle fleet costs are large in absolute terms, but only about 5-10 percent of a system's total capital cost.
- Life cycle <u>operating and maintenance</u> costs are about 10-20 percent of <u>total</u> life cycle costs (20-25 percent with the 4 percent discount rate) and about 9 cents per passenger mile for most of the study corridors.

The dominant cost category for all corridors is the initial capital cost of the system. These costs range from $5.7 billion to $21.4 billion (see Table 3.4) with high values reflecting longer distances and more urban area construction. The capital cost per mile ranges from $27 million to $46 million, reflecting the variations in construction conditions among corridors. It is lower per mile than the $50-100 million per mile cost of urban rail systems, mainly because intercity systems entail substantial rural (lower cost) mileage and because they have fewer stations per mile of guideway.

The maglev guideway is a major component of total life cycle cost, but other cost categories also comprise major portions of the total. Figure 3.5 shows that

Table 3.4
Maglev Initial Capital Costs by Corridor

INITIAL CAPITAL COSTS ($ Billions)				Length Miles	Dollars/Mile (Millions)
Corridor	Guideway Technology	Other	Total		
NEC	8.57	12.7	21.2	467	45.4
CA	10.29	11.1	21.4	540	39.6
LA-PHX	7.00	5.6	12.6	398	31.7
DAL-HOU	4.17	3.4	7.5	279	26.9
LA-LV	5.31	4.7	10.0	285	35.1
TEX-TRI	10.41	8.4	18.9	704	26.9
SEC	9.31	8.3	17.6	661	26.6
CHI-PIT	9.75	8.8	18.5	575	32.2
CHI-MSP	7.06	6.2	13.3	431	30.9
CHI-DET	5.27	4.4	9.7	315	30.8
CHI-KC	9.02	7.7	16.7	539	31.0
NYS	7.74	6.7	14.4	447	32.2
FL	4.32	3.7	8.0	297	27.0
HOU-NO	5.14	4.3	9.4	341	27.6
PA	5.30	4.3	9.6	311	30.9
SEA-POR	2.88	2.8	5.7	169	33.7

Notes: (1) Estimates are for baseline scenario using the limited sharing ROW alignment.
(2) Guideway technology costs include the guideway beam, supporting structures, and all electrical and magnetic components.
(3) Other costs include vehicles, stations and other fixed facilities, environmental mitigation costs, civil reconstruction, non-technology site preparation work, contingencies, and program management.
(4) A construction financing cost is included in these estimates using the 7 percent real interest rate. A 4 percent rate reduces all table dollar values by 4.2 percent.

corridor specific information can lead to relatively large differences in economic results.

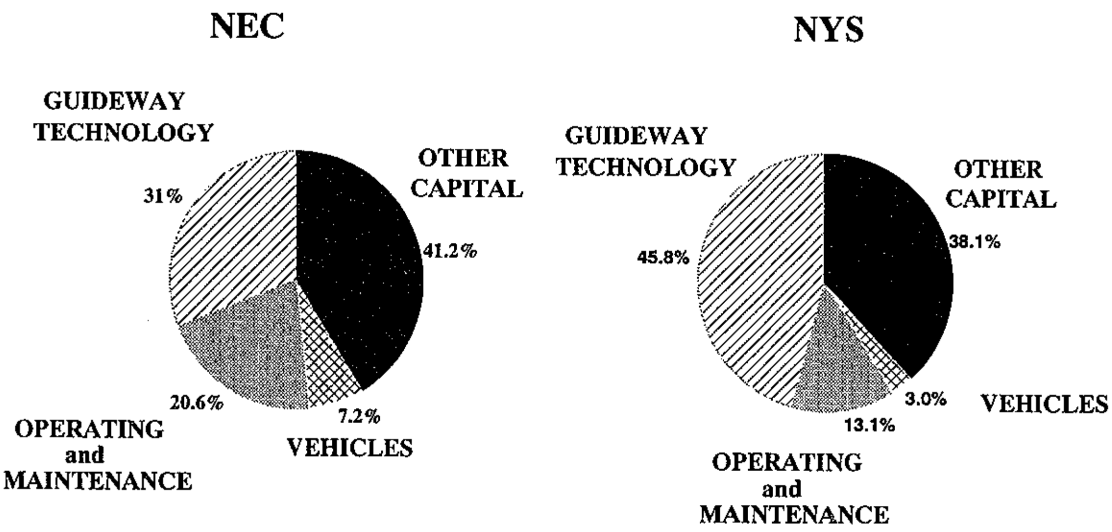
The estimates of corridor operating and maintenance costs are typically about 9 cents per passenger mile with a few low-volume corridors considerably different than the average (as high as 37 cents per passenger mile and as low as 7 cents per passenger mile). These costs are higher than the 3-5 cents used in some other studies of maglev.

3.3.3 Corridor Ridership and Revenues

Based on the NMI effort, the major conclusions about maglev ridership and revenues are:

- Diversion rates to maglev are highest for air origin/destination (OD) and rail passengers.
- The primary source of maglev revenue is from diverted common carrier, especially air OD, passengers.
- Diversion rates from auto travelers average only 2.1-percent, but diverted auto trips account for about 7-percent of revenue because of the large number of auto trips from which diversions are drawn.
- Corridor ridership and revenues for maglev generally come from a multiplicity of city pairs and modal markets, often with no single source accounting for 40 percent of revenues.

Figure 3.5
Maglev Lifecycle Cost Distribution, NEC and NYS Corridors



Notes: (1) Computations use a 7 percent discount rate.
(2) The share of operating costs is increased with a 4 percent discount rate, and the guideway and other capital shares decrease.

Maglev ridership and revenues arise mainly as a result of diversions from existing modes, especially air. These diversions are estimated by applying modal diversion rates to projected modal trips for each city pair and trip purpose and multiplying by projected fare levels. The modal diversion rates are estimated for the auto, rail, air origin/destination (OD), and air transfer (TR) modes. Table 3.5 summarizes the corridor diversion rates by mode and gives the range (reflected by the highest and lowest value from the 16 corridors) and the average value for the 16 study corridors (Appendix Table A1 contains corridor-specific diversion rates).

The low diversion rates for auto occur because auto travelers cannot easily be shifted to a new mode that is similar to air in cost, trip time, and other characteristics. Since auto travelers have chosen not to use air, few shift to the new mode which is similar to air, even though it often offers sizable trip time advantages over the auto.

The diversion rates for rail, air origin/destination (OD) and air transfer (TR) passengers, unlike auto, can be traced to the maglev trip time and fare advantages. Generally, if common carrier passengers are offered a competing service with similar cost, travel time, and comfort levels, significant numbers will elect to travel on the new mode. The air transfer passenger diversion rates are lower than the air OD rates because these passengers would encounter some extra transfer trip time and are not assumed to receive a discount in their total trip cost. The air transfer diversion rates are also low in some cases because they are treated as zero for metropolitan areas in which there is no maglev station assumed at an airport.

Maglev revenues are estimated by combining diversion rates with market size and fares and adding in estimates for induced travel and short distance markets for which no diversions are estimated. Table 3.6 summarizes the maglev revenue sources by corridor.

There are several noteworthy results evident in the Table 3.6 estimates for the study corridors. First, the primary source of maglev revenues is existing travelers using common carrier modes, especially air OD travelers. Second, in many corridors, there are significant secondary markets beyond the air OD passenger. Specifically, there are only 3 of the 16 study corridors that obtain as much as two-thirds of their expected maglev revenues from the air OD market and several obtain below 50 percent. Significant potential markets for

Table 3.5
Diversion Rates Summary by Mode

	Auto	Rail	Air OD	Air Transfer (TR)
Low	1.3%	44.8%	53.9%	10.0%
Average	2.1%	74.9%	67.9%	37.9%
High	7.5%	100.0%	81.1%	60.2%

Note: See Appendix A Table A1 for details by corridor.

Table 3.6
Level and Sources of Maglev Revenues by Corridor, Year 2020

Corridor	Total Revenue ($ millions)	Auto	Rail	Air OD	Air TR	Other
NEC	2,290.3	7.8%	30.8%	46.2%	6.7%	8.6%
CA	1,327.1	6.2%	5.6%	75.8%	3.5%	8.9%
LA-PHX	568.0	3.5%	0.4%	75.8%	12.3%	8.0%
DAL-HOU	443.5	3.9%	0.1%	66.3%	22.7%	7.0%
LA-LV	450.4	2.2%	24.1%[1]	57.5%	7.8%	8.4%
TEX-TRI	1,065.3	4.7%	0.1%	63.1%	25.1%	7.0%
SEC	810.7	8.7%	0.3%	43.5%	41.9%	5.7%
CHI-PIT	721.3	9.6%	2.1%	59.6%	20.7%	7.9%
CHI-MSP	526.8	8.6%	5.5%	44.1%	35.5%	6.3%
CHI-DET	367.5	3.9%	3.1%	62.6%	22.6%	7.8%
CHI-KC	559.8	6.2%	6.1%	57.8%	22.9%	7.1%
NYS	503.9	11.2%	19.6%	56.8%	2.9%	9.6%
FL	300.7	6.4%	1.2%	74.4%	9.6%	8.5%
HOU-NO	235.0	13.8%	0.7%	58.8%	18.6%	8.1%
PA	131.1	14.0%	5.8%	44.6%	29.1%	6.4%
SEA-POR	67.4	7.4%	9.3%	60.1%	14.1%	9.1%
AVG	648	7.0%	11.0%	58.0%	16.2%	7.4%

Note: Bus trips used instead of rail trips for LA-LV estimate.

intercity HSGT would be missed in any study that focuses only on air OD trips.

Third, the joint influence of market size and diversion rates is seen in the estimates of revenues from the rail mode. A corridor with large numbers of existing rail travelers derives a large proportion of its maglev revenue from the rail mode whereas a corridor with little or no rail travel does not (even if the diversion rate is high). Fourth, the revenues from the auto mode are higher than might be expected given their low diversion rates. This reflects the large absolute size of the intercity auto market in the study corridors.

The analysis of maglev financial performance in this study focuses mainly on corridors rather than individual city pairs or complex networks. For most corridors, reported costs and revenues are summaries for the multiple city pairs that would be served. Connecting more points tends to enhance the overall financial performance of a corridor if the extra distance and circuity are limited. This can be a key consideration in the planning and design of intercity systems and in comparisons among modal options.

Table 3.7 serves to illustrate this perspective by providing sources of estimated maglev passenger miles by category for the New York State (NYS) corridor. The diversity of ridership in terms of modal diversions and geographical patterns is clear and indicates the importance of evaluating all potential ridership sources for financial analyses. Further, even though air diversions are usually the largest potential source of maglev ridership and revenues, focusing on **single** air OD markets can seriously understate maglev's potential. Even the biggest market in the NYS corridor, New York-Buffalo, comprises less than 30-percent of the total estimated maglev market.

Table 3.7
Sources of NYS Corridor Passenger Miles

Mode	Market	Passenger Miles (millions)	Percent
Air	New York-Buffalo	436.0	28.9
	New York-Rochester	266.2	17.7
	New York-Syracuse	156.6	10.4
	Other Air OD	95.7	6.3
	Air Transfer	60.2	4.0
Rail	NY-Albany	86.2	5.7
	Other Rail	116.2	7.8
Auto	All OD	153.7	10.2
NA	Induced Demand	131.1	8.7
NA	Short Distance	5.0	0.3
Total		1507.7	100.0

3.3.4 Intercorridor Impacts on Financial Performance[1]

A financial analysis of maglev corridors joined into small systems or networks was performed with the following results:

- Intercorridor connections can result in modest additions to maglev ridership and revenues.
- The financial performance of intercorridor systems is somewhat better than the average achieved by the individual corridors.
- In some cases, the financial performance of an intercorridor system can be better than any of the corridors considered as separate units.

Up to this point, demand and cost estimates have been presented for 16 independent corridors. This section extends the analysis to corridor networks defined as combinations of adjacent corridors. Traffic demand on these networks will be greater than the sum of demand of their component parts due to new intercorridor demand generated from city pairs with origins in one corridor and destinations in another. However, diversion rates to high-speed ground modes might not be as great for intercorridor trips because trip distances will generally be longer and some trips might be expected to involve transfers.

Costs for the combined network are expected to increase much more modestly. Operating, maintenance, and vehicle costs should be roughly proportionate to demand, but the capital costs (the largest component of costs) should increase only marginally and might actually be lower than the sum for the separate corridors when corrections are made for duplicate track and stations at corridor junctions.

Not all connections among the study corridors or other possible corridors were considered. Thus, the results presented here are only indicative of likely impacts in this area. A more comprehensive analysis is needed to estimate the impacts of larger networks and to reduce the qualifications and uncertainties in these results.

Two networks were analyzed with procedures similar to those used for each of the independent corridors (ridership and revenues were estimated at the OD level using the demand models). Estimated financial ratios were also developed for four other networks that use the hub-and-spoke concept, although the analytical methods used were less detailed. The networks used in these analyses are displayed in Figure 3.6.

In the more detailed network analysis, maglev service between city pairs in these combined corridors is assumed to be similar to that provided in component corridors except for a 20-minute transfer penalty at the major intercorridor junctions

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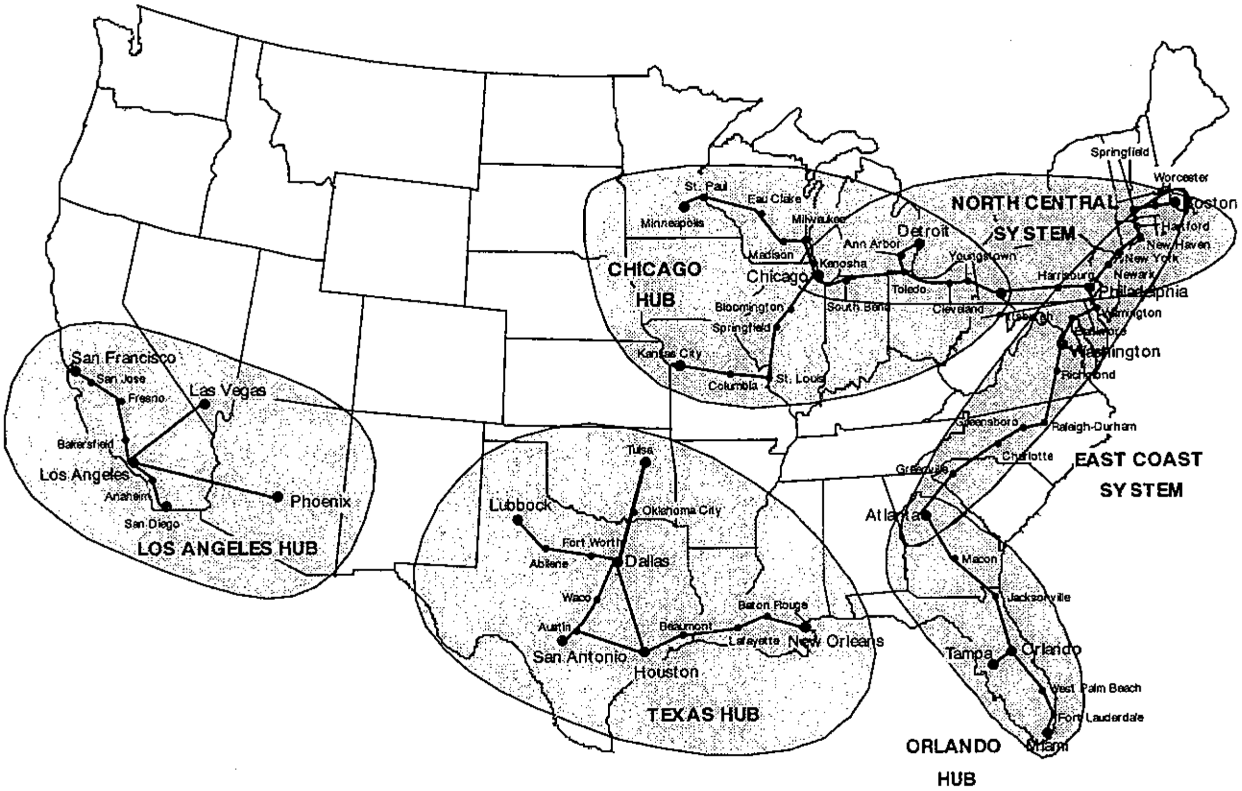
[1] Results in this section were estimated using the 7-percent discount rate. Whereas a 4-percent discount rate raises the R/C ratios, the patterns and conclusions are similar to those reported here. Appendix A, Table A2 contains network R/C ratio information corresponding to Table 3.8, but using the 4-percent discount rate.

Figure 3.6
Intercorridor System Definitions for Network Analysis



of Washington, D.C. and Philadelphia. Train frequency is assumed to be sufficient to serve the extra demand from the new city pairs served.

Added intercorridor trips increased total demand by 10.4-percent on the East Coast network and 13.2 percent on the North Central Network. Revenues increased by a larger amount (15.1 percent and 18.2 percent) due to the longer average trip lengths of the added intercorridor trips.

An approximate method was used to develop rough estimates of the financial impact of joining corridors into networks at potential hubs as defined in Figure 3.6. The approach employs relationships developed in analyzing the East Coast and North Central networks, combined with data on trip potential derived from forecasts of air and rail intercity travel. The results of this analysis are presented in Table 3.8. In all cases, intercorridor travel generated as a consequence of forming high-speed ground networks at hubs produced a modest positive impact on the average financial performance estimated for independent corridors. In particular, the revenue/cost ratios for the Chicago and Orlando hubs are higher than any of the R/C ratios of their components.

Using a 7 percent discount rate, the additional value of intercorridor travel is modest, increasing the average revenue/cost (R/C) ratio by 0.07 (East Coast) and 0.08 (North Central). If all intercorridor

Table 3.8
Impact of Intercorridor Network Travel on Revenue/Cost Ratio (R/C)

Network Concepts	Without Network	With Network
East Coast Corridor		
Range of R/C	0.40 - 1.03	
Average R/C	0.76	0.83
North Central		
Range	0.14 - 1.03	
Average	0.63	0.71
Chicago Hub		
Range	0.33 - 0.36	
Average	0.35	0.39
Los Angeles Hub		
Range	0.39 - 0.55	
Average	0.47	0.51
Orlando Hub		
Range	0.31 - 0.35	
Average	0.33	0.42
Texas Hub		
Range	0.22 - 0.48	
Average	0.37	0.40

Note: Estimates based on 7 percent discount rate.

revenues and costs were attributed to the corridors combined with the NEC (an incremental analysis), the R/C ratio for the SEC would rise from 0.40 to 0.59 and the R/C ratio for the combination of the Pennsylvania and Chicago-Pittsburgh corridors would rise from an average of 0.29 to 0.44. Although corridors with lower initial financial performance are enhanced by network effects, such corridors reduce the overall viability of the extended network. The R/C levels and size of the changes are increased when a 4 percent discount rate is used.

While this analysis shows that some enhancement in economic performance is possible by forming networks, the cost of an extensive network and the marginal performance of some network additions, despite the enhancement, would still make the implementation of large-scale networks questionable.

3.3.5 Effect of Alignment on Financial Performance

Two hybrid alignments were considered for each study corridor:

- An alignment with ES of existing highway and rail ROW.

- An alignment that, while involving LS of some highway and rail ROW mainly in urban areas, is built on mainly new ROW in rural areas.

While the operational and financial performance estimates of the USML system on the two alignments are similar (in part because the alignments are hybrids), there are consistent differences. In particular:

- Extensive ROW sharing alignments tend to be inferior to the LS alignments in ridership, cost, and overall financial performance.

Table 3.9 provides estimates of corridor ridership density and revenue-cost ratios for the baseline scenarios on both types of alignments for both the 7 percent and 4 percent discount rates. These results reflect the lower ridership levels and the cost disadvantage for the alignments with ES of existing ROW because of longer distances and overall higher costs per mile that usually occur.

3.3.6 Financial Potential of Maglev in Other Corridors

Ten of the 26 corridors originally chosen for study were not subjected to detailed analysis of trips diverted to maglev. Nevertheless, it is possible to approximate the financial performance of these 10 in relation to that of the other 16 by ranking all 26 according to O/D air traffic density (passenger miles per route mile) and seeing where the 10 rank in relation to the 16. This is the case because, as shown in Table 3.10, there is rough correlation between a ranking by air traffic density and a ranking by either projected maglev traffic density or revenue/cost ratio. From this analysis, it is evident that the corridors with highest potential are among the 16 studied in detail. The other 10 corridors do not appear to be among the financially stronger candidates for the implementation of maglev, though some of these corridors, or still others, may provide more potential as extensions to or connections within a network because of intercorridor trip making.

3.4 PUBLIC BENEFITS OF MAGLEV

The economic evaluation of maglev should include not only its financial viability but also its other public benefits and costs in areas such as congestion, petroleum consumption, emission, and safety. The estimated values of such public benefits and costs can, at least conceptually, be added to the corridor revenues and used to compute a societal benefit/cost (BC) ratio. There are also macroeconomic and other impacts of maglev that are identified but not included in the BC accounting; these are discussed in Section 3.5.

3.4.1 Airport Congestion Relief Benefit

Analysis of airport congestion relief indicated that:

- Passengers diverted to maglev from air reduce demand and congestion at airports.

- The congestion reduction benefit is received by remaining air passengers, i.e., airport users.

Table 3.9
Comparison of Maglev Financial Measures for Extensive Sharing and Limited Sharing Alignments

Corridor	Passenger Miles/Mile			Revenue to Cost Ratio			
	Extensive Sharing (millions)	Limited Sharing (millions)	Change (%)	Extensive Sharing ROW		Limited Sharing ROW	
				7%	4%	7%	4%
NEC	13.35	14.91	11.6%	0.93	1.33	1.03	1.47
CA	9.00	11.56	28.7%	0.43	0.65	0.55	0.81
LA-PHX	6.08	6.62	9.1%	0.33	0.52	0.39	0.60
DAL-HOU	5.68	6.31	11.3%	0.40	0.61	0.48	0.72
LA-LV	5.34	6.07	12.9%	0.31	0.48	0.39	0.59
TEX TRI	5.14	5.63	9.6%	0.40	0.61	0.48	0.72
SEC	3.63	4.49	23.5%	0.33	0.51	0.40	0.62
CHI-PIT	3.43	4.12	23.1%	0.27	0.42	0.36	0.55
CHI-MSP	3.41	4.10	20.4%	0.29	0.44	0.36	0.55
CHI-DET	3.32	4.08	22.7%	0.25	0.39	0.34	0.52
CHI-KC	3.37	3.86	14.5%	0.26	0.41	0.33	0.51
NYS	3.39	3.75	10.6%	0.28	0.43	0.33	0.50
FL	2.88	3.36	16.4%	0.24	0.37	0.31	0.48
HOU-NO	1.91	2.12	10.8%	0.18	0.29	0.22	0.34
PA	0.89	1.31	47.5%	0.09	0.13	0.14	0.21
SEA-POR	0.97	1.09	13.4%	0.09	0.14	0.11	0.17

- The congestion benefit at New York City area airports, is estimated to be $45 million a year from the NEC maglev.
- Maglev would have a sizable congestion relief benefit when aggregated over many cities, corridors, and years.

Table 3.10
Indicators of Maglev Financial Performance for 26 Study Corridors

Corridors	Air	U.S. Maglev, Limited Shared ROW			
	Pass. Miles Per Mile (Millions)	Rev/Cost Ratio		Passenger Miles Per Mile (Millions)	
		Value	Rank	Value	Rank
CA	14.0	0.55	2	11.56	2
NEC	11.0	1.03	1	14.91	1
LA-PHX	6.9	0.39	6	6.62	3
LA-LV	4.6	0.39	7	6.07	5
DAL-HOU	4.5	0.48	3	6.31	4
TEX-TRI	3.6	0.48	4	5.63	6
FL	2.7	0.31	13	3.36	13
SD-PHX (SAN DIEGO-PHOENIX)	2.7				
SEC	2.7	0.40	5	4.49	7
CHI-PIT	2.7	0.36	9	4.12	8
NYS	2.6	0.33	12	3.75	12
CHI-DET	2.4	0.34	10	4.08	10
CHI-KC	2.3	0.33	11	3.86	11
CHI-MSP	2.0	0.36	8	4.10	9
DAL-LUB (DALLAS-LUBBOCK)	1.9				
DAL-TUL (DALLAS-TULSA)	1.8				
HOU-NO	1.7	0.22	14	2.12	14
ATL-ORL (ATLANTA-ORLANDO)	1.6				
DEN-SLC (DENVER-SALT LAKE CITY)	0.9				
CHI-CIN (CHICAGO-CINCINNATI)	0.9				
SEA-POR	0.7	0.11	16	1.09	16
PA	0.7	0.14	15	1.31	15
SF-RENO (SAN FRANCISCO-RENO)	0.7				
BOS-ALB (BOSTON-ALBANY)	0.2				
IND-MEM (INDIANAPOLIS-MEMPHIS)	0.2				
OHIO (CLEVELAND-CINCINNATI)	0.2				

Notes: (1) Revenue-Cost ratio data based on life cycle present value estimates using a 7 percent discount rate (see Figure 3.4)
(2) Air and maglev passenger data are for year 2020.
(3) Air passenger data are OD only (no transfer passengers included).

Diversion of air traffic to HSGT modes will potentially reduce delays at congested airports. Although this benefit may be reduced by having new flights at popular departure times, having more air travelers, or by canceling or postponing airport/air traffic control improvements, the direct congestion reduction benefit can still be a good first approximation of the size of estimated benefit. However, the estimate is highly dependent on the assumptions that are made about airport capacity increases during the period of analysis.

Table 3.11 presents what is probably a very conservative order-of magnitude estimate of the airport congestion relief benefit for three of the larger cities (New York, Chicago, and Los Angeles) along potential maglev corridors. The first two rows of Table 3.11 give enplanement totals for 1988 and 2020. These data are for Chicago O'Hare, the three large New York airports (JFK, EWR, and LGA), and the four greater Los Angeles airports (LAX, SNA, BUR, and ONT).

The third row shows the percentages of projected 2020 enplanements diverted to a USML system for various proposed corridors involving the cities of New York, Chicago, and Los Angeles on LS alignments. Although the estimated percentages would be larger if several corridors were built reaching each city and intercorridor traffic were permitted, the combined corridor total diversion percentage does not include this intercorridor effect.

The fourth and fifth rows present estimates of the airport delay and delay reduction in the three cities. The 1988 delay per operation, in minutes, is the average for air carriers reporting this information in that year to the FAA. The delay reduction in 2020, in minutes, assumes that: (1) in the absence of maglev, changes would take place to keep 2020 delay at 1988 levels and (2) a given percentage diversion of enplanements will lead to the same reduction in delay per operation.

Table 3.11
Calculation of Congestion Reduction Benefit at Selected Airports

Row		Chicago	New York	Los Angeles
1	1988 Enplanements (millions)	31.5		28.8
2	2020 Enplanements (millions)	64.6	80.8	66.1
3	% Reduction in Enplanements	10.8	10.5	16.6
4	Average Delay (minutes)	10.2	11.0	7.5
5	Reduction in Average Delay (minutes)	1.1	1.2	1.2
6	2020 Benefit ($ millions)	41.6	54.8	45.1
7	2020 Benefit as % of Net Corridor Revenue	3.4	2.4	2.8

Also, the calculated dollar benefits in the sixth row of Table 3.11 apply the reduction to the nondiverted air passengers, valuing their time at the $39.50 per hour rate recommended by the FAA for such analysis.

Finally, the 2020 delay reduction benefits to remaining air passengers are compared to corridor net revenues in the seventh row of Table 3.11. These rough estimates indicate that societal benefits in the form of reduced airport congestion should be considered in the overall evaluation of a maglev development program and that improved estimates of these benefits would be of value.

Another way of thinking about congestion relief benefits is in terms of the cost of public facilities that would not have to be built as a result of building a maglev line. Specifically, we can deduce from Table 3.11 that, in the metropolitan areas shown, about 11 to 17 percent of projected total enplanements in these areas to all destinations in 2020 would be diverted by maglev. This is the equivalent of 22 to 30-percent of the projected <u>increase</u> in enplanements between 1988 and 2020. Thus, airport authorities intent on holding down future increases in delay would not have to build 22 to 30 percent of the new capacity otherwise needed. If this is replicated in other airports in the corridors, it is easy to see how it could represent several billion dollars of public benefit value in each corridor.

3.4.2 Impacts on Petroleum Usage, Emissions, and Safety

The NMI energy, emission, and safety impact analysis indicates:

- The petroleum savings from maglev, which uses electricity generated from nonpetroleum fuels, is a result primarily of diverting passengers from the airlines to maglev.
- The lower petroleum consumption for moving these passengers reduces the emission levels of carbon dioxide and most noxious gases.
- Maglev will result in net reductions in injuries and fatalities, primarily because of diversions from auto traffic.

The diversion of intercity trips from air, auto, and rail modes to maglev results in net reductions in energy usage, petroleum consumption, emissions of most airborne pollutants, and lives lost in accidents. The size and value of these impacts depend on the ridership estimates for each corridor. Estimates of these effects are summarized in Section 4.3.3 where they are considered along with an analysis of variations among technologies.

3.5 OTHER NATIONAL IMPACTS OF MAGLEV

The decision to pursue the development of maglev as an intercity passenger system depends mainly on its potential role as a new transportation mode, i.e., its technical and economic soundness. Maglev development can also, however, be viewed as a part of a broader strategic plan for United States economic development, and it is in this context that its national impacts are relevant. Strategic economic goals of job creation, technological advancement, and international competitiveness would be enhanced by the development and building of maglev systems. The following sections describe these potential national impacts of maglev.

3.5.1 Employment Implications

The development and implementation of maglev systems will cause jobs to be created in various industries, beginning with the engineering community that will design it, followed by the construction industry that will build it, and ending with the eventual operators that will operate and maintain it. The activities, types and number of jobs, and business opportunities will differ in each phase of implementation.

During the design phase, technical firms will propose a combination of components and subsystems integrated into a total system concept which includes a vehicle and guideway associated structure. Following design, components must be manufactured and constructed and tested as subsystems and ultimately integrated and evaluated as an operating system. The funds required for this engineering development program are estimated to be about $800 million and would support about 15,500 person-years of direct and secondary effort if a new system is developed in the United States. Lesser amounts of these funds would be spent here if the system is co-developed with Japan and very little would be spent here if the German system is chosen.

After the development phase is completed, an operational corridor might be constructed. The Northeast Corridor is selected to provide an example of the numbers and types of jobs to be expected. Construction of an operational maglev system extending from Washington, D.C. to Boston would require large amounts of labor. One hundred seventy-two thousand direct person-years of effort required were estimated on the basis of industry-specific statistical data for the value of outputs per employee. This estimate of direct effort, however, does not include the labor required to produce the materials and purchased parts passed through in the costs. An additional 180,000 person years, estimated on the basis of value added per employee, would be required in secondary jobs. After the Northeast Corridor system is operational, employees would be required to operate and maintain the system as well as to provide services to the passengers. In summary, a maglev technology development program and any consequent implementation of maglev systems in revenue service would create jobs. The extent to which these would be net new jobs rather than shifts from other economic activities depends on whether the economy is operating at full employment and on how the development and implementation are financed. Also, to the extent that these services are those that would have been provided to passengers travelling by an alternative mode, they are a transfer from one mode to another and will have little effect on total employment in the economy. Of possibly equal importance in terms of national impact is whether these jobs represent skills that improve the United States' ability to compete in the international marketplace and whether the technology spins off new applications that have similar effects. These are the subjects of the next two sections.

3.5.2 Technological Advancement and Spinoffs

Maglev systems feature new, innovative technological content when compared to existing transportation systems. As noted in Section 2.2, each of the United States conceptual system designs has a different approach to meeting the levitation, propulsion, guidance, and power transfer requirements for a high-speed magnetic levitation system. As the engineering designs in these areas are refined, technical advances with spinoff implications to other products and industries are likely.

Areas in which maglev technical development will be focused include:

- Magnetics – High temperature superconductivity, cryogenics, low temperature refrigerators, and superconducting magnet design and construction.
- Materials – Fiber reinforced plastics for vehicles and structural concretes.
- Electronics – Communication and high power solid state controls.
- Engineering – Vehicle design (aerodynamics and noise mitigation), precision manufacturing, construction and fabrication of concrete structures.

Possible advances and spinoffs in these areas are identified in the discussion below of innovations related to key maglev system components.

Guideways

To achieve the dynamic behavior and construction tolerances of the concrete structures, it will be necessary to develop new manufacturing techniques and facilities analogous to those developed in Germany for this purpose. New methods which could be used immediately in conventional civil construction projects for installing the system along existing highways with minimal disruption will be required. The use of nonconducting, nonmagnetic polymer reinforcing materials in concrete might have the potential for extending the life of concrete structures. If successful, these materials will significantly reduce the life cycle cost when used in the renovation of highways and bridges. Expansion of the fiber reinforced plastics industry would likely result in cost reductions and greater utilization of these materials in other applications. The guideway might also incorporate devices to assure that it is not obstructed by debris, or damaged by accidents or earthquakes, the latter being an important consideration in the United States, but only a minor consideration in Europe.

Power Equipment

The power equipment used between the transmission line and the guideway will differ for each system and must be developed. In one proposed system, the power conditioning is performed at the location of each coil in the guideway, requiring thousands of high-power solid state power control devices. In another, the ride quality of the vehicle is controlled, in part, by dynamically varying the phase of the power to the motor, requiring the development of high-power control systems to achieve this objective. Each of these components present opportunities for the development of similar systems for automated manufacturing and other purposes.

Vehicles

The vehicles will be constructed of aluminum or fiber reinforced plastic structures and will contain superconducting magnets, cryogenic systems, and high speed, highly reliable local, regional, and central communications and control systems. Maglev has stimulated a reexamination of passenger comfort and environmental requirements, and means of achieving them, that will carry over directly to other transportation modes. Means of ensuring minimal environmental impacts from routing, magnetic exposure, noise, and air pollution are being investigated that will influence our use of petroleum and electrical energy and livability of our cities and countryside. These considerations will have long-lasting effects on our lifestyles.

Magnets

Superconducting magnets are used for many purposes, but seldom in applications where lives depend on their operation or in transportation applications where they are subject to the vibrations expected in maglev systems. The development of vibration insensitive magnets might be of use in transportable magnetic resonance imaging systems, military magneto-hydrodynamic systems for ship propulsion and other mobile applications. Magnets that fail in a more controlled manner might also be expected, permitting safer operation of the system. Credible designs have already been proposed for systems using supercritical, rather than liquid, helium as the refrigerant, with a significant increase in power efficiency of the cryogenic system. The United States and other countries have devoted major efforts to the development of high-temperature superconductors operating at temperatures above 77 degrees Kelvin, and one proposed system design might be capable of using such conductors as they currently exist. Such magnets in a maglev system would effectively eliminate the concerns for cryogenic refrigeration aboard the vehicle. A dedicated maglev program could provide the impetus to further develop these magnets which have numerous projected uses for medical applications, shielding of magnetic fields, electric motors, oil exploration, magnetic separation of materials, and superconducting magnetic energy storage.

Summary

High technology businesses will be quick to capitalize on spin-offs that occur as maglev technology evolves. Of particular economic value could be the early implementation of fiber reinforced polymers in concrete structures, vibration insensitive superconducting magnets, and ruggedized cryogenic and refrigeration systems for ship propulsion and other mobile uses. Also of value could be higher power solid state devices for controlling motors in heavy industry, and linear synchronous motors for use in conveyors and manufacturing operations requiring precise control.

3.5.3 International Competitiveness

Developing high-speed maglev technology can contribute to the international competitiveness of the United States in two ways. First, the design and development effort will likely lead to technical advances and spinoffs as discussed in the previous section. Some of these advances and spinoffs will enhance U.S. productivity, and others will spawn new industries and products that could become future export industries.

Second, while the prospects for maglev implementation in the U.S. and other countries are still uncertain, it is in the national interest that U.S. systems be prime candidates for selection if maglev becomes an important mode of travel. The direct effects on the balance of payments anytime a U.S. system is selected is one obvious reason. It is also important to create high quality and high paying job opportunities for the well-educated United States work force. As noted earlier in this Chapter, the initial capital costs involved in building a maglev system would be about $21 billion for the NEC and generally between $5 billion and $21 billion for other corridors studied. It is estimated that about 63 percent of these expenditures would be for components produced by high technology industries. The other major initial expenditure is from the relatively well-skilled civil construction industry. Further, the replacement parts industries supporting an operating maglev system would provide on-going skilled employment opportunities.

Chapter 4: Comparisons of U.S. Maglev with Existing HSGT Systems – Transrapid (TR07) and TGV

4.1 OVERVIEW

The previous chapter examined the economic performance of a U.S. Maglev system in a number of intercity travel markets. This chapter compares that performance with the economic performance of existing HSGT technologies, assuming they were implemented instead of a USML system in the same markets. It seeks to answer the question. "Would a USML be better in U.S. applications than either TR07 or TGV-type technology, and would it be worth the additional development cost to make the new technology available?"

The short answer to these questions is that, at a 7 percent discount rate, a U.S. Maglev system would offer better financial performance than TR07 in all of the corridors studied, and offer equal or better performance than TGV in all corridors but one (Florida) when measured in terms of revenue to cost ratio. If a 4 percent discount rate were assumed, the financial ratio would favor U.S. Maglev by wider margins. The magnitude of the financial differences among technologies is highly dependent on the discount rate assumption because of significant differences in projected capital outlays and net revenues over time. Maglev systems are expected to require larger initial capital outlays, but are also expected to generate much greater revenues net of operating expenses once the systems are in full operation.

Finally, in making these comparisons, it must be kept in mind that the cost estimates for existing technologies, TGV and, to a lesser extent TR07, are derived from operating and construction experience, while the USML costs are only engineering estimates.

4.2 ANALYTICAL APPROACH AND METHODS

The approach used in this chapter parallels that of Chapter 3. Section 3.2 describes the process used in projecting travel by competing modes for origin/destination pairs, estimating the diversion from those modes and the resulting revenue, estimating the capital and operating costs and, finally, estimating the public benefits. In this chapter, a nearly identical process will be used to make the same estimates with regard to TR07 and, separately, TGV systems that could be built in each of those corridors. Once this is done, a number of comparisons will be made between various performance measures for USML versus the same performance measures for existing technologies. The remainder of this section highlights only the differences in methods regarding TR07 and TGV analysis versus those used regarding USML.

At this point in the analysis process, projections of high-speed ground system costs, ridership, and revenues are preliminary, and will need to be revised once a system, suited for U.S. operation, is fully designed and specified. Although NMI cost estimates were developed in ways that compensated for most cost understatement problems common in other transportation projects, costs for a U.S. Maglev system (a conceptual design) should be considered more uncertain than the costs of TGV (deployed in Europe) and TR07 (running on a test track).

With regard to the TR07, the identical alignments were considered as with USML; i.e., both an alignment with extensive sharing (ES) and limited sharing (LS) of existing highway and rail right(s)-of-way (ROW), primarily in urban areas. However, for TGV, only the LS alignment (identical to Maglev except where maximum TGV grade capability would be exceeded) was used. Unlike the analysis of USML, only one socioeconomic scenario, the "baseline," was used for TR07 and TGV.

The same demand model was used to estimate ridership and revenue for TR07 and TGV but the different, generally longer, trip times associated with these technologies resulted in lower estimates of diverted trips and consequently lower revenues than with USML. While the same general structure was used for the cost estimating model, different parameters and assumptions were used for TR07 and TGV because of the different cost characteristics inherent in their respective technologies relative to USML.

4.3 ECONOMIC COMPARISON OF HSGT TECHNOLOGY OPTIONS

In this section, German Maglev (TR07) and TGV/HSR technologies are compared to the USML in terms of travel time and financial performance for the same 16 corridors studied in Chapter 3. The operational performance and cost assumptions used to assess each technology are described in Section 2.4.

4.3.1 Sources of Economic Differences

Economic differences in demand and cost among the high-speed ground technologies are based on variations in their inherent technological characteristics (i.e., banking, acceleration, and vehicle and consist size/ seating). These technology distinctions are translated into differences in line haul travel time and speed profiles along corridor alignments, train frequencies, fares, operating costs, and capital costs.

Average total vehicle trip times (line haul, access/egress, and terminal time) by distance block between all city pairs represented in the 16 corridors are summarized in Figure 4.1. Additional estimates of corridor trip times and average speeds are provided in Table A3 of Appendix A. Major conclusions are:

- Travel time for the USML technology is lowest at each distance, followed closely by TR07. Both maglev technologies enjoy a significant speed advantage relative to TGV.[1]
- Although such details are not displayed in Figure 4.1, the pattern of trip time differences favoring USML is accentuated on the more highly curved alignments using ES of existing ROW.

The fares assumed for high-speed ground technologies are calculated as a percent of air fare to approximately maximize the net

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[1] In order to maximize TGV performance, the 200 mph Texas TGV was used for calculations of trip times.

revenue (revenue minus variable costs) that could be generated on each system. Higher fares produce more revenue up to the point where reductions in passenger demand offset the gains in per passenger yield. The more competitive a HSGT mode is with air on travel time, the higher the net revenue maximizing fare that can be set. Because both maglev technologies enjoy significant speed advantages over TGV, their fare levels are set at the highest fraction of competing air fares. The fares used in this analysis for distances up to 400 miles are shown in Table 4.1. Fares are assumed to decline to ⅔ of these levels at distances greater than 600 miles.

Figure 4.1
Trip Time By Technology

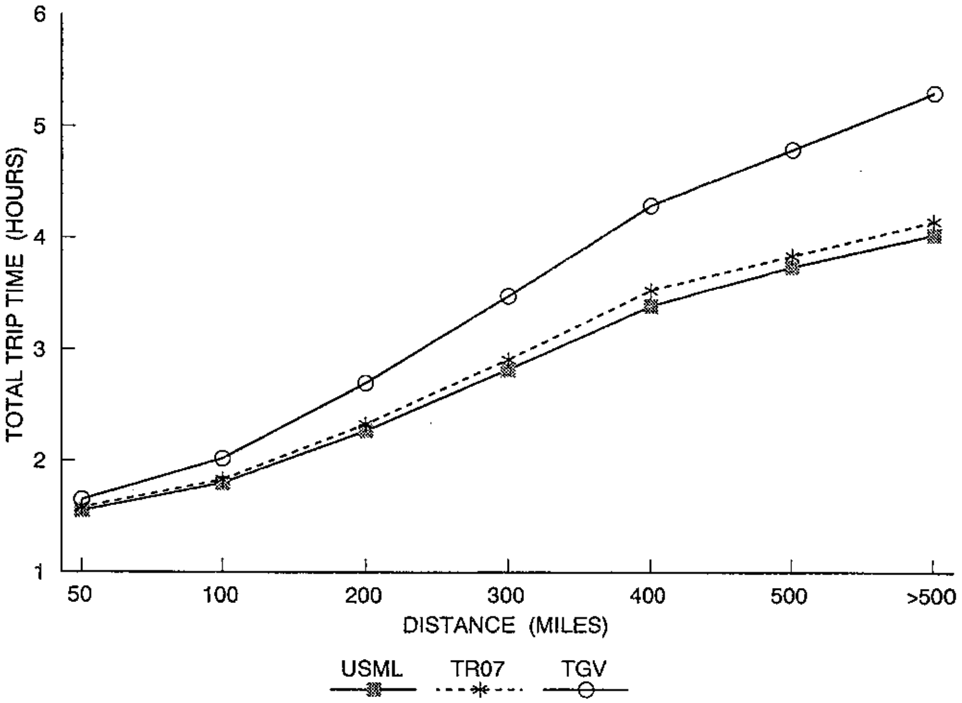


Table 4.1
Fare Level Assumptions by Technology and Alignment, Percent of Airfare

Technology	ROW	Fare (% of Airfare)
U.S. Maglev	Both	90%
TR07	Limited Sharing	90%
TR07	Extensive Sharing	80%
TGV	Limited Sharing	75%

The three HSGT technologies are also distinguished on the basis of operating and capital costs. Emphasis was placed on developing detailed cost estimates for the U.S. and TR07 Maglev systems; a more limited analysis was performed on TGV costs based primarily on published data.

In Table 4.2, data are presented for each of the technologies on initial capital

Table 4.2
Total Initial Capital Costs Assuming a 7 Percent Discount Rate ($ Billions)

	TGV			TR07			USML		
	Guideway Technology	Other	Total Cost	Guideway Technology	Other	Total Cost	Guideway Technology	Other	Total Cost
NEC	5.25	10.3	15.6	10.46	12.5	23.0	8.57	12.7	21.2
CA	6.43	8.9	15.3	12.61	11.0	23.6	10.29	11.1	21.4
LA-PHX	4.00	5.0	9.0	8.68	5.6	14.3	7.00	5.6	12.6
DAL-HOU	2.19	2.6	4.8	5.19	3.4	8.6	4.17	3.4	7.5
LA-LV	3.02	4.2	7.2	6.58	4.7	11.3	5.31	4.7	10.0
TEX-TRI	5.45	7.0	12.4	12.97	8.4	21.4	10.41	8.4	18.9
SEC	5.26	7.0	12.3	11.55	8.1	19.7	9.31	8.3	17.6
CHI-PIT	5.58	7.6	13.2	12.10	8.8	20.9	9.75	8.8	18.5
CHI-MSP	4.04	5.4	9.4	8.77	6.2	15.0	7.06	6.2	13.3
CHI-DET	2.77	3.4	6.1	6.57	4.4	11.0	5.27	4.4	9.7
CHI-KC	5.15	6.7	11.9	11.18	7.7	18.8	9.02	7.7	16.7
NYS	4.42	5.9	10.3	9.60	6.7	16.3	7.74	6.7	14.4
FL	2.26	2.9	5.2	5.38	3.7	9.1	4.32	3.7	8.0
HOU-NO	2.70	3.3	6.0	6.41	4.3	10.7	5.14	4.3	9.4
PA	3.03	3.9	6.9	6.58	4.3	10.9	5.30	4.3	9.6
SEA-POR	1.92	2.6	4.5	3.58	2.8	6.4	2.88	2.8	5.7

Notes:
(1) Estimates are for baseline scenario using the limited sharing ROW alignment.
(2) Guideway technology costs include the guideway beam, supporting structures, and all electrical and magnetic components.
(3) Other costs include: vehicles, stations, other fixed facilities, environmental mitigation costs, civil reconstruction, nontechnology site preparation work, contingencies, and program management.
(4) A construction financing cost is included in these estimates using the 7 percent real interest rate.

requirements for guideways and other capital expenditures, including vehicles, civil reconstruction, project management and contingencies. These data are calculated at the 7 percent discount rate, but would be only slightly smaller if calculated using the 4 percent discount rate assumption. For example, the initial capital cost for USML in the NEC is $21.2 billion at 7 percent, as compared to $20.3 billion at 4 percent. (See Table A4 in Appendix A.)

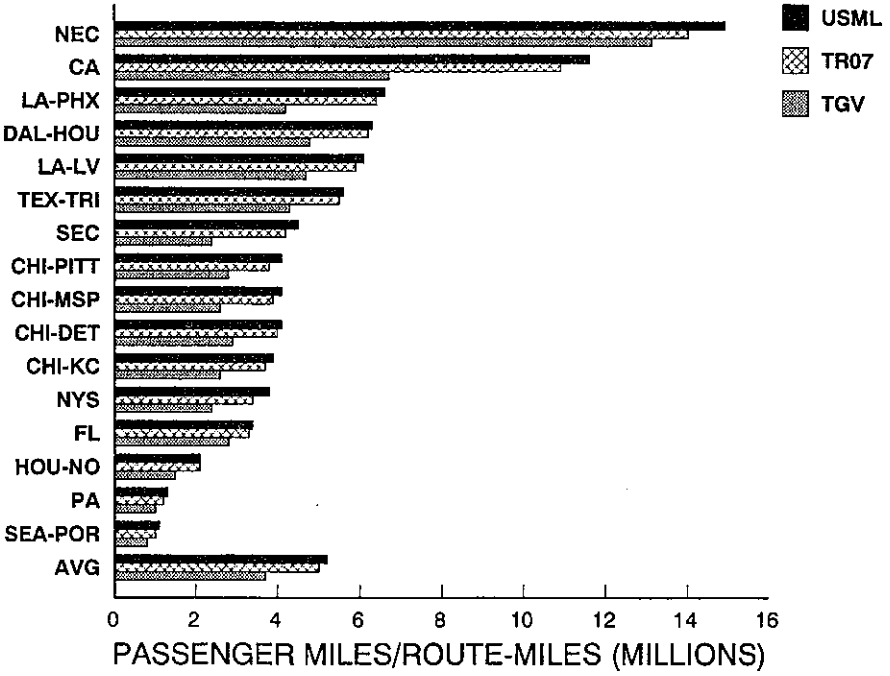
The per mile technology cost comparisons are given in Section 2.4 for elevated and at-grade construction. Vehicle purchase and some fixed capital cost estimates are adjusted to reflect differences in the ridership estimates for the three technologies. Energy consumption rates and vehicle operating costs also differ between maglev and TGV.

4.3.2 Comparisons of Corridor Financial Performance

The combination of travel times and fares results in a clear advantage for USML in attracting passengers. As can be seen in Figure 4.2:

- USML has significantly more ridership relative to the two other HSGT technologies. When averaged over the 16 corridors, on the LS alignment, passenger-miles per route-mile in 2020 is 4.6 percent higher for USML than TR07 and 28.5 percent higher relative to TGV.[1]

Figure 4.2
Passenger-Miles Per Route-Mile
Limited Sharing Alignment – 2020



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[1] Additional data on corridor trip levels, passenger miles, and passenger diversion rates are provided in Tables A1 and A5 of Appendix A.

- On the ES alignment, the advantage of USML over other technologies is even greater.

Tables 4.3 and 4.4 portray, for the three technologies, revenue-to-cost ratios and operating recovery ratios[1] for 7 percent and 4 percent discount rates. At both discount

Table 4.3
Revenue/Cost and Operating Cost Recovery Ratios over the Life of the Project Assuming a 7 Percent Discount Rate

	Revenue/Cost Ratio			Operating Cost Recovery Ratio		
	TGV	TR07	USML	TGV	TR07	USML
NEC	1.03	0.93	1.03	3.9	4.9	5.0
CA	0.39	0.48	0.55	2.2	3.2	3.3
LA-PHX	0.29	0.34	0.39	1.7	2.6	2.6
DAL-HOU	0.47	0.43	0.48	1.9	2.5	2.6
LA-LV	0.35	0.35	0.39	1.9	2.6	2.6
TEX-TRI	0.46	0.42	0.48	2.2	2.8	2.8
SEC	0.31	0.35	0.40	1.8	2.6	2.6
CHI-PIT	0.31	0.30	0.36	2.1	2.6	2.7
CHI-MSP	0.30	0.31	0.36	1.9	2.6	2.6
CHI-DET	0.33	0.30	0.34	1.8	2.3	2.3
CHI-KC	0.28	0.29	0.33	1.9	2.5	2.5
NYS	0.27	0.28	0.33	1.9	2.4	2.5
FL	0.33	0.27	0.31	1.5	1.9	1.9
HOU-NO	0.22	0.19	0.22	1.2	1.6	1.6
PA	0.13	0.12	0.14	0.9	1.2	1.2
SEA-POR	0.08	0.09	0.11	0.5	0.8	0.8

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[1] The operating recovery ratio is defined as the present value of revenues divided by the present value of O&M costs.

rates, USML is projected to have substantially higher revenues and consequently, operating recovery ratios than the other technologies. However, USML has only a small advantage over TGV in terms of overall revenue/cost ratio because projected capital outlays for USML are considerably greater. All revenue-to-cost ratios are considerably lower at the 7 percent discount rate. Although the present values of initial capital costs are similar at different discount rates, the present value of the stream of revenues and O&M costs over time vary significantly with the discount rate assumption.

Table 4.4
Revenue/Cost and Operating Cost Recovery Ratios over the Life of the Project Assuming a 4 Percent Discount Rate

	Revenue/Cost Ratio			Operating Cost Recovery Ratio		
	TGV	TR07	USML	TGV	TR07	USML
NEC	1.42	1.34	1.47	3.9	4.9	5.0
CA	0.58	0.73	0.81	2.3	3.3	3.4
LA-PHX	0.45	0.53	0.60	1.8	2.8	2.8
DAL-HOU	0.68	0.65	0.72	2.0	2.7	2.7
LA-LV	0.52	0.53	0.59	2.0	2.7	2.7
TEX-TRI	0.67	0.64	0.72	2.3	2.9	2.9
SEC	0.47	0.54	0.62	1.9	2.7	2.8
CHI-PIT	0.46	0.47	0.55	2.2	2.7	2.8
CHI-MSP	0.46	0.48	0.55	2.0	2.7	2.7
CHI-DET	0.49	0.46	0.52	1.9	2.4	2.4
CHI-KC	0.43	0.45	0.51	2.0	2.6	2.6
NYS	0.41	0.43	0.50	2.0	2.5	2.6
FL	0.49	0.42	0.48	1.6	2.0	2.0
HOU-NO	0.33	0.30	0.34	1.3	1.7	1.7
PA	0.19	0.18	0.21	1.0	1.2	1.2
SEA-POR	0.12	0.14	0.17	0.6	0.8	0.9

Table 4.5
U.S. Maglev Advantage in Revenue Per Route Mile (2020) over the TR07 and TGV Technologies by Alignment

USML Adv. Over:	Revenue Per Route Mile (Percent Difference)	
	Limited Sharing ROW	Extensive Sharing ROW
TGV	53.0%	n/a
TR07	4.1%	28.6%

Notes: (1) Percent difference computed from sum of data over all 16 corridors.
(2) Baseline scenario.

Table 4.6
U.S. Maglev Advantage in Revenue to Cost Ratio by Alignment

USML Adv. Over:	Revenue to Cost Ratio (Percent Difference)	
	Limited Sharing ROW	Extensive Sharing ROW
TGV	10.7%	n/a
TR07	12.4%	24.0%

Notes: (1) Percent difference computed from sum of data over all 16 corridors.
(2) Baseline scenario, 7 percent discount rate.

Tables 4.5 and 4.6 show that the differences between USML and TR07 are greatest on the ES alignment, where constraints limit elimination of curves along the route, accentuating travel time differences between the technologies. In addition, both U.S. and German Maglev technologies compare favorably to the TGV on the LS alignment. These results hold for both the 7 percent (shown) and 4 percent discount rate assumptions.

In Table 4.7, estimates are presented of operating costs, revenues, and operating surplus for a typical year, 2020. These financial measures are identical at the 7 percent and 4 percent discount rates. An operating surplus is anticipated for all

Table 4.7
Operating Costs, Revenues, and Operating Deficit/Surplus, 2020 ($ Millions)

	TGV			TR07			USML		
	2020 O&M Cost	2020 Revenue	Surplus or Deficit	2020 O&M Cost	2020 Revenue	Surplus or Deficit	2020 O&M Cost	2020 Revenue	Surplus or Deficit
NEC	491.6	1,948.6	1,457.0	473.3	2,375.8	1,902.5	486.3	2,490.3	2,004.0
CA	287.4	700.3	412.9	361.5	1,264.2	902.7	374.4	1,327.1	952.7
LA-PHX	155.6	316.5	160.9	181.7	552.7	371.0	184.5	568.0	383.5
DAL-HOU	136.7	297.0	160.3	151.4	437.7	286.3	149.0	443.5	294.5
LA-LV	138.6	297.1	158.5	151.0	437.4	286.4	153.7	450.4	296.7
TEX-TRI	286.7	724.0	437.3	327.7	1,045.1	717.4	332.1	1,065.3	733.2
SEC	216.5	445.4	228.9	264.5	768.4	503.9	272.7	810.7	538.0
CHI-PIT	174.7	435.2	260.5	233.4	669.1	435.7	247.6	721.3	473.7
CHI-MSP	146.2	318.7	172.5	169.3	504.8	335.5	173.6	526.8	353.2
CHI-DET	113.5	235.4	121.9	138.6	359.9	221.3	140.9	367.5	226.6
CHI-KC	169.2	367.9	198.7	208.2	579.4	371.2	213.0	599.8	386.8
NYS	139.1	299.7	160.6	173.5	469.8	296.3	179.2	503.9	324.7
FL	115.9	218.8	102.9	129.1	292.4	163.3	130.6	300.7	170.1
HOU-NO	106.0	154.4	48.4	122.1	228.8	106.7	124.0	235.0	111.0
PA	86.3	89.6	3.3	94.9	124.8	29.9	96.2	131.1	34.9
SEA-POR	60.8	39.6	(21.2)	68.6	63.8	(4.8)	69.2	67.4	(1.8)

corridors and each technology except for Seattle-Portland. The operating surplus is greatest for the USML and TR07 technologies. Although TGV is estimated to have lower O&M costs, its 2020 projected revenues are considerably smaller than USML and, to a lesser extent, TR07.

In Section 3.3.4, the effects of intercorridor travel on Maglev (USML on the LS alignment) financial performance were estimated. Table 4.8 presents the results of this analysis for the TGV technology in the East Coast HSGT network at the 7 percent discount rate (similar results occur at the 4 percent discount rate). Major findings indicate that:

- Relative to air, average intercorridor HSGT trips are expected to have longer

Table 4.8
Comparison of Financial Impacts Due to Intercorridor Effects on the East Coast Corridor, 2020

Inter-Corridor Effect	U.S. Maglev	TGV
Change in Ridership (%)	10.4%	5.7%
Change in Revenue (%)	15.1%	8.4%
Change in R/C Ratio (%)	11.8%	7.0%

Notes: (1) East Coast corridor is combination of Northeast (Boston to Washington) and Southeast (Washington to Atlanta).
(2) Baseline scenario, 7 percent discount rate, and limited sharing alignment for both technologies.

travel times than within corridor trips, resulting in lower average diversion rates.

- Intercorridor diversions for TR07 and TGV (on either alignment) will be smaller than for USML.

- Intercorridor travel will improve the financial performance of TR07 and TGV to a lesser degree than for USML. The network effect on the TGV revenue/cost ratio is only about 60 percent of the network effect attributable to combining corridors for the USML case.

The net financial assistance required to build HSGT systems in each of the corridors is estimated in Figures 4.3 (total) and 4.4 (amortized per passenger-mile). Estimates are calculated in terms of present value at 7 percent for the LS alignment; projected net financial assistance at lower discount rates would be substantially lower because of the higher present value of net revenues available to offset capital cost. For ES alignments financial assistance would be greater because of lower present value of net revenues. Additional data on corridor ticket prices, passenger costs, and required subsidies (financial assistance) using both the 4 percent and 7 percent discount rates are provided in Tables A6, A7, A8, and A9 of Appendix A.

Results show that:

- At the 7 percent discount rate, total financial assistance is the least for TGV in all corridors except for the NEC where both systems show small surpluses. Financial assistance requirements are reduced at the 4 percent discount rate; however, the pattern favoring TGV is maintained in all corridors, but the NEC, California, and LA-Phoenix where USML has the lowest estimated financial assistance requirements. In the NEC the surplus for maglev is higher than TGV.

- USML will likely have lower public funding requirements than TR07 because its construction costs are lower and because the U.S. technology is expected to generate more ridership and revenue.

Figure 4.3
Total Net Financial Assistance – 7 Percent Discount

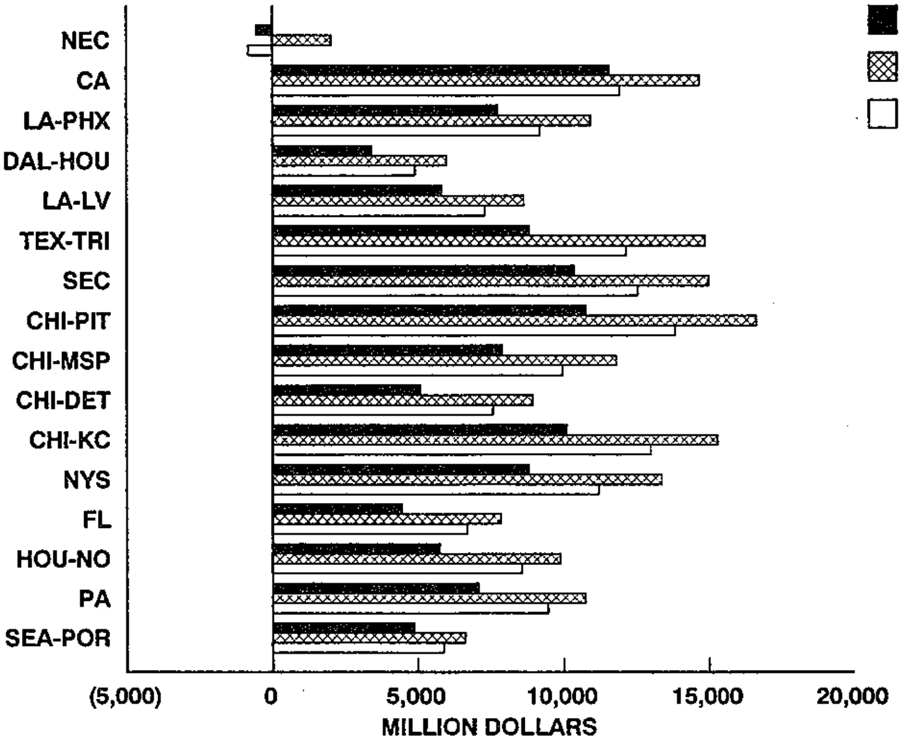
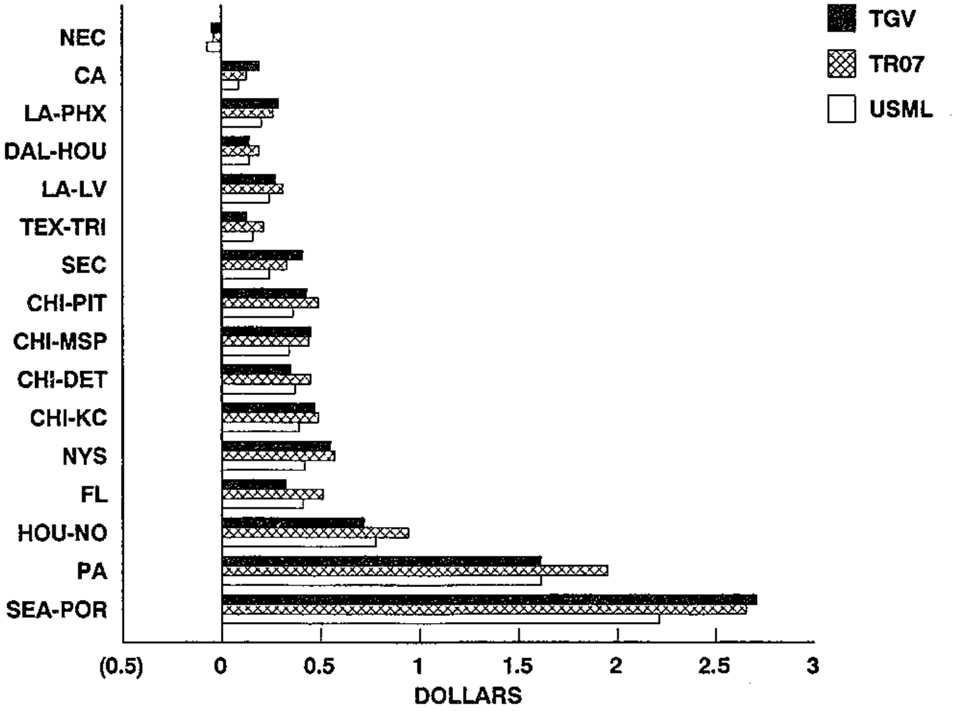


Figure 4.4
Net Financial Assistance Per Passenger Mile
@ 7 Percent Discount Rate, Year 2020



4.3.3 Public Benefit Comparisons

In addition to revenue and cost issues associated with a major public investment in transportation infrastructure, there are significant benefits and costs in externalities that are not always captured in the marketplace. Chief among these externalities are energy use, dependence on petroleum imports, emissions, and public safety.

The congestion benefits for the USML system, as presented in Section 3.3, are based on the passenger diversion from the air mode. With respect to the other HSGT technologies:

- The lower diversions for the TR07 and TGV systems, relative to the USML, result in lower congestion benefits that are approximately proportional to the reduced ridership.

- Congestion benefits for TGV are the lowest, estimated to be about 70 percent of the benefit of USML.

- Higher diversion rates for both maglev systems result in larger petroleum use benefits relative to the TGV technology option.

- Some emission savings for TGV are the largest due to its significantly lower energy intensity per seat-mile and despite its much lower estimated ridership.

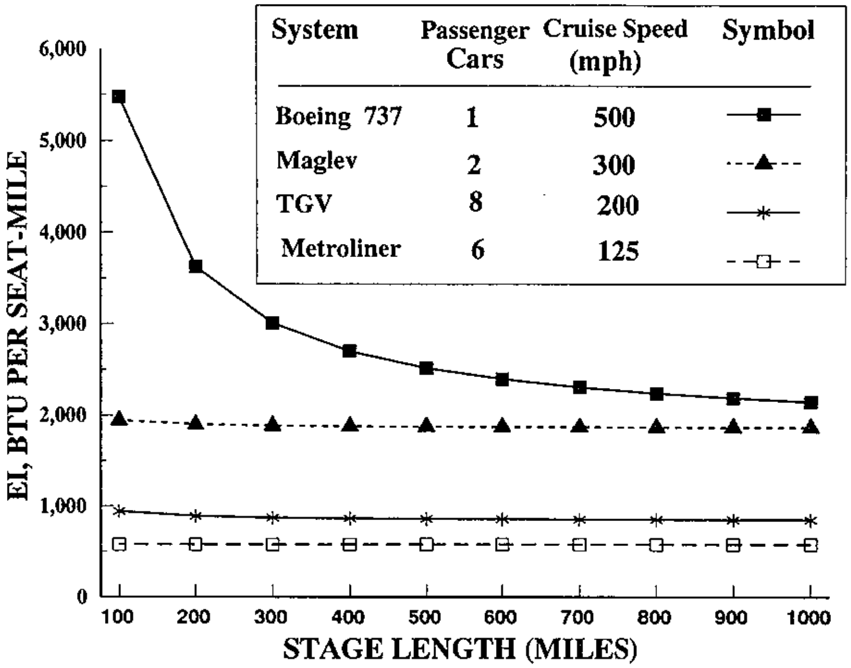
Petroleum Savings

Significant fuel efficiency improvements in light-duty vehicles have curtailed the growth in energy use by automobiles and light trucks. The energy use by commercial modes is expected to exceed that of personal vehicles by the year 2005. Even with expected efficiency improvements, air transport is expected to continue to account for about 30 percent of the commercial transportation energy use. Diversion of air traffic to maglev or high-speed rail (HSR) not only has potential to improve overall energy efficiency of intercity travel, but can change the fuel mix from jet fuel (petroleum) to electricity (almost entirely non-petroleum).

Figure 4.5 presents information on the energy intensity, measured in BTU per seat-mile, of intercity transportation modes in 2020 for typical non-stop trips of varying lengths. Energy intensities are measured at the point of production of component fuels and include factors for losses due to refining, domestic transport, electric generation, and conversion.

Although there are technical differences between the USML concept and the current TR07 prototype design, especially with regard to improved aerodynamics and efficiencies in the linear synchronous motor (LSM) and power conditioning equipment, no overall energy efficiency differential can reliably be attributed to these future systems in revenue service. Therefore, for purposes of calculating energy and emissions impacts, all maglev designs are considered equivalent. Maglev is more efficient than the Boeing 737 (Series 300), which is among the most energy-efficient, short-haul aircraft in current service. The TGV train, despite its reliance on the less efficient steel-wheel-on-rail design, is estimated to be significantly more energy-efficient per seat-mile than maglev due primarily to its slower top speed (200 versus 300 mph) and its longer train length (ten-car consist versus two-car consist).

Figure 4.5
Energy Intensity of Intercity
Transportation Modes versus Stage Length



Analyses of maglev and TGV operations in 16 corridors were carried out in order to obtain estimates of petroleum and net emissions savings resulting from the diversion of passengers from conventional to high-speed ground technologies.[1] Energy use and emissions generation are impacted by corridor characteristics and differences due to vehicle and system design. These are reflected in differences in passenger miles of travel and energy intensity for each corridor and technology alternative.

Total petroleum savings, over 16 corridors for the year 2020, are 21 million barrels for maglev and 15 million barrels for the TGV. The lower number for TGV is a consequence of fewer passengers being diverted from the air mode by this technology. The energy calculations assume the average fleet aircraft efficiency in 2020 for domestic short-haul service will be equivalent to the current energy efficiency of the Boeing 737; automobiles will become more fuel efficient than current vehicles (average 36.7 mpg); and conventional rail service will improve by introducing higher efficiency technology and increasing vehicle utilization from current levels.

The alignments that use LS of existing ROW have higher petroleum savings than those using ES of existing ROW, and the maglev technology has higher savings than

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[1] Only 14 of the 16 study corridors were considered for the analysis in this section because the other 2 corridors, Chicago-Detroit and Dallas-Houston, are included as parts of the first 14.

the TGV. In corridors where most of the ridership is diverted from aircraft, maglev's potential petroleum savings tend to be the greatest. In corridors where HSGT routes are circuitous relative to air routes, energy savings are minimized. Overall, the total petroleum saved for these 16 corridors represents the equivalent of several days imported petroleum.

Reductions in Pollutant Emissions

In 1991, there were 74 million people in the United States residing in counties that were not in compliance with national ambient air quality standards. Ozone and carbon monoxide levels have the highest degrees of non-attainment, while sulfur dioxide has the lowest.

By substituting maglev vehicles for aircraft, diesel electric locomotive-drawn trains, and highway vehicles, emissions from these mobile sources are replaced by emissions from electric generating plants. Since the mix of primary energy sources varies widely across the United States only the national picture is considered. Using DOE's reference case, the nationwide primary energy sources for electricity generation in the year 2010 are projected to be: 52.3 percent coal, 17.5 percent natural gas, 16.5 percent nuclear, 5.2 percent oil, and 8.6 percent other (generally considered to be renewable sources such as hydro, wind, solar, etc.).

Table 4.9 shows the net average percent reduction in emissions in 16 corridors from intercity passenger travel of greater than 85 miles. All pollutants, except sulphur oxides, show sizable reductions due to the introduction of high-speed ground transportation. Despite its much lower estimated ridership, some emissions savings for TGV are the greatest due to its significantly lower energy intensity per seat-mile.

The dollar-equivalent benefit of reducing emissions in a particular region depends on the level of severity of non-attainment of that region and the avoided cost of controlling those emissions. The costs of reducing HC, NO_x, and CO are based on estimates of the cost of needed emission control equipment, while the cost of reducing SO_x is based on the value of pollution credits on the Chicago Commodity Market.[1, 2]

Table 4.9
Average Percent Reduction in Intercity Passenger Emissions
Limited Sharing ROWs, 16 Corridors – 2020

Technology	Hydro-carbons	Carbon monoxide	Nitrous Oxides	Sulphur Oxides	Carbon dioxide
MAGLEV	11%	28%	40%	-21%	10%
TGV	9%	20%	30%	7%	15%

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[1] "Increasing the Efficiency and Effectiveness of Environmental Decisions: Benefit-Cost Analysis and Efficient Fees - A Critical Review," L. Lave and H. Gruenspecht, May, 1991.

[2] "Electricity" Electricity Committee Report, California Energy Commission, November, 1992. (Contact Joseph Diamond).

Table 4.10 shows the average annual dollar benefit of reducing emissions due to the introduction of maglev on the LS alignment. There is a net positive benefit for all pollutants except SO_x; it increases due to the large percentage of coal projected to be used to generate electricity.

Safety Benefits

Given the well-recognized importance of maintaining high levels of safety and reliability on any new high-speed ground system, it is appropriate to assume that it could be operated with a safety record equally as good as the best existing intercity modes, i.e., scheduled air and rail. In fact, a significant benefit of maglev compared with conventional rail is that all guideway will be grade separated, eliminating grade-crossing accidents which account for about half of the fatalities involving intercity U.S. passenger rail.

Potential deleterious effects of electromagnetic fields (EMF), though considered minor for maglev, will be evaluated more extensively in further technical studies.

Based on data from the 1992 National Transportation Statistics, the rate of fatalities involving passenger cars and taxis has risen slowly in recent years, reaching 1.11 per 10^8 passenger miles traveled (PMT) in 1990. For accidents involving intercity passenger trains, the average fatality rate including grade crossing accidents since 1985 is about 0.54 per 10^8 PMT. For scheduled commercial flights, the fatality rate averaged over the period 1985 to 1990, was about 0.08 per 10^8 PMT. The high-speed ground fatality rate is assumed to be the same as for air travel.

To the extent that passengers are diverted from other modes to maglev, their chances of being involved in a fatal accident are reduced. For the 16 corridors studied, the estimated lives saved on each mode due to diversions from auto, air, and rail to maglev are given in Table 4.11. The figures under the USML column are estimates of fatalities on the USML system if implemented in 16 corridors.

Table 4.10
Total Savings ($ Million) in Intercity Passenger Emission Costs
Limited Sharing ROWs, 16 Corridors – 2020

Technology	Hydro-carbons	Carbon monoxide	Nitrous Oxides	Sulphur Oxides	Total
MAGLEV	$26.8	$37.9	$363.6	$-1.1	$427.2
TGV	$23.1	$27.4	$281.5	$.3	$332.3

Table 4.11
Estimated Lives Saved as a Result of Diverting Trips
to U.S. Maglev on the Limited Sharing Alignment

Year	Air	Auto	Rail	USML	Total
2000	10.5	20.0	23.0	-16.1	37.5
2030	25.3	25.7	37.4	-35.3	53.1

Chapter 5: Options For Acquiring Maglev Technology

5.1 INTRODUCTION

Previous chapters have shown that a potential exists in the United States for using HSGT in high density corridors as an alternative to existing intercity transportation modes (air, auto, conventional train) and that maglev systems offer advantages over high-speed rail in certain of these corridors. The issue then arises as to how best to introduce maglev technology into the U.S. transportation system. Three basic options exist, each dictating different roles and responsibilities for both the Federal Government and the private sector and also different technological and economic impacts. These options are identified and described below.

5.2 DESCRIPTION OF OPTIONS

The three basic options are:

- Reliance on existing foreign technology.
- Improvement upon existing technology through joint venture with a foreign maglev system developer.
- Development of a USML system.

5.2.1 Reliance on Existing Foreign Technology

This is the *status quo* option and represents a typical supply versus demand environment wherein local and regional transportation demands are being addressed by existing private sector supply. In the case of maglev systems, existing supply today is very limited to the extent that only the German TR07 system is of sufficient technical maturity to be considered for deployment in the United States at this time. For the past several years, interest in HSGT systems has been at a high level, particularly in maglev systems, which have been proposed in the states of California, Nevada, Texas, Florida, and Pennsylvania. In all of these cases, the interest in HSGT systems originated in the local area without any market stimulus or role from the Federal Government.

An example of this option, where the Federal Government does play a role, is the planned maglev system in Orlando, Florida that would operate between the airport and a point near Disney World. Maglev Transit, Inc., a private sector group, is the franchisee for the project which is designed to address a local need of transporting a high flow of tourists between two points. The proposed project uses existing technology, i.e., the German Transrapid system, which was developed completely with German funding. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 awarded the project $97.5 million which is to be used by the franchisee for ROW acquisition and site-specific guideway design and construction. Aside from this funding, the only Federal involvement in this deployment is the significant role of safety assurance, i.e., developing safety standards for the system and assuring that the design and operation of the system meets these standards. The Federal Government also has an oversight role in the environmental impact assessment now in preparation.

5.2.2 Improvement on Existing Technology Through Joint Venture with Foreign Maglev System Developer

For the purpose of this study, joint ventures can be characterized as cooperative efforts between foreign and American firms for the introduction of maglev systems into the United States. Joint ventures could take the form of government-to-government ventures or industry-to-industry or some combination thereof.

In contrast to the "existing technology option," the joint venture option is characterized by a general objective to develop an improvement in the technology, whether it be performance-, cost-, or safety-based, so that the resultant system meets U.S. requirements through a shared development program. Since Germany and Japan are the only countries with running prototype systems, the joint venture process would use either the Japanese or German maglev systems as a baseline and then improve on it with U.S. industry participation.

In theory, joint ventures such as this should prove beneficial to both parties. For example, the United States could provide its expertise, primarily at the component and subsystem level and also its first-hand knowledge about the U.S. transportation market and environment. Also, the U.S. industry would naturally obtain engineering experience and technical knowledge to build a better system. Foreign industry, in turn, would bring to the venture their system-level expertise in maglev technology and gain an easier entry into the American market. Thus, both partners would benefit from the joint venture.

There are, however, two serious practical issues that must be resolved before a joint venture could work; simply, who does the work and who pays for it. For example, developing improvements to the German Transrapid (TR07) system to meet U.S. specifications (i.e., better acceleration/deceleration and vehicle tilt capability) would require significant effort and funding. Most likely, to limit redevelopment time and costs, the developer would prefer to perform the necessary redesign and testing with experienced staff in Germany. (It is highly unlikely in the short run that the joint venture partners would fund and build facilities in the United States that duplicate those in Emsland, Germany.) The German side may question the need for further development since its key focus has been to penetrate the U.S. market with existing technology. Private investors on both sides would probably balk at putting money into a development program because of the length of time before realizing a return on their investment.

The degree to which the German Government would fund further TR07 development on behalf of an American joint venture partner is debatable. The advisability of the U.S. Government providing funds for the further development of a German or Japanese or any other foreign system, which could compete with American firms interested in pursuing maglev development, would depend on the amount of the development that took place in the United States.

These issues raise concern on the practicality of a joint venture under such a scenario. Considering the relative immaturity of the current American market and the long lead time necessary to design and construct a system, private industry is unlikely to have the incentive to develop the technology on its own. Intergovernmental cooperation will be necessary to help coordinate and possibly fund the private sector whose internal priorities would most likely supersede any national commitment.

At the same time, in view of the potential benefits of the experience gained by potential joint venture foreign partners, there would appear to be very little to lose in allowing joint venture participants in a design competition, provided that a substantial share of the development is guaranteed to take place in the United States.

5.2.3 Development of a USML System

5.2.3.1 Background

Historically, the concept of maglev as a high-speed transportation system has had strong support in the United States and the recent responses of the private sector and academia during the NMI program demonstrate both the interest and capability to initiate a U.S.-designed system. It has been demonstrated in previous sections of the report that a U.S.-designed system would better serve the characteristics of the U.S. market including such factors as:

- Greater distances between major cities.
- Widely variable climatic, topographical, seismic, and geological conditions.
- Operational demands for airline-quality service.
- Consumers demanding higher levels of intercity service.

These characteristics, when translated into technical requirements, could result in a U.S. concept that offers distinct improvements over foreign technology.

5.2.3.2 USML Development Program

The typical approach to developing a new, advanced technology transportation system relies on a multiphased program to reduce technical risk and cost exposure. Any new technology has risks associated with it. The development program should be designed to systematically resolve those issues by first assessing the technology state-of-the-art, evaluating candidate system concept definitions (SCD) and determining potential applications. This has already been accomplished during the NMI study. Twenty-seven technology assessment contracts have been completed along with four SCD studies. The market and economic potential of maglev systems for application in the United States has also been addressed. These studies have shown that a USML system is technically feasible and there are significant areas for technical improvements compared to competing systems. The conclusion is that the U.S. industry is ready to proceed with the initial phase of a maglev system prototype development program.

This type of development program would be conducted in three phases and would provide sufficient competition to ensure the best designs are generated and the best design teams are selected. The program duration would be selected to maximize the development of innovative ideas while keeping the technical and cost risks at a reasonable level. At the same time, periodic program reviews would be built into the program, allowing for reevaluations of the benefits and costs of the program based on the latest technical and economic information. As already noted, participation of foreign firms in collaboration with U.S. partners should not be discouraged, provided that a substantial share of the development is guaranteed to take place in the United States. This development option would permit the maglev system to meet the U.S.-unique transportation and service requirements, thus maximizing the major factor in indicating acceptance by the traveling public. An aggressive schedule to achieve these goals would have the prototype under operational test in about 8 years at a technology demonstration test site.

5.3 EVALUATION/RATING OF THE THREE MAGLEV OPTIONS

In order to provide a consistent evaluation of the three options on how to proceed with maglev, the following criteria were established:

- Development Cost: The cost of developing the technology.
- System Performance: The ability to provide competitive trip times in a variety of ROW conditions and with flexible service patterns.
- Economic Performance: The ability to cover costs from revenues and generate public benefits.
- U.S. Industry Competitiveness: The contribution to U.S. industry's expertise in high technology enterprises.
- U.S. Jobs: The creation of skilled jobs within the United States.

Each option is provided a qualitative rating for each criterion, ranging from an H rating (high) which says the option satisfies the criterion, an L rating (low) which says the option poorly satisfies the criterion, and an M rating (medium) for somewhere in between.

- Development Cost: While reliance on existing foreign technology would not totally eliminate the cost of development (some cost is necessary to adapt a foreign system to the U.S. environment), Option 1 is certainly the best in this regard and would be given an H rating. A USML development program could cost around $800 million and is given an L rating. Option 2, the joint venture, is somewhere in between with an M rating.
- System Performance: The capability to follow existing ROW and difficult topography without severe time penalties, to serve off-line stations, and to provide the shortest trip times while maintaining passenger comfort, points to the USML getting an H rating since it can be optimized for these characteristics. A joint venture would get an M rating, the exact rating level depending on the amount of development. Option 1 gets an L rating.
- Economic Performance: As discussed in the previous section, a U.S. system out performs existing maglev technology, particularly in the most important markets. On this basis it

receives an H while existing technology gets an L and the joint venture an M.

- U.S. Industry Competitiveness: Developing U.S. industry high technology engineering expertise is accomplished best by having U.S. industry design and build their own system, giving an H rating for Option 3. Neither buying foreign technology nor a joint venture will achieve a meaningful capability in U.S. industry in an acceptable time period, although a joint venture would be marginally better than buying foreign technology, thus a rating of L for buying foreign and M for a joint venture.

- U.S. Jobs: Implementing a maglev system in the United States would mean essentially the same infrastructure construction jobs for each option, assuming the system is built in the same corridors under each option. That is, since the construction has to be done in the United States, a reasonable assumption is that the construction work would be done by U.S. companies. These jobs are mostly in the "blue collar" category. Since the USML provides superior economic performance, it could result in a more extensive system being built and, hence, more jobs in a less than full employment economy. The remaining jobs are the high technology, research and development, and design engineering jobs using engineers and technicians. Again, since the USML would have the most U.S. jobs, an H rating, with buying foreign having the least, an L rating, and the joint venture with only a limited number of these jobs, an M rating.

Table 5.1 summarizes the comparison of maglev options. To obtain the performance optimized for the U.S. transportation needs and to protect U.S. competitiveness and develop U.S. capability in this advanced technology area, the U.S. designed maglev has the clear advantage. The issue of development cost must be evaluated in terms of maintaining the U.S. industry as a player in the international competition for advanced technology and from the standpoint of what the relative costs and benefits are among the options. The higher profit and lower funding requirement on the NEC corridor of USML relative to TR07 add up to more than enough to offset the development cost. The USML has lower public funding requirements and a higher

Table 5.1
Evaluation of Maglev Options

	Development Cost	System Performance	Economic Performance	U.S.Industry Competi-tiveness	U.S. Jobs
Foreign	H	L	L	L	L
Joint Venture	M	M	M	M	M
U.S. Maglev	L	H	H	H	H

revenue-to-cost ratio than TR07 in the remaining corridors studied. Table 5.1 shows that the USML development program is the proper choice among these options.

Chapter 6: Conclusions and Recommendations

6.1 CONCLUSIONS

This study has examined magnetic levitation technology to determine its potential in terms of how it would perform and compete with existing and future transportation options for application in the United States in the early twenty-first century, and how the Federal Government should be involved to assist in achieving that potential. The study assessed U.S. industry's capability to design and build a competitive maglev system and compared the performance of such a system with that of existing maglev (German Transrapid TR07) and of high-speed rail (such as French TGV) as alternatives, in competition with existing air, highway, and conventional rail.

6.1.1 U.S. Industry Can Develop an Advanced Maglev System

Maglev is a technically feasible alternative transportation system. There were no technical impediments identified and the safety and environmental issues can be satisfactorily addressed within the context of a suitable development program.

The Transrapid TR07 Maglev is a pre-production prototype system undergoing final acceptance testing in Germany for possible application in the Orlando, Florida area. Based on a comprehensive analysis of that system, the conclusion is that maglev has been demonstrated as a technically feasible transportation system. This is supported by the status of the Japanese MLU002 prototype system under development in Japan. Although not as far along as the German TR07, the Japanese maglev has also demonstrated technical feasibility. Since these systems have not been operated in revenue service, the public's reaction to them has not been determined. Generally, individuals who have taken rides on the TR07 have reacted favorably.

The NMI study concluded that U.S. industry can develop a maglev system that has specific performance improvements over the German and Japanese maglev systems. This evaluation is based on the collective data from the technology assessment and system concept definition contracts. Several design improvements could result in significant performance and economic benefits compared to the other high-speed ground alternatives. For example, tilting mechanisms and high powered, efficient propulsion systems will allow USML vehicles to follow existing right(s)-of-way (ROW) at speeds substantially higher than the German and Japanese maglev systems. New composite materials and innovative vehicle and component designs can be used to reduce the weight of maglev vehicles and improve energy consumption. Although none of these improvements are considered to "leap frog" the existing maglev designs, taken together, they represent a significant opportunity for U.S. industry to participate in the maglev competition. These improvements were translated into performance terms to evaluate a U.S. design in the market and economic studies. Cost estimates were also developed for the U.S. design maglev system and used in the economic studies. It should be pointed out that the estimated costs for TGV are supported by significant operational experience in France and for TR07, significant test experience in Germany. For USML, the cost estimates were derived from analytical studies by 4 system contractor teams and are considered reasonable, yet, until a U.S. maglev system is built and operated in the United States, there is uncertainty regarding these estimates.

In addition to the issue of opportunities for a U.S. design, there is the related issue of how to acquire the improved technology – that is, buy a foreign system or design and build one in the United States. One approach is a U.S. and foreign industry partnership to implement a foreign maglev design in the United States. The maglev system design in this case is assumed to require modification to optimize it for U.S. application. The cost for this development work could be shared with the U.S. and foreign industry partners, but, from a practical standpoint, the foreign industry will not likely spend additional development funds unless there is an assured market with a reasonable return time period. Modifications to an existing design are best made by the personnel that did the original design; hence, there will be little opportunity for U.S. industry to benefit in the high technology job areas.

Although joint ventures are a possibility, they work much better when both sides have some equivalent experience or capability to bring to the table. For example, with the German Transrapid design being so far along, the primary expertise the United States brings to the table is knowledge of local U.S. transportation construction issues. The high technology benefit to the U.S. industry will be limited, with a relatively long time to realize any significant benefit.

6.1.2 A USML System Has the Potential for Revenues to Exceed Life Cycle Costs in One Corridor, and to Cover Operating Costs and a Substantial Portion of Capital Costs in Others

If a USML system with the characteristics shown in this report were installed in the 10 top U.S. corridor markets, its revenues would cover operating costs, with substantial contribution to capital costs in all corridors. In the Northeast Corridor, its revenues would cover total life cycle costs. In the other corridors significant public investment would be required. These projected results reflect the ability of the technology to offer the best door-to-door travel time for distances up to 300 miles and very competitive trip times even up to 600 miles. They also, however, reflect the high cost of building such systems, $27 million to $46 million per mile, including site preparation and other costs that depend on terrain, degree of urbanization, and other factors.

The detailed economic results depend on the discount rate used in the calculations. A 7 percent discount rate with constant dollar prices was used as the baseline rate for this report. When translated into market terms (where inflation is taken into account), it would be about 10 to 11 percent. This is the rate required to be used by the Office of Management and Budget for making economic decisions regarding all Federal Government sponsored or assisted projects. It is intended to reflect the average return to capital investments in all sectors of the economy and, thus, the social opportunity cost of using resources for maglev investments. With a 7 percent rate USML revenues would be slightly higher than life cycle costs in the Northeast

Corridor, but would cover only about 30 to 50 percent of life cycle costs in the other nine corridors. Under more favorable assumptions about future travel growth, congestion, and cost of competing modes, two of the corridors would cover life cycle costs and the others would cover about 50 to 80 percent.

A 4 percent discount rate was also used for the same calculations as a sensitivity analysis. When translated into market terms, this is representative of the type of financing that could be available to sponsors of high-speed ground-transportation projects under the Administration's recommendation to exempt HSR bond interest from income taxes without annual limits. In this case, in the Northeast Corridor, a U.S. Maglev system would produce a surplus of revenues about 47 percent above life cycle costs. In the other nine corridors, revenues would cover about 50 to 80 percent of the life cycle costs. Under the more favorable assumptions, six corridors would cover total costs, with the other three covering about 75 percent.

Generally, revenue-to-cost ratios would be higher for USML versus both TR07 and TGV at both discount rates; however, outside the Northeast Corridor, where revenues are less than life cycle costs, USML would require higher public investment than TGV, though lower than for TR07. In the Northeast Corridor, the revenue-to-cost ratio for USML would be about the same as for TGV at the 7 percent discount rate, but higher than for TR07, while at the 4 percent rate it would be higher than for both TGV and TR07. The advantages for USML are more pronounced when it is compared to other systems using existing ROW, because of the superior ability of USML to operate on curves at high speed.

USML produces public benefits of reduced environmental pollution, petroleum consumption, and congestion at airports because of its ridership diversion from highways and air systems. Generally, these public benefits are also larger for the USML than for TR07 or TGV because of its comparative attractiveness as an alternative to air and auto travel.

This analysis supports the conclusion that USML can be considered as a potentially effective intercity passenger transportation alternative for the twenty-first century in high-density corridors.

6.1.3 A USML System Would Provide an Opportunity to Develop new Technologies and Industries with Possible Benefits for U.S. Businesses and the Work Force

U.S. industry competitiveness benefits are significant with a USML development program. The generation of high technology jobs would be greater for designing and implementing a U.S. system as opposed to buying a foreign system. However, the U.S. system development costs would be considerably more than the costs associated with bringing in the foreign system; yet, if comparable performance were required of the foreign maglev system to meet the level of the U.S. design, significant developmental costs would also be required for the foreign system. With the development of a U.S. maglev system, domestic industry would also gain through high technology businesses capitalizing on spin-offs that will occur as maglev technology evolves. Examples that offer particular economic value could be the early implementation of fiber reinforced polymers in concrete structures, vibration insensitive superconducting magnets, and ruggedized cryogenic systems for ship propulsion and other uses.

6.1.4 A U.S. Maglev is not Likely to be Developed Without Significant Federal Government Investment

The U.S. industry is not likely to fund a significant amount of the development of a maglev prototype. Maglev has both technical and financial risks associated with it. The fact that the ultimate payback to the private investors is very long term and that there are risks makes it unlikely that the private sector will fund the development costs. The major development costs will be associated with the vehicle/guideway interaction and propulsion/levitation/guidance and control issues. These are not associated with the area where the most implementation costs reside, namely guideway construction. The industry partners involved in the most intricate development activity will not be the ones with the largest potential return. The likelihood of industry supporting significant cost sharing is very low, particularly as the cost exposure escalates in the later phases of a development program.

In conclusion, development is unlikely to move forward at all unless the U.S. Government funds the major portion of the development costs. If maglev were implemented, the ultimate sponsors, i.e., the state and local governments, would be expected to share in the construction costs because they would be the ones to ultimately benefit and the pay-back period would be much reduced relative to the development time frame.

6.2 RECOMMENDATIONS

The NMI study team recommends that the Federal Government should initiate Phase I (Conceptual Design) of a USML Prototype Development Program. The Federal Government should fund the majority of the development since industry will not fund a significant amount of it. The recommended program differs in its implementation from that defined in the ISTEA legislation. Because of the mixed results of some of the economic analysis and uncertainties about the cost and performance of a U.S. maglev system compared to other high-speed ground transportation alternatives, several program reviews should be built into the program allowing for reevaluations of the benefits and costs of the program based on the latest technical and economic information. The first such review should be at the end of 1994, based in part on information available from the study of the commercial feasibility of high-speed ground transportation mandated under ISTEA.

The entire program would be a three-phased development plan leading to a technical demonstration at a test site. A program option for a revenue service demonstration should be retained during the development program, subject to a determination that all technical risks are adequately understood and mitigated, that the design is mature enough, and that the net benefits are great enough to warrant such a step. The requirements of the ISTEA should be modified to reflect this approach and incorporate a modified development schedule to assure reasonable technical and cost risks.

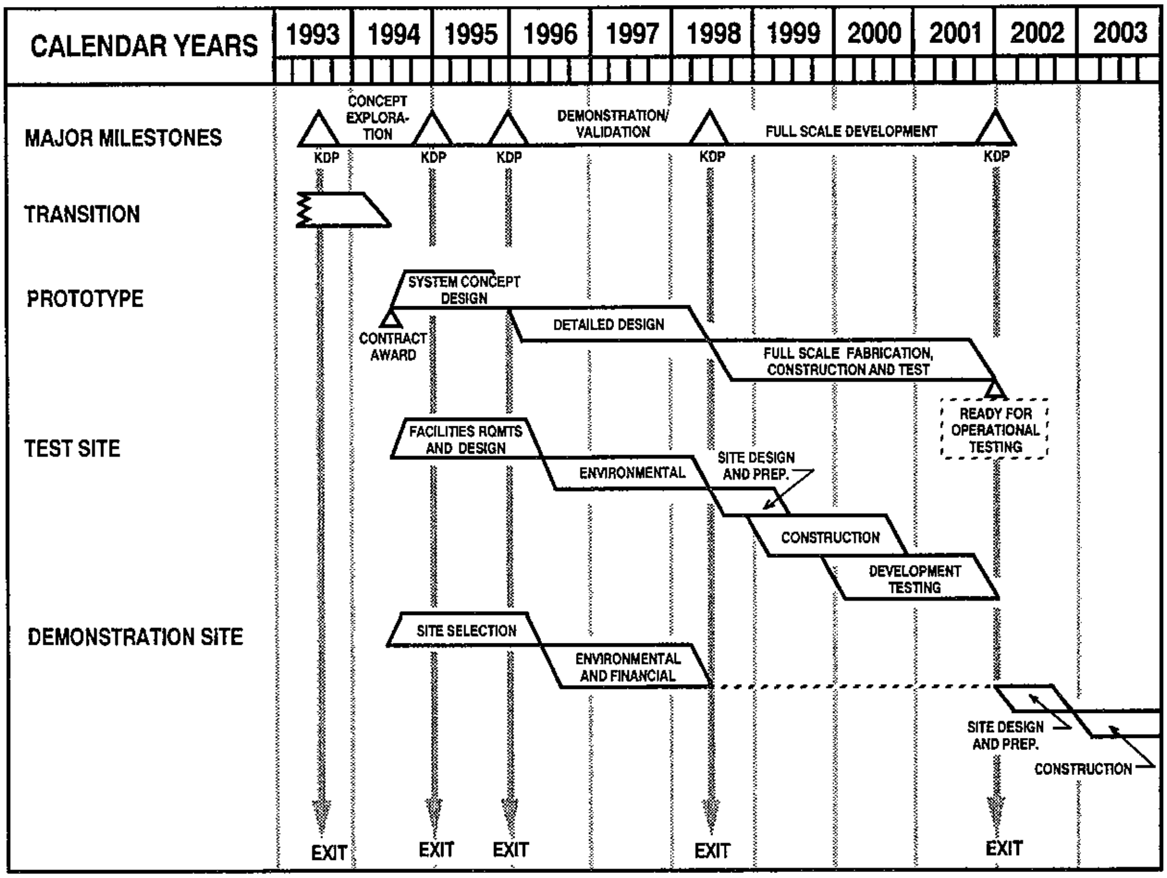
This recommendation is based on the conclusions from the NMI study and from recognition of the future need to address expected and unexpected issues of airport and highway congestion, petroleum dependence, and environmental (pollution) restrictions. To respond to those issues, action is required now to have a transportation option available in the next 15 to 20 years. The United States must also maintain its capability to compete in the advanced technology market. A USML system is a step toward achieving an improved position in the ground transportation field.

6.3 RECOMMENDED PROGRAM

The recommended program as illustrated in Figure 6.1 would require a transition period from the NMI program and would be executed in three phases:

- Phase 1 – Concept Exploration/ System Concept Design
- Phase 2 – Demonstration/Validation/ System Detailed Design
- Phase 3 – Full Scale Fabrication/ Construction and Test

Figure 6.1
Prototype Development Plan



KDP = Key Decision Point

Concept Exploration will feature full and open competition with multiple entrants, a down selection to two system concepts in Demonstration and Validation, and a final down selection to a single concept for Full-Scale Development. Key decision points at the end of 1994 and at the end of each phase will allow the Government to examine the need to continue the program prior to committing additional funds.

Concurrent with the development work performed by contractor teams, site selection, and environmental assessments for a test track located at a Government facility and possibly at a demonstration track located in a revenue corridor will be scheduled to preserve the option to complete full-scale development at the demonstration site if remaining risks are sufficiently low.

Compared to ISTEA the principal changes called for in the recommended program are:

- An additional 24 months of development time to reduce technical risk by allowing extended testing, particularly for system features which have not yet been demonstrated in any maglev system, such as tilt.
- Placement of the test track at a Government facility to allow less restrictive and more complete testing, including testing outside the typical design parameters of the system.
- Clarifying the ability of the competitors in the program to employ elements of foreign technology as long as a substantial share of the development program takes place in the United States.

The changes are based on the conclusion that the tight schedule called for by ISTEA would not provide sufficient time for development of technological advancements and testing of the U.S-designed maglev system in order to ensure that safety, reliability, and maintainability standards are achieved. Of specific concern is the inability for testing the maglev system under "worst case" scenarios that would be inappropriate on a revenue corridor, i.e., high-speed runs, endurance testing, emergency egress, and weather effects testing. Because of these needs, it would be desirable to test the system at a test track prior to fielding the system at a revenue site.

APPENDIX A

ADDITIONAL INFORMATION

Appendix A: Additional Information

Guideway Cost Estimates

The Government Maglev System Assessment (GMSA) team developed guideway cost estimates for the TR07 and each of the four SCD concepts. This was necessary because the cost estimating approach varied widely from one SCD contractor to another; variances resulted from different guideway heights, different unit prices for similar commodities, non-uniform allocation of components into subsystems, missing items, and differences in the application of contingencies, overhead, and profit factors.

The GMSA team, therefore, reworked the contractors' cost estimates in order to compare the different technologies on an equivalent basis. First, a standard method was applied to allocate components into subsystems, then the unit costs were developed for each subsystem, and finally the estimates were compared, based upon a common set of parameters such as guideway height. In the case of the TR07, the GMSA team's estimate was derived from the California-Nevada proposal by Transrapid International/Bechtel.

The cost of the USML was developed by examining the subsystem costs for each SCD concept, deleting the costs that were substantially too high or too low (based on engineering judgment), and averaging the remaining costs. This is justified by the fact that each contractor optimized the design of different subsystems, and that some high unit costs resulted from innovations that more conventional approaches with lower cost solutions could avoid. For example, one contractor proposed the use of a LCLSM, which the Government team priced at a very high unit cost, while another concept required a very large amount of aluminum in the guideway structure. Both of these extremes were deleted from the average costs of subsystems for USML.

Table A1
Percentage Diverted from Highway and Air, by Technology
(2020, Limited Sharing Alignment)

Corridor	TGV			TR07			USML		
	Percent Diverted from			Percent Diverted from			Percent Diverted from		
	Air O/D	Air Tr	Auto	Air O/D	Air Tr	Auto	Air O/D	Air Tr	Auto
NEC	59.0%	18.4%	2.4%	63.9%	27.9%	2.2%	68.3%	31.0%	2.2%
CA	32.1%	1.6%	2.1%	51.3%	8.9%	2.0%	53.9%	10.0%	2.0%
LA-PHX	48.8%	7.1%	7.7%	66.0%	37.8%	7.4%	67.5%	40.4%	7.5%
DAL-HOU	69.0%	24.8%	4.8%	75.9%	54.2%	4.5%	76.6%	55.7%	4.6%
LA-LV	49.2%	7.8%	4.4%	62.9%	31.7%	4.2%	64.9%	34.8%	4.3%
TEX-TRI	70.8%	24.7%	2.3%	76.0%	50.6%	2.2%	76.9%	52.6%	2.2%
SEC	48.1%	25.3%	1.8%	65.0%	43.9%	1.5%	68.65	46.1%	1.5%
CHI-PIT	61.2%	10.8%	2.0%	71.5%	31.7%	1.8%	74.8%	36.6%	1.9%
CHI-MSP	60.9%	28.1%	1.5%	74.4%	56.3%	1.3%	76.9%	60.2%	1.3%
CHI-DET	68.6%	20.2%	2.2%	79.9%	52.6%	2.0%	81.1%	54.7%	2.0%
CHI-KC	61.8%	23.6%	2.0%	76.9%	49.0%	2.0%	79.1%	51.8%	2.0%
NYS	37.5%	2.6%	2.4%	61.2%	8.7%	2.5%	67.2%	10.8%	2.6%
FL	63.2%	5.9%	2.6%	68.9%	10.6%	2.3%	70.6%	11.2%	2.3%
HOU-NO	62.2%	11.3%	1.7%	71.8%	32.7%	1.7%	73.3%	34.8%	1.7%
PA	68.8%	24.8%	2.9%	74.0%	49.1%	2.5%	76.5%	54.2%	2.6%
SEA-POR	49.2%	16.4%	1.6%	67.4%	33.2%	1.7%	70.7%	37.4%	1.8%

Table A2
Impact of Intercorridor Network Travel on Revenue/Cost Ratio (R/C) at 4 Percent

NETWORK CONCEPTS	WITHOUT NETWORK	WITH NETWORK
East Coast Corridor		
Range of R/C	0.62 - 1.47	1.21
Average R/C	1.11	
North Central		
Range	0.21 - 1.47	1.03
Average	0.92	
Chicago Hub		
Range	0.51 - 0.55	0.60
Average	0.54	
Los Angeles Hub		
Range	0.59 - 0.81	0.76
Average	0.70	
Orlando Hub		
Range	0.48 - 0.50	0.63
Average	0.49	
Texas Hub		
Range	0.34 - 0.72	0.58
Average	0.54	

Notes: (1) Estimates calculated using a 4 percent discount rate.
(2) Corresponds to Table 3.8 in Chapter 3.

Table A3
Trip Times (Hours) and Average Speed (MPH), by Technology
(2020, Limited Sharing Alignment)

Corridor Trip Endpoints			TGV		TR07		USML	
Corridor	City 1	City 2	Line-Haul Trip Time	Average Speed	Line-Haul Trip Time	Average Speed	Line-Haul Trip Time	Average Speed
NEC	Boston	Washington	3.47	132	2.71	169	2.48	184
CA	San Diego	San Francisco	3.54	149	2.68	197	2.60	203
LA-PHX	Los Angeles	Phoenix	2.25	163	1.59	231	1.55	237
DAL-	Dallas	Houston	1.58	166	1.14	228	1.12	233
LA-LV	Los Angeles	Las Vegas	1.76	154	1.24	217	1.19	228
TEX-TRI	Dallas	San Antonio	1.79	165	1.32	224	1.26	234
SEC	Washington	Atlanta	3.98	159	2.83	224	2.71	234
CHI-PIT	Chicago	Pittsburgh	3.80	129	2.69	182	2.51	196
CHI-MSP	Chicago	Minneapolis	2.58	160	1.80	229	1.72	241
CHI-DET	Chicago	Detroit	2.06	148	1.43	213	1.38	221
CHI-KC	Chicago	Kansas City	3.19	169	2.25	239	2.17	248
NYS	New York	Buffalo	2.78	155	1.95	221	1.77	244
FL	Miami	Tampa	1.84	163	1.40	214	1.36	220
HOU-NO	Houston	New Orleans	2.02	144	1.41	206	1.36	214
PA	Philadelphia	Pittsburgh	2.00	153	1.45	212	1.35	228
SEA-POR	Seattle	Portland	1.19	137	0.87	188	0.79	208

Note: These travel times and speeds are weighted averages between nonstop and multistop service, reflecting the performance for the typical traveler.

Table A4
Total Initial Capital Costs Assuming a 4 Percent Discount Rate ($ Billions)

Corridor	TGV			TR07			USML		
	Guideway Technology	Other	Total Cost	Guideway Technology	Other	Total Cost	Guideway Technology	Other	Total Cost
NEC	5.0	9.9	14.9	10.0	12.0	22.0	8.2	12.1	20.3
CA	6.2	8.5	14.7	12.1	10.5	22.6	9.9	10.7	20.6
LA-PHX	3.8	4.8	8.6	8.3	5.3	13.6	6.7	5.4	12.1
DAL-HOU	2.1	2.5	4.6	5.0	3.2	8.2	4.0	3.2	7.2
LA-LV	2.9	4.0	6.9	6.3	4.5	10.8	5.1	4.5	9.6
TEX-TRI	5.2	6.4	11.6	12.4	8.1	20.5	10.0	8.1	18.1
SEC	5.0	6.7	11.7	11.1	7.8	18.9	8.9	7.9	16.8
CHI-PIT	5.3	7.3	12.6	11.6	8.4	20.0	9.3	8.4	17.7
CHI-MSP	3.9	5.1	9.0	8.4	5.9	14.3	6.8	5.9	12.7
CHI-DET	2.6	3.2	5.8	6.3	4.2	10.5	5.0	4.2	9.2
CHI-KC	4.9	6.4	11.3	10.7	7.3	18.0	8.6	7.4	16.0
NYS	4.2	5.6	9.8	9.2	6.4	15.6	7.4	6.4	13.8
FL	2.2	2.8	5.0	5.2	3.5	8.7	4.1	3.5	7.6
HOU-NO	2.6	3.2	5.8	6.1	4.1	10.2	4.9	4.1	9.0
PA	2.9	3.7	6.6	6.3	4.1	10.4	5.1	4.2	9.3
SEA-POR	1.8	2.4	4.2	3.4	2.7	6.1	2.8	2.7	5.5

Note:
(1) Estimates are for baseline scenario using the limited sharing ROW alignment.
(2) Guideway technology costs include the guideway beam, supporting structures, and all electrical and magnetic components.
(3) Other costs include vehicles, stations and other fixed facilities, environmental mitigation costs, civil reconstruction, non-technology site preparation work, contingencies, and program management.
(4) A construction financing cost is included in the estimates using the 4 Percent discount rate.

Table A5
HSGT Person Trips, Passenger Miles, by Technology
(2020, Limited Sharing Alignment)

Corridor	TGV		TR07		USML	
	Trips (thousands)	Pax-Miles (millions)	Trips (thousands)	Pax-Miles (millions)	Trips (thousands)	Pax-Miles (millions)
NEC	30,829	6,125	31,837	6,547	33,297	6,962
CA	10,813	3,622	16,196	5,909	16,988	6,241
LA-PHX	4,593	1,676	7,012	2,559	7,222	2,636
DAL-HOU	5,274	1,345	6,807	1,736	6,908	1,762
LA-LV	5,236	1,340	6,553	1,678	6,760	1,731
TEX-TRI	12,878	3,049	16,295	3,878	16,641	3,964
SEC	6,722	1,599	9,773	2,752	10,247	2,965
CHI-PIT	5,695	1,588	7,623	2,184	8,239	2,367
CHI-MSP	4,027	1,116	5,581	1,683	5,838	1,769
CHI-DET	3,343	915	4,500	1,255	4,604	1,284
CHI-KC	4,686	1,362	6,362	1,996	6,590	2,081
NYS	3,989	1,060	5,316	1,537	5,699	1,678
FL	3,679	845	4,179	967	4,300	997
HOU-NO	2,157	528	2,840	701	2,923	723
PA	1,358	308	1,666	385	1,762	409
SEA-POR	808	127	1,123	175	1,194	185

Table A6
Estimated 2020 Ticket Price and Financial Assistance per Rider Assuming a 7 Percent Discount Rate (1991 Dollars)

Corridor	TGV		TR07		USML	
	2020 Average Ticket Price	2020 Financial Assistance per Rider	2020 Average Ticket Price	2020 Financial Assistance per Rider	2020 Average Ticket Price	2020 Financial Assistance per Rider
NEC	63.20	(10.90)	74.63	(7.94)	74.79	(14.61)
CA	64.76	63.73	78.06	48.96	78.12	34.27
LA-PHX	68.92	105.54	78.83	93.16	78.65	72.41
DAL-HOU	56.31	34.56	64.30	48.33	64.20	35.66
LA-LV	56.73	68.43	66.75	79.69	66.63	62.50
TEX-TRI	56.22	35.42	64.13	50.27	64.02	37.16
SEC	66.26	97.62	78.62	92.97	79.12	70.43
CHI-PIT	76.42	120.56	87.77	139.64	87.55	104.01
CHI-MSP	79.14	124.98	90.46	132.37	90.24	102.62
CHI-DET	70.42	95.21	79.98	126.47	79.82	101.85
CHI-KC	78.50	139.78	91.07	154.42	91.01	123.22
NYS	75.13	145.43	88.37	164.42	88.41	124.64
FL	59.48	72.70	69.97	116.99	69.91	94.06
HOU-NO	71.59	177.19	80.56	232.57	80.38	192.76
PA	65.95	364.98	74.89	452.15	74.42	373.21
SEA-POR	48.99	424.54	56.86	412.89	56.48	342.84

Table A7
Estimated 2020 Ticket Price and Financial Assistance per Rider Assuming a 4 Percent Discount Rate (1991 Dollars)

Corridor	TGV		TR07		USML	
	2020 Average Ticket Price	2020 Financial Assistance per Rider	2020 Average Ticket Price	2020 Financial Assistance per Rider	2020 Average Ticket Price	2020 Financial Assistance per Rider
NEC	63.20	(22.78)	74.63	(24.87)	74.79	(29.50)
CA	64.76	30.44	78.06	14.76	78.12	4.76
LA-PHX	68.92	59.62	78.83	45.44	78.65	31.41
DAL-HOU	56.31	13.35	64.30	18.81	64.20	10.08
LA-LV	56.73	36.19	66.75	39.38	66.63	27.74
TEX-TRI	56.22	12.76	64.13	19.47	64.02	10.63
SEC	66.26	54.61	78.62	45.76	79.12	30.27
CHI-PIT	76.42	66.23	87.77	75.36	87.55	51.25
CHI-MSP	79.14	70.15	90.46	69.49	90.24	49.34
CHI-DET	70.42	52.19	79.98	69.09	79.82	52.50
CHI-KC	78.50	80.27	91.07	84.92	91.01	63.79
NYS	75.13	84.77	88.37	92.50	88.41	65.31
FL	59.48	39.81	69.97	66.01	69.91	50.42
HOU-NO	71.59	111.98	80.56	144.32	80.38	117.39
PA	65.95	244.97	74.89	298.59	74.42	244.83
SEA-POR	48.99	294.44	56.86	279.41	56.48	231.34

Table A8
Estimated 2020 Cost per Passenger Mile
Assuming a 7 Percent Discount Rate (Dollars)

Corridor	TGV			TR07			USML		
	Annualized Capital per Pass. Mi.	O&M Cost per Pass. Mi.	Total Cost per Pass. Mi.	Annualized Capital per Pass. Mi.	O&M Cost per Pass. Mi.	Total Cost per Pass. Mi.	Annualized Capital per Pass. Mi.	O&M Cost per Pass. Mi.	Total Cost per Pass. Mi.
NEC	0.18	0.08	0.26	0.25	0.07	0.32	0.22	0.07	0.29
CA	0.30	0.08	0.38	0.29	0.06	0.35	0.25	0.06	0.31
LA-PHX	0.39	0.09	0.48	0.40	0.07	0.47	0.34	0.07	0.41
DAL-HOU	0.25	0.10	0.35	0.35	0.09	0.44	0.31	0.08	0.39
LA-LV	0.39	0.10	0.49	0.48	0.09	0.57	0.42	0.09	0.51
TEX-TRI	0.29	0.09	0.38	0.40	0.08	0.48	0.34	0.08	0.42
SEC	0.55	0.14	0.69	0.51	0.10	0.61	0.42	0.09	0.51
CHI-PIT	0.60	0.11	0.71	0.69	0.11	0.80	0.56	0.10	0.66
CHI-MSP	0.61	0.13	0.74	0.64	0.10	0.74	0.54	0.10	0.64
CHI-DET	0.48	0.12	0.60	0.63	0.11	0.74	0.54	0.11	0.65
CHI-KC	0.62	0.12	0.74	0.68	0.10	0.78	0.58	0.10	0.68
NYS	0.70	0.13	0.83	0.76	0.11	0.87	0.62	0.11	0.73
FL	0.44	0.14	0.58	0.67	0.13	0.80	0.58	0.13	0.71
HOU-NO	0.82	0.20	1.02	1.10	0.17	1.27	0.93	0.17	1.10
PA	1.62	0.28	1.90	2.03	0.25	2.28	1.69	0.24	1.93
SEA-POR	2.53	0.48	3.01	2.62	0.39	3.01	2.20	0.37	2.57

Table A9
Estimated 2020 Cost per Passenger Mile
Assuming a 4 Percent Discount Rate (Dollars)

Corridor	TGV			TR07			USML		
	Annualized Capital per Pass. Mi.	O&M Cost per Pass. Mi.	Total Cost per Pass. Mi.	Annualized Capital per Pass. Mi.	O&M Cost per Pass. Mi.	Total Cost per Pass. Mi.	Annualized Capital per Pass. Mi.	O&M Cost per Pass. Mi.	Total Cost per Pass. Mi.
NEC	0.12	0.08	0.20	0.17	0.07	0.24	0.15	0.07	0.22
CA	0.20	0.08	0.28	0.19	0.06	0.25	0.17	0.06	0.23
LA-PHX	0.26	0.09	0.35	0.27	0.07	0.34	0.23	0.07	0.30
DAL-HOU	0.17	0.10	0.27	0.24	0.09	0.33	0.21	0.08	0.29
LA-LV	0.26	0.10	0.36	0.32	0.09	0.41	0.28	0.09	0.37
TEX-TRI	0.20	0.09	0.29	0.27	0.08	0.35	0.23	0.08	0.31
SEC	0.37	0.14	0.51	0.35	0.10	0.45	0.29	0.09	0.38
CHI-PIT	0.40	0.11	0.51	0.46	0.11	0.57	0.38	0.10	0.48
CHI-MSP	0.41	0.13	0.54	0.43	0.10	0.53	0.36	0.10	0.46
CHI-DET	0.32	0.12	0.44	0.42	0.11	0.53	0.36	0.11	0.47
CHI-KC	0.41	0.12	0.53	0.46	0.10	0.56	0.39	0.10	0.49
NYS	0.47	0.13	0.60	0.51	0.11	0.62	0.42	0.11	0.53
FL	0.29	0.14	0.43	0.45	0.13	0.58	0.39	0.13	0.52
HOU-NO	0.55	0.20	0.75	0.74	0.17	0.91	0.63	0.17	0.80
PA	1.09	0.28	1.37	1.37	0.25	1.62	1.14	0.24	1.38
SEA-POR	1.70	0.48	2.18	1.77	0.39	2.16	1.48	0.37	1.85

APPENDIX B

LIST OF
NMI PARTICIPANTS

Appendix B: List of NMI Participants

Government Agencies

Argonne National Labs, Argonne, IL
Brookhaven National Labs, Upton, NY
National Academy of Science, Transportation Research Board, Washington, D.C.
National Maglev Initiative Program Office, Washington, D.C.
National Aeronautics and Space Administration, Langley, Hampton, VA
National Aeronautics and Space Administration, Ames, Mountain View, CA
New York State Department of Transportation, Albany, NY
State of California, CALTRANS, San Francisco, CA
U.S. Army Corps of Engineers/CEHND, Huntsville, AL
U.S. Army Corps of Engineers/CRREL, Hanover, NH
U.S. Army Corps of Engineers/WES, Vicksburg, MS
U.S. Army Corps of Engineers, Washington, D.C.
U.S. Army, Office of the Assistant Secretary (Civil Works), Washington, D.C.
U.S. Department of Energy, Washington, D.C.
U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C.
U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.
U.S. Department of Transportation, Federal Railroad Administration, Washington, D.C.
U.S. Department of Transportation, Research and Special Programs Administration, Washington D.C.
U.S. Department of Transportation, Federal Transit Administration, Washington, D.C.
U.S. Department of Transportation, Office of the Secretary, Washington, D.C.
U.S. Department of Transportation, Volpe National Transportation System Center, Cambridge, MA
U.S. Environmental Protection Agency, Washington, D.C.

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Battelle, Columbus, OH
Bechtel, San Francisco, CA
Beech Aircraft, Wichita, KA
Berger/ABAM Engineers, Federal Way, WA
Boeing, Seattle, WA
Bombardier, Boucherville, Quebec, Canada
Bromwell & Carrier, Lakeland, FL
Charles River Associates, Boston, MA
Charles Stark Draper Labs, Cambridge, MA
Council on Superconductivity for American Competitiveness, Washington, D.C.
DeLeuw Cather & Company, New York, NY

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EG&G Dynatrend Inc., Transportation Division, Burlington, MA
EG&G Dynatrend Inc., Technologies Integration Group, Arlington, VA
EG&G Washington Analytical Services Center, Inc., Rockville, MD
Electric Research and Management, State College, PA
ENSCO, Inc., Springfield, VA
FAI, Inc., Vienna, VA
Failure Analysis Associates, Menlo Park, CA
Foster-Miller, Waltham, MA
General Atomics, San Diego, CA
General Dynamics, Arlington, VA
General Electric Company, Schenectady, NY
General Motors, Electro-Motors Division, Washington, D.C.
Gibbs & Hill, Inc., New York, NY
Grumman Aerospace Corp., Bethpage, NY
Harris, Miller/Miller Hansen, Inc., Lexington, MA
Honeywell, Minneapolis, MN
Hudson Engineering Corporation, Houston, TX
Hughes Ground Systems Group, Fullerton, CA
Intermagnetics General, Guilderland, NY
Kaman Science, Santa Monica, CA
Lockheed Corp, Calabasas, CA
Louis Berger & Associates, Inc., Waltham, MA
Madison, Madison International, Detroit, MI
Magneplane International, Bedford, MA
Martin Marietta Information Systems Group, Washington, D.C.
Martin Marietta, Denver, CO
Morrison-Knudsen Corp., Washington, D.C.
Parsons Binkerhoff, Quade & Douglas, Inc., Herndon, VA, Atlanta, GA, and Boston, MA
PSM Technologies, Pittsburgh, PA
Process Systems International, Westborough, MA
Raytheon Co./Equipment Division, Marlborough, MA
United Engineers and Constructors, Technical Services, Boston, MA
U.S. Travel Data Center, Washington, DC

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Canadian Institute of Guided Ground Transportation, Queens University, Kingston, Ontario, Canada
Cornell University, Ithaca, NY
Massachusetts Institute of Technology/Mechanical Engineering, Cambridge, MA
MIT Center for Transportation, Cambridge, MA
MIT Lincoln Laboratory, Cambridge, MA

Academic Institutions *(Cont'd)*

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Northwestern University, Evanston, IL
Texas A&M University, College Station, TX
State University of New York, Albany, NY
University of Washington, Seattle, WA
West Virginia University, Morgantown, WV

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GLOSSARY

BAA	Broad Agency Announcement. A notice from the Government that requests scientific or research proposals from private firms concerning certain areas of interest to the Government. The proposals submitted by private firms may lead to contracts.
bogie	A railroad car or locomotive undercarriage.
commutate	Reverse the direction of an alternating current each half cycle to yield a unidirectional current.
consist	The composition (number and specific identity) of individual units of a train.
cryogenics	The science of low temperature phenomena.
cryostat	A device for maintaining constant low temperature.
DOE	Department of Energy.
DOT	Department of Transportation.
EDS	electrodynamic suspension.
EMS	electromagnetic suspension.
Emsland	Test site of the TR07 in Germany.
ES	Extensive sharing of right-of-way.
externalities	public benefits.
FHWA	Federal Highway Administration.
fiber reinforced plastic	A polymer-based alternative to ferrous reinforcement of concrete and other materials.
FRA	Federal Railroad Administration.
FRP	Fiber Reinforced Plastic.
FY	Fiscal Year.

GMSA	Government Maglev System Assessment.
guideway	A riding surface (including support structure) that physically guides vehicles specially designed to travel on it.
H-bridge	A four-arm, alternating current bridge, the balance of which varies with electrical frequency.
headway	The interval between the passing of the front ends of successive vehicles moving in the same direction along the same lane, track, or other guideway.
HSGT	High Speed Ground Transportation.
HSR	High Speed Rail.
HSST	High Speed Surface Transportation.
ICE	Intercity Express.
intermodal	Unified, interconnected forms of transportation.
invertor	An electrical circuit device which reverses an input to an opposite output in terms of some electrical characteristics such as polarity, voltage, or frequency.
ISTEA	Intermodal Surface Transportation Efficiency Act.
IVHS	Intelligent Vehicle/Highway Systems.
LCLSM	locally commutated linear synchronous motor.
levitation	To rise or cause to rise into air and float in apparent defiance of gravity.
levitation, magnetic	Support technology that keeps a vehicle separated from its guideway by riding a surface of magnetic force.
life cycle	The useful or total productive time span of an asset or system.
life cycle cost	The present value total cost for acquisition and operation over the useful life of an asset or system.
LIM	linear induction motor.

linehaul time	Transportation service time between points without consideration of external time factors such as access to the system or entry and exit requirements.
long-stator	Propulsion using an electrically powered linear motor winding in the guideway.
LS	Limited sharing of rights-of-way.
LSM	linear synchronous motor.
maglev	magnetic levitation.
magnetic levitation	Support technology that keeps a vehicle separated from its guideway by riding a surface of magnetic force.
MLU	A Japanese maglev system employing a U-shaped guideway.
MN	Mainly new right-of-way.
NMI	National Maglev Initiative.
NITS	National Intermodal Transportation System.
O&M	Operation and maintenance.
OD	Origin-destination.
pantograph	A device for collecting current from an overhead conductor, characterized by a hinged vertical arm operating by springs or compressed air and a wide, horizontal contact surface that glides along the wire.
PMT	Passenger Miles Traveled.
PSE	The Paris-Lyon Route on which the TGV has been in service since 1981 in France.
right-of-way	A general term denoting land, property, or interest therein, usually in a strip, acquired for or devoted to transportation purposes.
ROW	Right(s)-of-way.
RTRI	Railway Technical Research Institute, the research section of the newly privatized Japan Rail Group.

SCD	system concept definition.
Shinkansen	Japanese "bullet train".
short-stator	Propulsion technology using a linear induction motor winding onboard the vehicle and a passive guideway.
spline	Any of a series of projections on a shaft that fit into slots on a corresponding shaft.
stator	The nonrotating part of the magnetic structure in an induction motor.
superconductivity	The abrupt and total disappearance of resistance to direct current which occurs in some materials at temperatures near to or somewhat above absolute zero (like 90 K for some high temperature superconductors).
TGV	*Train a Grande Vitesse.*
Train a Grande Vitesse	The French National Railway's high speed, steel-wheel-on-rail train.
Transrapid (TR07)	The German high speed maglev system. This system is nearest to commercial readiness.
USACE	United States Army Corps of Engineers.
USML	United States Maglev.
WES	Waterways Experimental Station, U.S. Army Corps of Engineers.

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