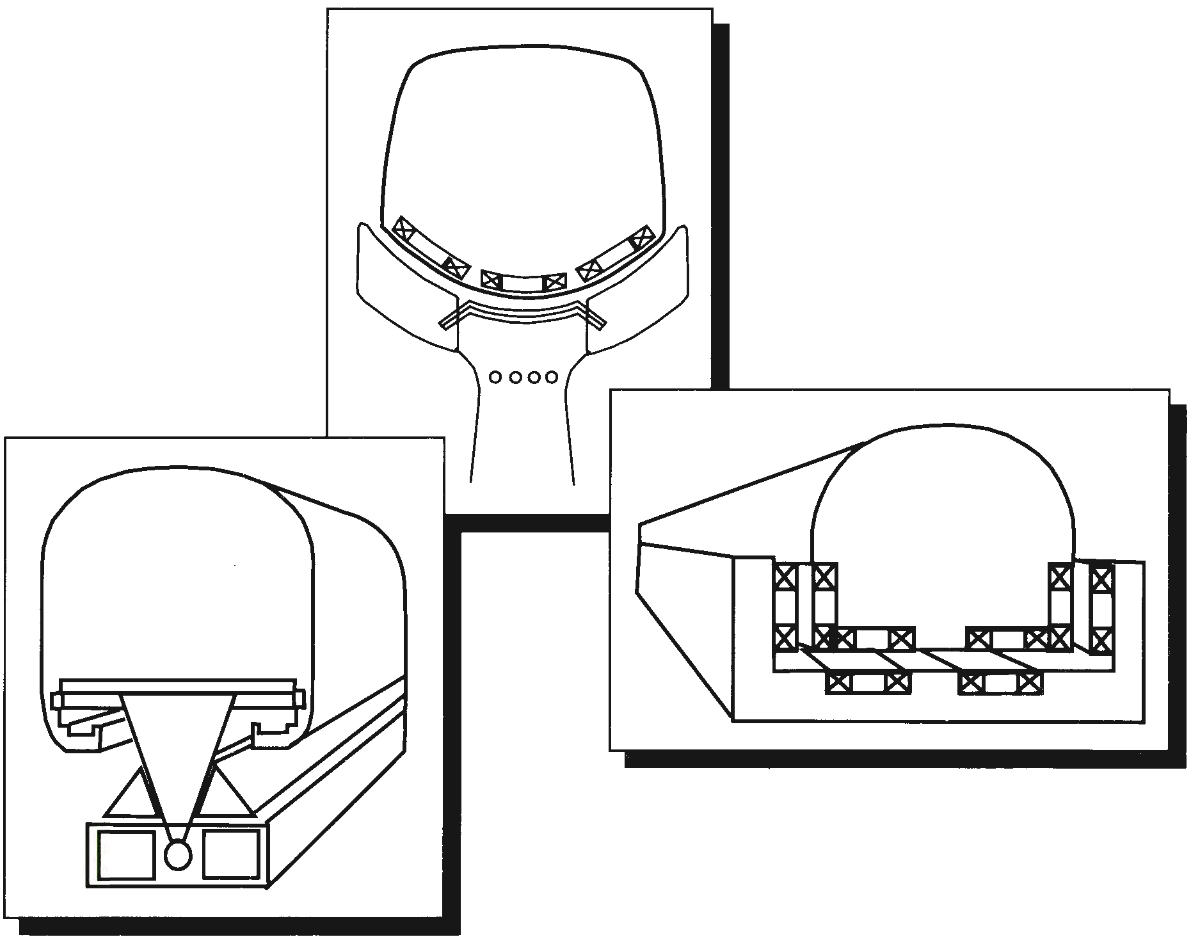
KAMHI

U.S. Department
of Transportation

**Federal Railroad
Administration**

Assessment of the Potential for Magnetic Levitation Transportation Systems in the United States

Report Supplement



Moving America
New Directions, New Opportunities

June 1990

INTRODUCTION TO THE REPORT SUPPLEMENT

The Supplement of this report to Congress includes a more detailed discussion of technological, economic and legal issues involved in advancing a U.S. maglev system. Chapter I of the Supplement describes generic maglev concepts, the history of U.S., German, Japanese, and other maglev development as well as future plans and potential applications.

Chapter II describes the current state of maglev technological development, based on available information on the German attractive electro-magnetic system (EMS) suspension, the Japan Railways repulsive superconducting electro-dynamic system (EDS) suspension, the Japanese High Speed Surface Transportation (HSST) EMS maglev system, the U.S.-designed Magneplane system (EDS), and other design concepts. Chapter III assesses the technical feasibility of maglev in the United States and discusses the potential for a U.S. role in advancing development of maglev technology, particularly in the areas of guideway technology and vehicle and levitation/propulsion system design.

In assessing the financial feasibility of maglev, Chapter IV forecasts net revenues and capital cost coverage based on ridership and revenue forecasts from projections of fares, travelers and trip times for maglev and competing modes, and estimates of fixed facility and vehicle costs. The potential for social, economic, and environmental public benefits are estimated, and possible "spinoff benefits" to other industries are suggested.

Chapter V reviews ways to assist U.S. industry efforts to assume a leadership role in maglev, including funding for research and development, incentives and disincentives to private investors, new financing options that may be attractive to pursue, and legal and institutional issues involved in construction and operation of maglev systems. This chapter incorporates input from FRA's extensive discussions with senior executives of firms that can be expected to participated in a maglev development program.

A glossary of terms and a bibliography are included at the end of this Supplement.

I. MAGLEV SYSTEM CONCEPTS

The possibility of levitating objects by means of magnetic forces has stirred the imagination of many inventors and inspired designers for nearly a century. The original concept of supporting a vehicle by magnetic forces was proposed in the early 1900s and was based on the attraction of permanent magnets to ferromagnetic plates. Such suspensions turned out not to be practical without controls for stabilization. This led to the use of electromagnets that could be controlled by an active power supply, so as to maintain a constant airgap between the electromagnet and the ferromagnetic plate.

While interest in attractive levitation continued throughout the years, it was not until advances in electronic control systems that the practicability of magnetic levitated vehicles for ground transportation became fully accepted. Advances in lightweight superconducting magnets and cryogenic refrigeration systems subsequently made repulsive force maglev systems practical. Today, interest in both the attractive force suspension technology and the superconducting repulsive force suspension technology remains high, with both methods being developed internationally.

As research in magnetic levitation of vehicles progressed, alternatives for stabilization and propulsion of the levitated vehicles were studied. The introduction of the "null-flux" concept by Danby and Powell in 1966 provided additional options for vertical and lateral vehicle stabilization [1]. In spite of the substantial engineering progress in maglev technology over the years, there is no consensus today on what constitutes an optimum design for any of the systems applications.

SUSPENSION (LEVITATION)

Three types of suspension capable of providing the magnetic forces required for vehicle suspension are currently the subject of maglev development efforts.

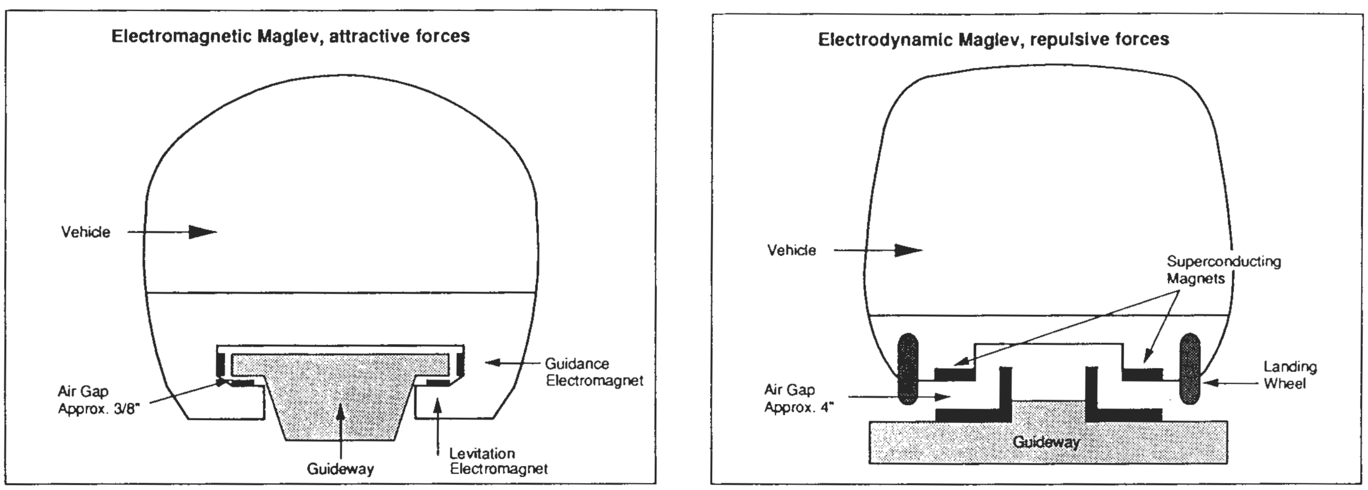
> Electromagnetic suspension (EMS): electromagnets on the vehicle interacting with guideway ferromagnetic rails; characterized by a relatively small separation or air gap, on the order of 10 mm, (3/8 in) in the current prototypes. EMS is referred to as attractive force maglev because the vehicle with its electromagnets is attracted to the guideway which has ferromagnet rails. (See schematic (a) in Figure I-1.)

> Electrodynamic suspension (EDS): superconducting (SC) magnets on the vehicle interacting with a conductive guideway; characterized by a relatively large gap, on the

order of 10 cm, (4 in) in the current prototypes, and little or no need for a gap control system. EDS is referred to as repulsive force maglev because the levitation force that suspends the vehicle over the guideway is repulsive.

Permanent magnet suspension (PMS): permanent magnets on the vehicle interacting with either guideway permanent magnets, guideway ferromagnetic rails, or induced currents in guideway conductive plates/coils. PMS may be configured as either attractive or repulsive force (maglev) depending upon whether the interacting secondary is a ferromagnet or an electrical conductor respectively.

Almost all high speed maglev development has focused on the electromagnetic (EMS) and electrodynamic (EDS) suspensions although there is increasing interest in permanent magnet suspensions for high speed applications.



(a) (b)

Figure I-1
EMS and EDS Suspensions

EMS suspensions using vehicle-borne electromagnets and iron rails fixed on the guideway have been investigated in a number of countries including Great Britain, West Germany, Japan, Romania, and the United States. Only West Germany and Japan have maintained active high speed EMS maglev programs over the past two decades.

EMS suspensions operate with small air gaps and limited range of air gap movement. The suspension has a characteristically high stiffness and a secondary suspension is provided in current prototypes to ensure acceptable ride quality. EMS suspensions are generally designed to distribute the levitation forces over the full length of the vehicle. This provides higher levitation effectiveness than a scheme employing concentrated magnetic forces. EMS systems require a control mechanism to ensure maintenance of a constant separation (air gap) between the vehicle's magnets and the ferromagnetic rails on the guideway.

Electrodynamic suspension technology uses superconducting magnets (SCMs) to generate the intense magnetic fields which provide much larger air gaps (10 cm) between the levitated vehicle and the guideway. SCMs weigh less and require less power to operate than equivalent iron-core electromagnets. EDS levitation is inherently stable and characterized by low stiffness. This may make it necessary to provide secondary stabilization for acceptable ride quality.

Permanent magnets can be used for both attractive-type levitation (using ferromagnetic secondaries) and repulsive-type levitation (using repulsive force interaction of like-pole permanent magnets). Permanent magnet levitation is appealing because it could avoid the need for an on-board magnet power supply and leads to lower vehicle weight. With the discovery in the 1960s of improved permanent magnet material (based on iron oxides) with very high strength and capable of being manufactured at a reasonably low cost, there was renewed interest in permanent magnet suspensions. Recent progress in superconducting permanent magnets fabricated by a "melt quench" process raises the possibility that such materials may one day be used for permanent magnet suspensions.

PROPULSION

Maglev propulsion options have focused on three basic types: (1) the on-board prime mover; (2) the "short stator" linear motor powered by wayside or overhead power rails; and (3) the "long stator" linear motor with powered guideway track.

On-board Prime Mover

The on-board prime mover (motor and its energy source are on-board the vehicle) offers the most straightforward solution to propulsion and eliminates the problem of high-speed power collection. While the gas turbine with jet propulsion was once considered for vehicle propulsion, it has been discarded because of noise, pollution from exhaust gases, dependence on petroleum fuel, and the large weight/volume penalty it introduces.

Short Stator Propulsion

Short stator propulsion employs either a single-sided or double-sided linear motor on the vehicle and a passive guideway element, usually an aluminum rail in the case of an induction motor or a toothed iron rail in the case of a synchronous motor. Propulsion power is provided by wayside power pickup. The principal advantage of short stator propulsion is low guideway cost. The disadvantages are increased vehicle capital, operating and maintenance costs and added weight and power requirements. A German-French consortium has formed to develop the STARLIM, a medium speed maglev combining EMS suspension with LIM propulsion, illustrating the continued interest in this approach.

Long Stator Propulsion

Long stator propulsion requires heavy copper or aluminum windings which are installed over the full length of the guideway. These windings are powered by a variable frequency converter or cyclo-converter which, together with switch gear, are located alongside the guideway at intervals of several hundred meters. The propulsive force results from the interaction between the traveling electro-magnetic field produced by the stator winding and the dc field generated by the vehicle magnet. The active guideway concept has the advantage of low vehicle weight and low vehicle capital and operating costs, at the expense of increased guideway cost. West Germany and Japan use long stators in their respective high-speed electromagnetic and electrodynamic maglev systems.

GUIDANCE

Techniques for guidance of maglev vehicles can generally be separated into either active types requiring continuous monitoring and control circuitry or passive types relying upon different magnet configurations or arrangements of electrically conducting elements. Passive guidance of EMS systems can be achieved by staggering the poles of the on-board electromagnets. An alternative is to position the suspension magnets to produce a sideward component of magnetic field. EDS guidance schemes use either conducting plates or coils attached to the guideway to generate the repulsive stabilizing fields. The pros and cons of conducting plates versus coils is still being debated and are yet to be resolved.

Null-Flux Stabilization

The null-flux scheme of Powell and Danby of the Brookhaven National Laboratory has important implications for vertical and lateral vehicle stabilization. Null-flux operation is achieved by cross-connecting a pair of coils to effectively give zero flux coupling when coupled to a uniform magnetic excitation field. Maglev null-flux generally takes the form of figure-eight coils which are attached either to the guideway or to the vehicle depending upon the particular design configuration. In layman's terms, this system exerts no lateral force on a vehicle unless the vehicle deviates from a central position with respect to the guideway mounted coils. When a vehicle deviates from the central position, the reaction between the vehicle mounted coils and guideway mounted coils generate magnetic forces that move the vehicle back to a central position. Advantages of null-flux are reduced magnetic drag and increased suspension efficiency. The reduced magnetic drag is accompanied by an increase in suspension stiffness so that ride quality may dictate the use of secondary suspension to achieve acceptable ride comfort. One method proposed to control suspension stiffness is the use of ferromagnets in combination with the null-flux suspension.

HISTORICAL DEVELOPMENT OF MAGLEV TECHNOLOGY

Since the initial concept of magnetically levitating a vehicle was conceived nearly 80 years ago, at least six countries have undertaken projects which have involved significant research commitments. Until 1975, the United States was a leader in the development of this technology. Today, however, the efforts of West Germany and Japan dominate the field of magnetic levitation development.

U.S. MAGLEV DEVELOPMENT

During the mid-1960's, the U.S. initiated studies into a number of high speed ground transportation concepts. Maglev appeared to offer advantages over other concepts and to be economically feasible. Maglev also offered the opportunity to apply recent advances in the field of superconductivity to high speed ground transportation. Several concepts were proposed and maglev programs were initiated at several institutions including Brookhaven National Laboratory, Massachusetts Institute of Technology (MIT), Stanford Research Institute (SRI), Avco's System Division, Raytheon's Equipment Division, and Ford Motor Company.

In 1966, Dr. Gordon Danby and Dr. James Powell, both of Brookhaven, proposed an electrodynamic suspension which used the magnetic repulsion between superconducting coils on the vehicle and aluminum ground coils mounted on the guideway.

In 1967, Avco's Systems Division proposed a concept for a superconducting high-speed EDS transportation system which was dual functioned--it served as both a high-speed transportation system and as a low loss, high-power transmission system. With the growth in demand for electric power, particularly in the fast growing urban corridors, there was an increasing need to transmit greater quantities of electric power in the intercity network. The use of superconducting loss-free current-carrying track conductors to transmit power could at the same time be used to interact with superconducting coils on the vehicle to levitate a vehicle. The vehicle was designed to use four rows of superconducting coils, two on each side of the vehicle. The dual rows of coils were arranged so that each was canted downward into an inverted "v," thereby providing lift and guidance simultaneously. The major drawback to this system was the cost of the superconducting track conductors which was partially offset by the reduced heating losses in the power distribution system. Work on this approach was subsequently discontinued due to lack of Federal funding.

In the fall of 1971, a team consisting of MIT, Avco, and Raytheon developed the "Magneplane" concept. The Magneplane used superconducting coils mounted on the vehicle interacting with a continuous plate of aluminum mounted on the guideway to produce lift by magnetic repulsion. A 1/25th-scale model was demonstrated on a 122 meter (400 foot) track. Dynamic problems were experienced early-on in the test program; however, with the third model constructed, methods of dynamic control were developed.

In 1971, FRA initiated cooperative feasibility studies of high-speed maglev vehicles at Ford and SRI. These studies included a broad range of analytical and experimental developmental efforts for EMS, EDS and PMS systems as well as various options for guideway materials. A number of models were built for various experiments and tests, including a 4.2 meter (14 foot) vehicle weighing 0.5 metric tons (1,100 pounds). Along with other Federal research on high-speed maglev, this research was terminated in 1975.

MAGLEV DEVELOPMENT IN WEST GERMANY

In West Germany, development of contactless high-speed systems began in the late 1960s and early 1970s with the investigation into a variety of levitation and propulsion principles. Both magnetic levitation and air cushion suspensions were investigated, including a wide range of configurations. The air cushion was the first to be terminated.

After a detailed analysis of the technical and economic aspects of EMS and EDS technologies (1976-1978), the EMS system was chosen for development and the EDS system with its superconducting magnets was abandoned. The principal reasons given for choosing the EMS technology were: lower investment and operating costs, significantly less energy consumption, no stray magnetic fields (precluding the need to deal with biological effects of magnetic fields), no need for an additional takeoff and landing system, and applicability to the lower speed range of 300-400 km/h (186-248 mph). With the advent of higher temperature superconducting materials, the comparison was again made in 1987 with similar results.

Thus in 1978, the development concentrated on electromagnetic support and guidance with long-stator propulsion based on the Transrapid technology. The first public service demonstration of the Transrapid 05 (TR-05) was at the International Transport Fair in Hamburg in 1979. The first 21 km (13 miles) of the Emsland test guideway was completed by 1984 at which time testing of the Transrapid 06 (TR-06) was started. The facility was completed at the end of 1987. In 1989, Transrapid 07 (TR-07) was delivered, and December 18, 1989, achieved the highest speed to date for the Transrapid technology of 435 km/h (270 mph). As of 1989, over $1 billion (U.S.) has been spent on this development program.

In December 1989, the West German government approved the first Transrapid application, an 82 km route between Cologne/Bonn airport and Essen Central Station. As a first step, the link between Colgone/Bonn airport and Duesseldorf Airport will be implemented.

Figure I-2 shows the progress schedule for the Transrapid development technology.

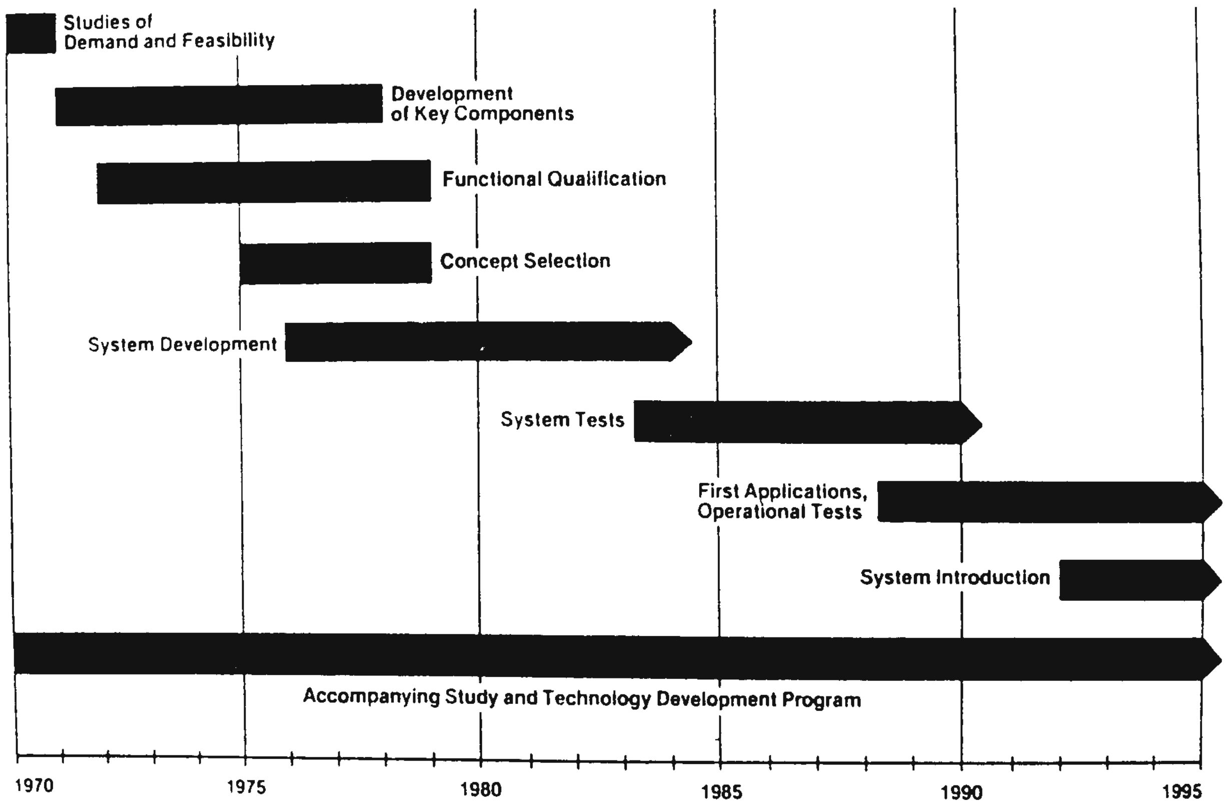


Figure I-2
Development of the Transrapid Magnetically Suspended
Transportation System in West Germany

The TR-06 shown in Figure I-3 is a two-vehicle train which can carry 196 passengers. Each vehicle is 27.4 meters (90 feet) long and weighs 59 metric tons (130,000 pounds). On December 12, 1985, this train achieved a speed of 355 km/h (220 mph).

The TR-07 shown in Figure I-4 is a two vehicle consist which can carry up to 200 passengers. On December 8, 1989, the TR-07 achieved a speed of 435 km/h (270 mph).

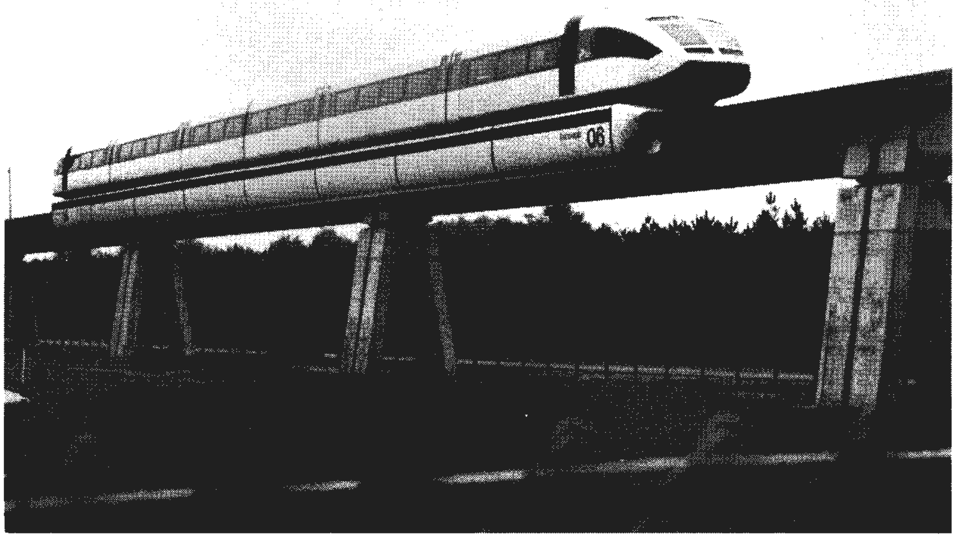


Figure I-3
Transrapid 06

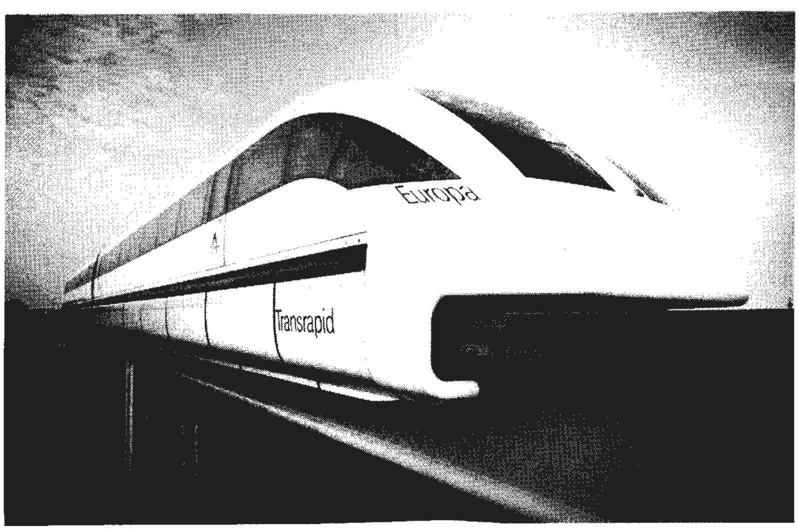


Figure I-4
Transrapid 07

M-BAHN Transit System

The development of the low speed M-Bahn transit system proceeded in parallel with that of the high-speed Transrapid system. The M-Bahn is a magnetically levitated Automated Guideway Transit (AGT) system designed for urban intra-city applications. It uses permanent magnets for the attraction-type levitation and long-stator linear synchronous motor (LSM) for vehicle propulsion. The design speed range for the M-Bahn is 40-80 km/h (25-50 mph). Figure I-5 shows a view of the M-Bahn system.

Figure I-5
M-Bahn

JAPANESE MAGLEV DEVELOPMENT

Japan has taken a broad programmatic approach since the beginning of its work on maglev development, choosing to develop several maglev concepts simultaneously rather than be restricted to one system. Extensive research is being conducted in both the superconducting (EDS) and electro-magnetic (EMS) maglev technologies.

Japan's maglev development began with experiments by the Japanese National Railway (JNR) using rotating wheels and scale models of vehicles on short linear test guideways. This work eventually led to the full-scale construction and testing of EDS superconducting vehicles--the ML500, MLU001, and MLU002. The ML500 was the first test vehicle to demonstrate the feasibility of high speed transportation using superconducting EDS maglev technology. In 1979, it achieved a speed of 517 km/h (320 mph) at the Miyazaki test track. Considerable advances in vehicle technology have been made since then. The prototype MLU002 shown in Figure I-6 illustrates the test configuration of the current superconducting maglev developed by JNR.

Government subsidies were provided to JNR to assist in the development of superconducting maglev. At the same time the superconducting train development was proceeding, Japan Air Lines (JAL) engaged in studies of electromagnetic suspension (EMS). The latter used the vehicle guidance concept initially conceived and developed by Krauss-Maffei A. G., Munich. Early test vehicles operated successfully at speeds up to 308 km/h (190 mph).

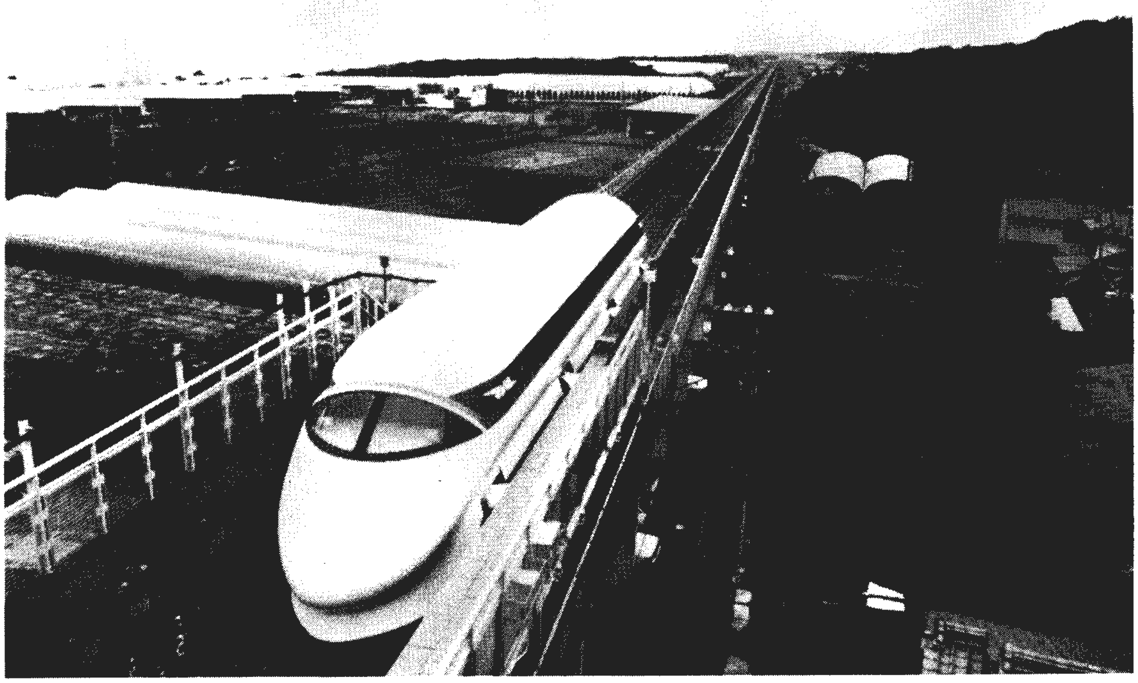


Figure I-6
MLU002 Japanese Maglev

Railway Technical Research Institute (EDS)

The JNR venture into maglev development began in the early 1970s and has since evolved into a major project to develop a superconducting Linear Train for high speed intercity travel. In 1987, JNR was privatized and became the "JR Group," which included six separate passenger railways. Maglev project responsibility was assigned to the Railway Technical Research Institute (RTRI), formerly a part of JNR organization. In addition to maglev, RTRI had other research and development responsibilities related to railroad operations in Japan. Last year, RTRI's budget was $100 million (U.S.). Government subsidies make up approximately 6 percent of RTRI's budget.

While not listed above, the Ministry of Transport (MOT) provides important leadership and overall program coordination. Key technical personnel from academia are granted freedom to pursue basic research in critical maglev areas. This cooperative venture of government, industry, and academia has been a major factor in Japan's steady progress in superconducting maglev train development.

Development milestones and future program plans are summarized in Figure I-7.

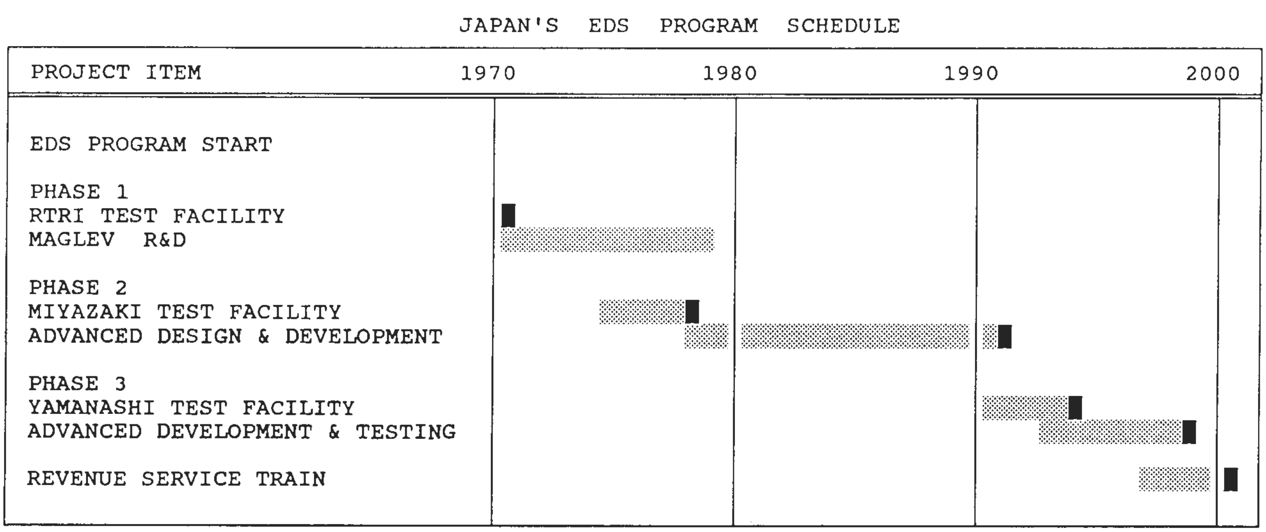


Figure I-7

High Speed Surface Transportation Corporation (EMS)

The HSST maglev program was initially under the direction of JAL. The decision to adopt EMS-type suspension by JAL was made based on a study of the applicability of various maglev technologies in an urban environment. (Elements of the HSST design used concepts initially conceived and developed by Krauss-Maffei A. G., Munich and subsequently licensed by JAL.) The current HSST maglev design uses wayside power pickup for all vehicles.

HSST Corporation took control and acquired all rights and technology from JAL in 1987. Under this reorganization, HSST Corporation provides project coordination, systems analysis, test and evaluation, but continues to receive important support from various technical departments of JAL. The principal participants in the HSST maglev development are: HSST Corporation, Japan Air Lines Co., Ltd., Sumitomo Electric Industry Ltd., Toyo Denki Seizo, K. K., Kyosan Electric Mfg. Co., Ltd, and the Takenaka Corporation.

Development milestones and future program plans are illustrated in Figure I-8. Only a decade and a half was necessary to reach a state of maglev commercialization. This rapid development was possible because of the already mature status of the technology (compared with the superconducting EDS approach) and the availability of considerable data from past research and development in short stator linear induction motors.

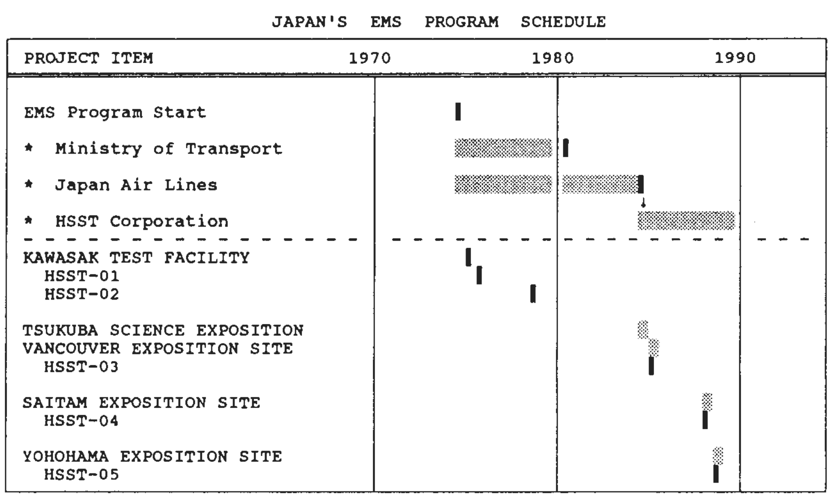


Figure I-8

The HSST EMS program calls for the development of four different revenue service maglevs having operating speeds between 100 and 400 km/h. All test vehicles have been limited to peak speeds under 100 km/h, except for the first test vehicle which used rocket boosters for added propulsion. This is not a basic limitation in peak speed for the short stator maglev. The short stator maglev is well on its way to being implemented at medium speeds (200-300 km/h).

The most recent HSST vehicle design is illustrated in Figure I-9 which shows the HSST-04 at the 1988 Saitama Exposition. A slightly modified version of this vehicle, i.e., the HSST-05 has been introduced into revenue service at the Yokohama Exposition Site.

Figure I-9
HSST-04

REFERENCES TO CHAPTER I

1. J.R. Powell, G.R. Danby, "High Speed Transport by Magnetically Suspended Trains," ASME 66-WA/RR-5, November 27, 1966.

2. Source: L. Johnson, et.al., "Maglev Vehicles and Superconductor Technology: Integration of High-Speed Ground Transportation into the Air Travel System," Argonne National Laboratory Report ANL/CNSV-67, April 1989.

3. H. Weh, "Magnetic Levitation Technology and its Development Potential," 11th International Conference on Magnetically Levitated Systems and Linear Drives: Maglev '89, Yokohama, Japan, July 7-11, 1989, pp. 1-9.

4. Rhodes, R.G. and Mulhall, B.E., "Magnetic Levitation for Rail Transport," Oxford University Press, New York, 1981.

II. DESCRIPTION OF CURRENT TECHNOLOGY

This chapter will briefly describe the technical aspects of current maglev systems that have reached prototype stage plus American maglev system concepts that are at varying levels of development. Current system parameters and recent innovations will be highlighted and opportunities for further improvement will be identified.

The maglev concepts discussed in this chapter cover the range of new system development from systems that exist only in paper studies, to systems that have advanced to scale model tests, to systems undergoing full scale prototype testing, to systems ready for commercial service. Of necessity, the following discussions will offer different levels of detail that reflect the different stages of development for each of these systems.

The information provided in this chapter is the information and data that the designers, manufacturers and promoters of these various system concepts have made available. The limited time and funds available for this study did not permit an independent evaluation by FRA of the information contained in this chapter and therefore FRA cannot vouch for its reliability. The detailed feasibility studies that FRA proposes to undertake in cooperation with the U.S. Army Corps of Engineers and the U.S. Department of Energy during fiscal years 1991 and 1992 will include an independent assessment of the state of maglev development and the opportunities for American industry to play a role in the further development of this technology.

TRANSRAPID SYSTEM

The Transrapid TR07 Maglev System is an electromagnetically suspended EMS system designed for speeds between 400 and 500 km/h (249 - 311 mph). It is a small gap, 8 mm (0.315 in), system which uses attractive magnetic force technology for suspension as well as guidance. For propulsion, it uses a long-stator synchronous electric motor which permits operation on grades of up to 10 percent. The vehicle mounted suspension electromagnets are attracted to the iron core or stator packs of the guideway mounted linear long-stator motor. It uses a primary suspension system which closely follows the guideway and a mechanical air bag secondary suspension system for improved ride quality. Some components, such as air compressors, are shared between vehicle sections with exact layout depending on consist configuration [1][2][3][4][5].

Table II-1
Transrapid TR 07 System Characteristics

System Characteristics - TR-07	metric	U.S. equivalent
Vehicle section length	25.5 m	84 ft
Vehicle width	3.7 m	12 ft
Vehicle height	4.06 m	13 ft
Vehicle section weight	45 t	50 short tons
Payload wt per vehicle sect.	8 t	9 short tons
2 Vehicle Consist - current configuration at Emsland		
Empty weight	90 t	100 st
Payload Weight	16 t	17.5 st
Support and guidance	19.5 t	21.5 st
Vehicle section capacity	72 to 100 passengers	
Operating speed	500 km/h	311 mph
Operating speed through turnout	200 km/h	124 mph
Max operational acceleration	1.00 m/s^2	3.28 ft/s^2
Average acceleration	0.60 m/s^2	1.97 ft/s^2
Nominal air gap	8 mm	0.315 in
Guideway - steel and prestressed concrete		
max grade	10%	1:10
max superelevation	12%	
min radius of curvature	6,530 m (500 km/h)	21,425 ft
	4,180 m (400 km/h)	13,714 ft
min vertical radius of curvature (500 km/h)		
positive (for valleys)	19,290 m	63,291 ft
negative	38,580 m	126,581 ft
min vertical radius of curvature (400 km/h)		
positive	12,350 m	40,518 ft
negative	24,700 m	81,037 ft
Beam length	25 m	82 ft
Weight (steel)	35 t	38.5 st
Weight (concrete)	330 t	363.5 st
Stations	on-line	
Switches	wayside steel-bending	
Operational control	automatic block control	
Energy consumption at 400 km/h		
total	~ 60 Wh/seat/km	
levitation	~ 4 Wh/seat/km	
Environmental emissions		
Magnetic fields at seat level	.01 to .03 gauss	
Magnetic fields at floor	.1 to 1 gauss	
earth's magnetic field	.5 gauss	
Energy equivalent noise level at 400 km/h and 25 m distance	84 dB(A)	

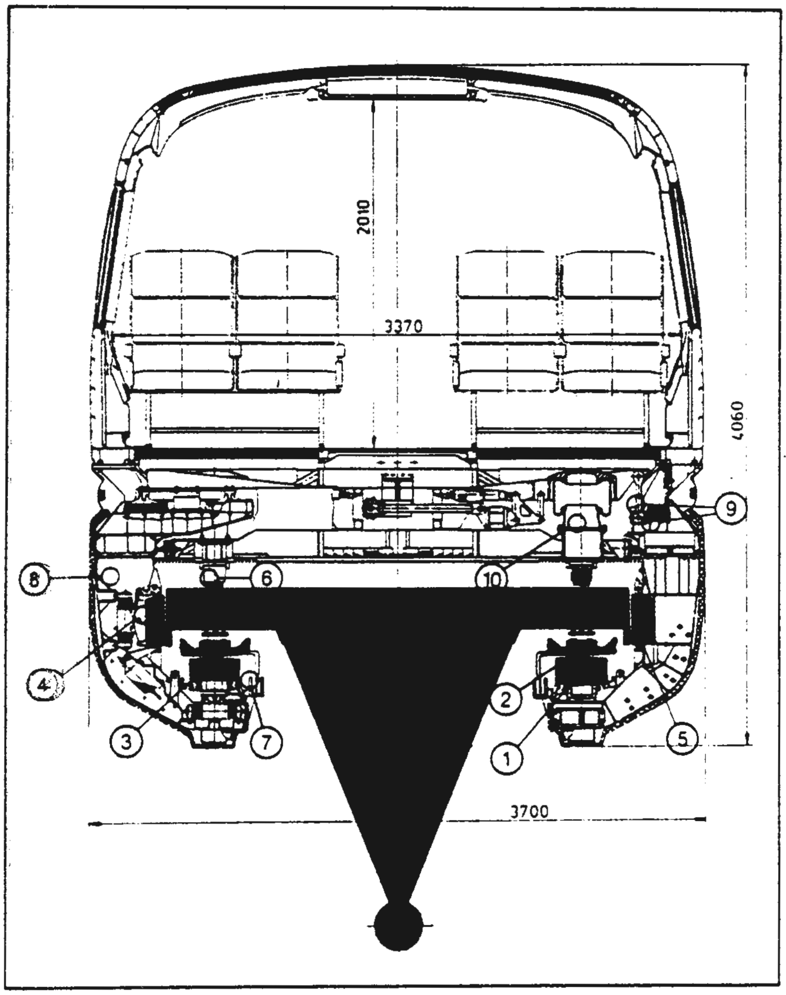
Vehicle

The Transrapid TR07 vehicle uses a contactless electromagnetic suspension system for support and guidance. Propulsion is supplied by a pair of linear, long-stator electric motors which directly convert electrical energy into vehicle motion. These linear motors are supplied by wayside power thereby obviating the need to transfer large quantities of electrical power to the vehicle. The electrical energy needed to meet the vehicle levitation, control, and environmental conditioning (hotel) functions is supplied by a linear generator which transfers electrical energy and charges on-board batteries. These batteries provide a certain level of stored power should wayside collection fail.

The vehicle configuration is shown in Figure II-1 [6]. The vehicle is wrapped around the hatted triangular guideway (variant of a "T" configuration) section so that there is no possibility of derailment under normal conditions. Severe damage would have to occur to the vehicle or track before it would be derailed. Therefore, this positive envelopment of the track provides a high degree of passive safety.

Sixteen suspension and twelve guidance electromagnets are longitudinally distributed uniformly along the vehicle section. These electromagnets apply uniformly distributed reaction loads to the guideway. The longitudinal flux suspension electromagnets are dual functioned and in addition to suspension provide the reactive element on-board the vehicle which is excited by the active element of the long-stator motor. The long-stator motor is installed continuously along the track and consists of stator packs and three-phase cable windings [7]. Feedback to control the air gap between the support magnets and the stator packs is provided by a series of sensor packs [8].

Contactless lateral guidance is provided by vehicle mounted electronically controlled guidance magnets [9] which react against steel rails along the side of the guideway. In the event of linear motor failure, adequate braking force is provided by the on-board eddy-current brake [10]. Support skids are used for the final stage of emergency stopping (where eddy current brakes are no longer effective or if the fail safe emergency hover system is disabled. Power is provided during emergencies from on-board batteries.



① = Support magnet (longitudinal flux magnet) / ② = Stator pack with propulsion winding / ③ = Linear generator windings / ④ = Guiding magnet (cross flux magnet) / ⑤ = Eddy-current brake magnet (longitudinal flux magnet) / ⑥ = Support skids / ⑦ = INKREFA sensor (vehicle location) / ⑧ = Levitations bogies / ⑨ = Cabin suspension / ⑩ = Pneumatic spring

Figure II-1
Configuration of the Transrapid Vehicle

The TR07 vehicle body was designed to have high structural stiffness per unit weight, low aerodynamic drag and noise, heat and fire protection, a maintainable design, and a low manufacturing cost [11][12]. The coach body uses a combination of aluminum truss stiffened formers joined together by bonded sandwich plates to form a stiff underfloor structure, light aluminum alloy sides, and fiberglass sandwich shells for the roof, nose, and rear wall.

Doors are located at the extremes of the vehicle structure for increased stiffness. They are single-wing, swinging-sliding doors with inflatable seals. To meet passive fire protection standards, the interior furnishings meet the 1988 Air Transport Standards (5 minute fire at 1100°C without the emission of harmful fumes - at 120°C on the outside of the interior vehicle cladding to protect the vehicle structure) [13].

Support and Guidance

The support and guidance system of the TR07 consists of a primary suspension system which closely tracks the guideway and a secondary mechanical system which isolates the guideway tracking for increased ride comfort. The primary suspension system is characterized as stiff, whereas the secondary is soft. The support and guidance system is made up of a series of eight magnets on each side of the vehicle section which are attached to levitation bogies (see Figure II-2) [14]. The magnets are hinged to allow articulation in the vertical and horizontal planes. The 16 secondary level-control pneumatic springs are mounted between the levitation bogie and the vehicle.

The function of the magnet feedback control loop shown in Figure II-3 is to maintain the mechanical distance between the magnet and the reaction rail at 8 mm (0.315 in). The forces of magnetic attraction acting in the air gap between the magnet and the reaction rail are varied to accommodate changing loads and geometries.

The TR07 support and guidance magnets are designed for a 10:1 magnetic force to magnet weight ratio. A newly developed method of field coil manufacture resulted in improvements in thermal behavior, less magnetic leakage, improved reliability and produced a 20 percent increase in the force to weight ratio.

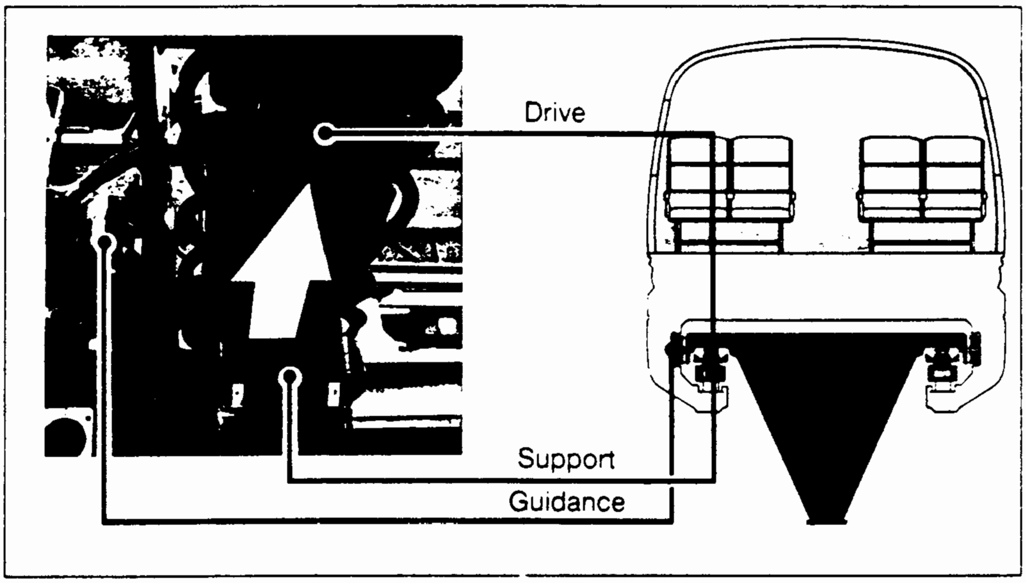


Figure II-2
Cross Section of the Support and Guidance System

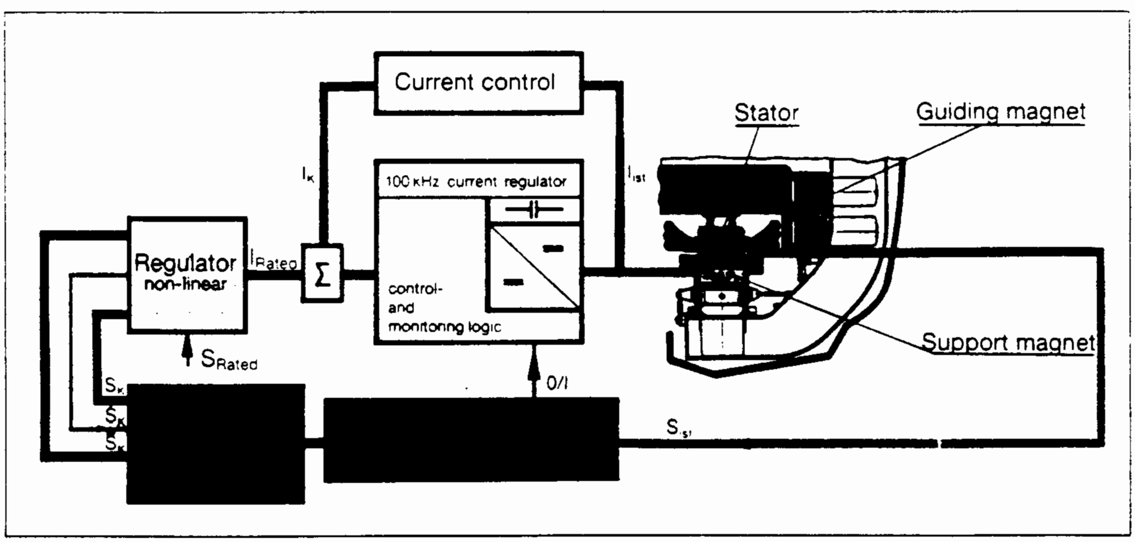


Figure II-3
Magnet Air Gap Control Loop

Guideway System

The guideway system consists of the beam, main supporting structure and functional components which include the long-stator motor, guide rails, and the sliding surface. The guideway system accounts for a substantial portion of the capital cost of Transrapid. Based on a study of a proposed line between Los Angeles and Las Vegas, it represents some 63 percent of the capital cost [15]. Therefore, it is important to minimize the guideway cost. This can be achieved by automating the manufacture, installation, and assembly process. Computer integrated manufacture (CIM) technology integrates the design with the manufacturing process.

The guideway beam is fabricated from either steel or prestressed concrete, and it is supported on concrete columns. To-date only zero settlement designed footings have been employed. Switches are fabricated from steel. They use hydraulic or electric actuators to bend a special steel guideway beam from track-to-track.

The triangular cross supporting section is formed by a steel cover plate and two inclined plates. The lower seamless tubular profile has been replaced by a simple web. Solid diaphragms are used at bearing points. Triangular cross frames are used in beam fabrication. A guideway cross section is shown in Figure II-4 [16].

A key functional component of the guideway system is the iron-cored, long-stator linear motor which is the prime mover. It permits the direct transmission of thrust and deceleration forces without contact and it is independent of friction. This friction independence allows high grades to be negotiated. In turn, good grade climbing ability allows considerable flexibility in route planning and alignment which results in reductions in the capital costs.

The other functional components are fastened to the fabricated beam only after it has been measured and actual dimensions are transferred to an automatic numerically controlled drilling and screw carriage machine which accurately drills fastening holes and installs the functional components on the guideway beam. The lateral guidance rails are attached by welding the left and right rails simultaneously and synchronously to eliminate distortions. Thus, true position dimensions determined from three-dimensional routing data are compared to actual dimensions of the beam and this positioning data is transferred to the assembly machine for accurate location of the functional components. The assembled guideway beams are then measured again and the data stored in a computer for accurate installation of the beam on site. This process of automatic fabrication greatly reduces the cost of labor involved in the fabrication process.

Superelevation and radius of curvature are directly transferred from the computer aided routing model (i.e., route alignment and guideway design) to an automatically controlled numerically controlled (NC) cutter which cuts the plates. The plates are then assembled in a large fixture capable of rotating the 35 metric ton beam and welded automatically by robots. Heating during the welding process is carefully controlled to minimize distortion.

<u>Switch</u>

Transrapid uses a wayside articulated switch for transfers from one guideway to another. The switch uses a bending beam design to connect an off-line guideway with the mainline. The steel beam is a narrow rectangular box girder 149.64 m in length [17]. The beam is bent to the turnout setting by 8 hydraulic actuators set transversely on columns 18.5 m apart. The radius of curvature at the turnout setting is 2,300 m. This permits a turnout speed of 200 km/h (124 mph) with a lateral acceleration of 1.5 m/s^2 (4.92 ft/s^2) and a jerk of 5 m/s^3 (16.4 ft/s^3). Permissible speed through the setting is 400 km/h (249 mph). A safety system removes power from the previous power section until the beam is in a safe-locked position. Figure II-5 shows the basic switching concept.

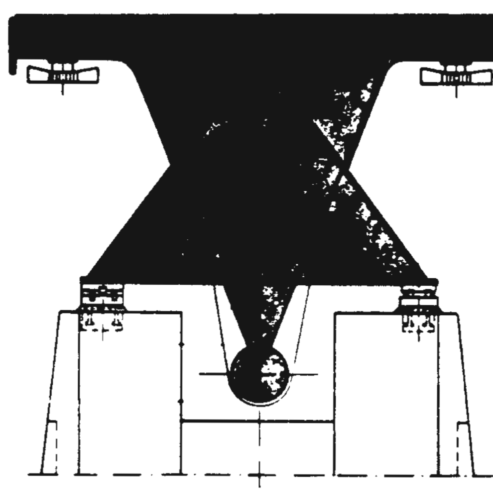


Figure II-4
Guideway Cross Section

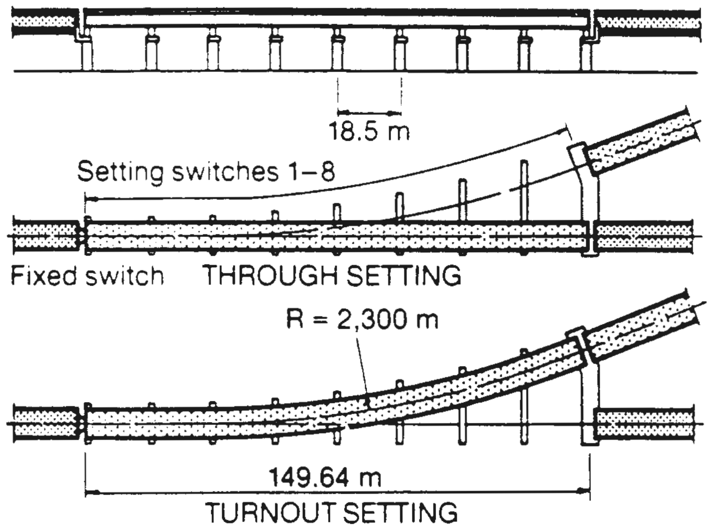


Figure II-5
Transrapid Switch

Operational Control

A block controlled, scheduled, slot reservation system is used for operational control. Operational control functions are spatially distributed to the vehicle, to decentralized wayside, and to centralized wayside. The vehicles are automatically controlled by varying voltage and frequency of propulsion power. Operational control is achieved by wayside control of the propulsion system. Power is switched on only in occupied track sections.

The high speed of the Transrapid maglev system requires full automatic control. At 500 km/h the vehicle is traveling at 455 ft/s. Any delay in response at these speeds due to human indecision or inattentiveness could end in disaster. Therefore, human control, if used, would require long headways between vehicles and long blocks to allow for the longer stopping distances.

TR07 uses full automatic control which is spatially distributed at three hierarchical levels: on-board, decentralized wayside control, and centralized wayside control. Data is acquired, transmitted, and processed at all three levels. Figure II-6 shows the basic configuration of the operational control system [18].

The on-board vehicle functions are vehicle location, vehicle protection and control, and fail-safe data and voice transmission with the wayside. The vehicle location functional element determines the vehicle position, travel direction, speed, acceleration, and braking capability. The vehicle protection and control functional element processes vehicle detection data, the status, and error messages, and monitors on-board equipment including the emergency braking subsystem.

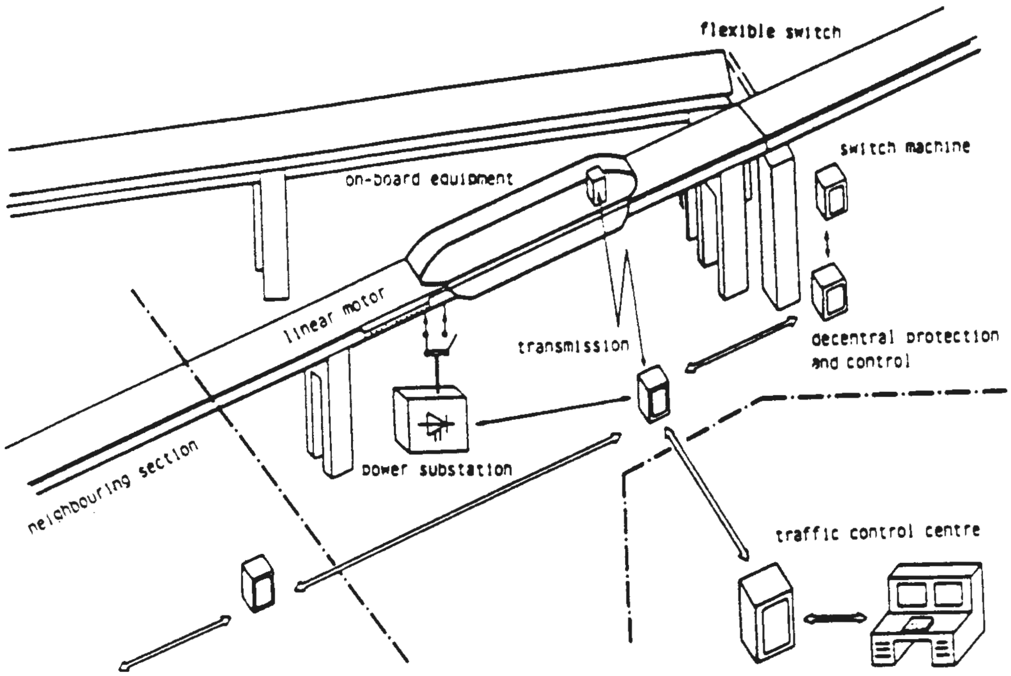


Figure II-6
Basic Configuration of Operational Control System

Longitudinal speed control is executed by means of the long-stator, linear propulsion system which is arranged in blocks or sections at the wayside. Particular importance is attached to the decentralized wayside equipment because of the propulsion concept and the high operating speed which together warrant fully automatic operation. This decentralized wayside equipment provides the functions of route control, vehicle control, station supervision and control, and communications. The route control functional element sets, locks, supervises, and releases routes. The vehicle control functional element calculates the setpoint for longitudinal position, velocity, and acceleration and compares the setpoint values to actual position and velocity.

Separate and alternative power feeding of the left and right long-stator drive sections are implemented to assure fail-safe vehicle control. One vehicle control unit is assigned to one power supply substation area. A vehicle can be fully braked to a standstill within a single substation section, in case the next section is occupied. Substation section lengths are between 10 - 15 km.

Traffic control operations are performed centrally at the traffic control center where operational status is displayed, timetables are revised and stored, and execution of decisions concerning system operations are made. For example, decisions are made about which vehicles will be put into service and which time table revisions will be used to clear disturbances. In the event of major problems, the central operator can take preplanned measures to correct or bypass faults via timetable revision.

Environmental Effects

Measurements were made of electromagnetic compatibility at the Transrapid Test Facility (TVE) in Emsland on the TR06 vehicle to determine if magnetic leakage or electromagnetic fields presented any limiting conditions. Two questions were of significance: (1) would electro-magnetic interference (EMI) and leakage flux interfere with telecommunications; and (2) would passengers with pacemakers in the coach be at risk? The German Federal Post Office in conjunction with the Office of Telecommunication Technology developed a set of tests and made measurements over a range up to 400 Hz. Magnetic vehicle specific emissions were only detected within a frequency range of 25 to 70 Hz at levels clearly below the limiting values recommended by DIN Standard 57871 (see Figure II-7).

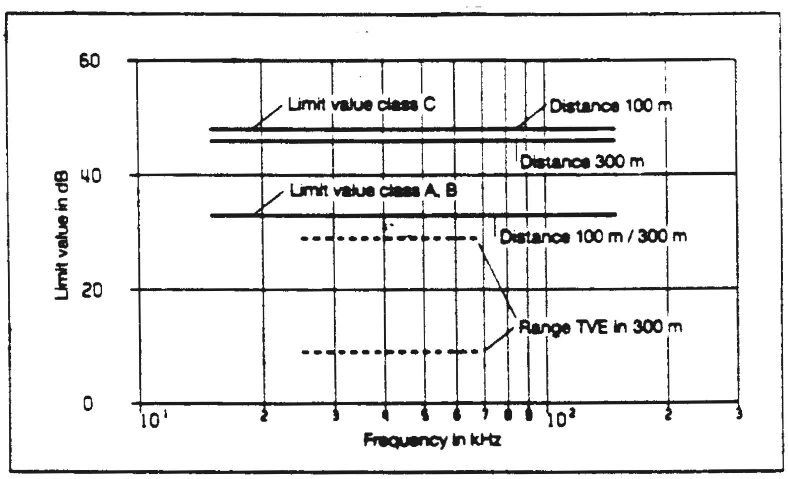


Figure II-7
Limiting Values of TVE Electromagnetic Noise Values
Compared to DIN 57871 Standard

Measurements of the magnetic field leakage as a function of frequency at the floor of the TR06, at the seat level, and at passenger chest level have been made at Emsland. They are all relatively small - of the order of Earth's magnetic field. Because the frequencies of these relatively small leakages are mostly below 150 Hz, effects on pacemakers are highly unlikely because possible induced input voltages are below the limiting value of 1 mV. In addition, two different pacemakers (Type Dialog 718, Siemens Elma and AFP 283, Siemens Pacesetter) were instrumented and tested on the floor and seat level of the TR06 with no impairment of the pacemaker function. Thus, passengers with pacemakers run no risk in Transrapid [19][20], according to the manufacturer.

The inductive effect of the weak magnetic leakages on telecommunications or signal lines in free space near the guideway was also not a problem. This is due to shielding on the power supply cabling.

In addition, Transrapid does not produce significant noise levels (84 dB(A) at 400 km/h and 25 m distance). Because of the contactless suspension no mechanical running noises are produced. Only aerodynamic noise is generated. Furthermore, because of the lighter uniformly distributed load on the guideway, vibrations imparted to the earth are significantly reduced over high-speed, heavy-rail, point load, wheeled systems [21]. Not only is the earthshake effect reduced, but the effects on column settlement is reduced.

Japanese EDS Maglev System Description

The Japanese superconducting train (Chuo Linear Train) being developed under the auspices of the Railway Technical Research Institute (RTRI) is designed to transport 75,000 to 100,000 passengers (each way) per day between Tokyo and Osaka. Traffic forecasts for the year 2000 show that the present Tokaido Shinkansen will be unable to meet the increased traffic demand at that time [22]. The high speed superconducting train is seen as the most practical means for providing this additional transportation capacity required in the next decade [23].

Over the last years, RTRI has engaged in engineering research in many areas, including component development, and system applications. More recently the system-oriented projects have received greater attention with particular emphasis on power engineering and power distribution systems. Development efforts continue on improving vehicle ride quality, new magnetic suspension and guidance and aerodynamics for vehicle braking.

Japan's superconducting train program is proposed for expansion to include three major maglev facilities. The current Miyazaki Test Facility, used throughout the years for experimental testing of the superconducting train, will continue to remain as a maglev test facility. When necessary, the test track will be retrofitted to accommodate the special needs of future test requirements.

A site west of Kofu in the Yamanashi prefecture has been selected for the construction of a 43 km test facility. This facility, referred to as the Yamanashi Test Facility, will be the main one for future tests of the revenue service maglev, the "Chou Linear Train." The requirement for the new test facility became apparent during the test runs of the MLU002 at Miyazaki where the short track distance limited the experimental testing at high speeds. Total construction cost including equipment and real estate is estimated at $350 billion yen ($2.5 billion) U.S. [24] The Yamanashi Test Facility will be eventually incorporated into the 500 km maglev line connecting Tokyo and Osaka.

SYSTEM DESCRIPTION

Table II - 1 lists the design specifications for the revenue service train [25]. The revenue service train includes a 14-car consist with 950 passenger capacity and has a peak speed of 500 km/h (311 mph).

Because of the high power demands of the superconducting train, the utility source power must have a capacity of about 50 megawatts (peak) [26]. Power substations are required at 30-50 km (18-31 miles) intervals over the length of the guideway to power and control up to 10 trains operating simultaneously over the track.

Yamanashi Test Facility

The future Yamanashi test facility will be the primary facility for testing the revenue service train. The test trains will be of two types: a 3-car train (70 m, 230 ft), and a 5-car train (120 m, 394 ft). Additional test facilities will include power stations, tunnels, train yards, bridges, and other structures [27].
A sketch of the test track layout is shown in Figure II-8. The maximum track gradient will be 4 percent (4:100) and minimum track radius of curvature, 8 km.

The facility will include a transverse switch used for switching between the dual tracks (shown in Figure II-9). The switch length is 70 m (230 ft), and constructed of six articulated sections supported on wheels which allow the mechanism to move horizontally from "through-line" to "off-line" positions. Vehicles negotiating the curved switch at high speeds are constrained laterally by guidance wheels attached to the vehicle. Trains entering the off-line switch are limited to speeds of 70 km/h (44 mph).

Table II-2
Specifications for latest Prototype Design
Chuo Linear Train

	Metric	U.S. Equiv.
System Operational Parameters:		
Cruise velocity	500 km/h	311 mph
Liftoff velocity	100 km/h	62.5 mph
Average acceleration	0.1g	0.1g
Maximum grade	4%	4%
Revenue Service Train:		
Number of cars	14	
Length	315 m	1008 ft
Mass	270 t	297.5 tons
Seating Capacity	950	
Vehicle:		
Length	28 m(end)	89.6 ft
	21.6 m(mid)	69 ft
Width	2.8 m	8.96 ft
Height	2.65 m	8.48 ft
Mass	27 t(end)	29.7 tons
	18 t (mid)	19.8 tons
Superconducting Magnet:		
No. of SC coils	4	
Length	2.2 m	7.04 ft
Width	0.5 m	1.6 ft
Pitch	2.7 m	8.64 ft
Magnetomotive force	700 kA	
Levitation Ground Coil:		
Length	0.6 m	1.96 ft
Width	0.3 m	.98 ft
Pitch	0.9 m	2.95 ft
Propulsion/Guidance Ground Coil:		
Length	1.5 m	4.92 ft
Width	0.6 m	1.97 ft
Pitch	1.8 m	5.90 ft

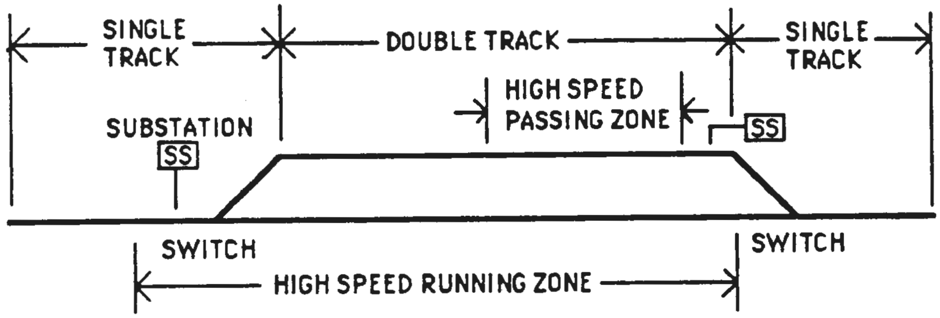


Figure II-8
Yamanashi Test Track Layout

Figure II-9
Maglev Transverse Switch

Superconducting Magnet Design

The revenue service SCM design has a coil length of 2.3 m (compared with 1.7 m for that used on the MLU002) and a pole pitch of 2.7 m. The new SCM design reduces the thickness of the winding and cryostat which allows the SCM to be positioned closer to the track coil for the same vehicle/guideway clearance. The reduction of the SCM mass from 950 kg to 895 kg and heat leakage into the inner vessel of the magnet are two major improvements in magnet design. Table II-3 lists the SCM design specifications [28].

Table II-3 Superconducting Magnet Specifications

Item	Specification
Composition	1 coil/cryo x 2
Dimension (pair)	5.18 m(L)x 1 m(H)
Magnetomotive Force	700 kA
Copper:SC ratio	1:1
SCM mass	895 kg (1969 lbs)
Refrig. Capacity	5 W at 4.4 K
Maglev force/SCM weight	10
Heat leak/Maglev force	0.03 W/kN (.134W/lbf)

The heat leakage into the inner vessel is 3 watts which is a considerable improvement over earlier designs given that the magnet coil is substantially larger. This reduces the weight of the on-board helium cryocoolers required to maintain the windings at their operating temperature as well as on-board electric power consumption.

Figure II-10 illustrates the progressive improvement achieved in reducing the SCM weight and heat loss over two decades [29].

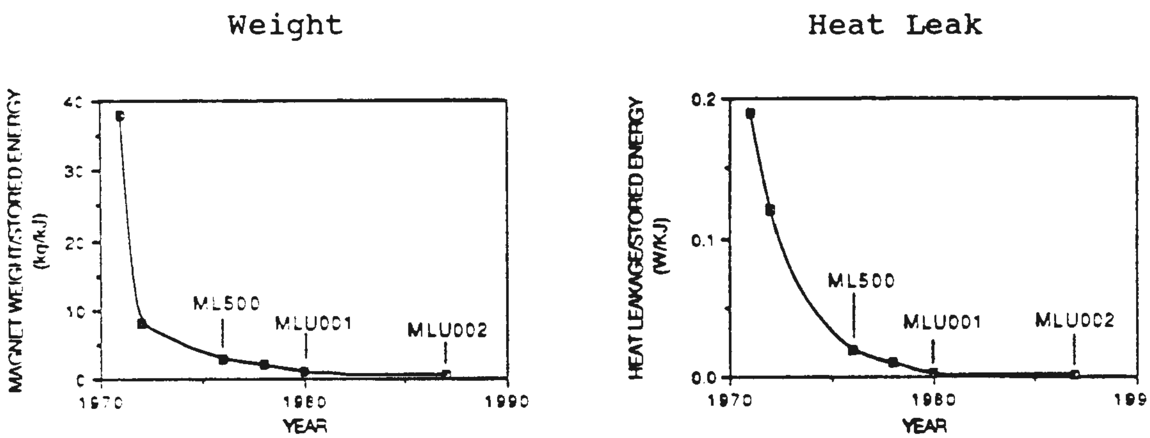


Figure II-10
Superconducting Magnet Design Improvements

<u>Cryogenic System</u>

The cryogenic system uses a closed helium gas system and an on-board Claude cycle refrigerator. The purpose of the cryogenic system is to keep liquid helium on-board for a long period with no loss of helium. The refrigerator serves as a combined liquefier-refrigerator with low power consumption. The capacity of each refrigerator is 5.5 W at 4.2 K [30]. Under normal operation, the heat load (loss) is about 3 W.

The complete cryogenic system includes both an on-board vehicle system and a backup ground system. During normal operations, the on-board system is independent of the backup system.

RTRI has developed an improved persistent current switch [31] for better control of the normal-to-superconducting state transition. The new high resistance switch (100 ohms) reduces the amount of helium vapor generated during energizing/de-energizing of the SCM and thereby increases the SCM operating efficiency.

Null-flux Suspension

RTRI has announced the decision to use sidewall null-flux levitation as a substitute for the normal repulsive levitation based on horizontal-type ground coils [32]. A sketch of null-flux using upright, square figure-eights type coils is shown in Figure II-11.

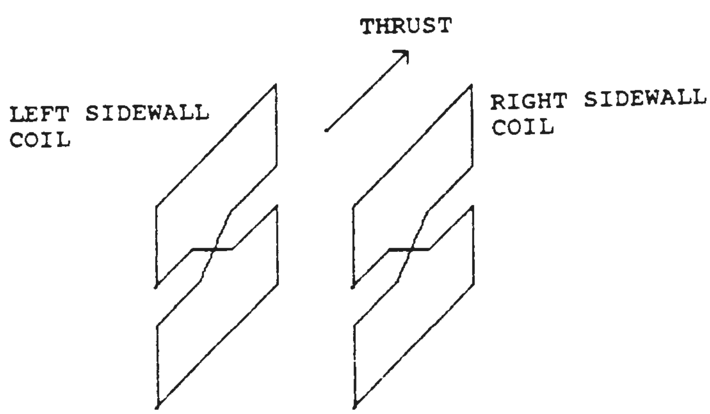


Figure II - 11
Sketch of Null-Flux Configuration

The null-flux coils are mounted on the guideway sidewalls in front of the propulsion coils [33]. The sidewall null-flux suspension will offer tighter suspension, lower vehicle lift-off speed, and a higher lift-to-drag ratio than the normal repulsive force system. However, the tighter suspension may produce a poor ride quality (as verified by tests conducted at Miyazaki using a 40 m section of retrofitted guideway) and can necessitate the use of a secondary suspension system to improve ride quality. A summary of the vertical and lateral suspension stiffness constants for null-flux and normal repulsive force type suspensions is given in Table II-4.

Table II-4 Vertical/Lateral Stiffness Constants

	Vertical Stiffness meganewtons/m 100km/h	Vertical Stiffness meganewtons/m 500km/h	Lateral Stiffness meganewtons/m 100km/h	Lateral Stiffness meganewtons/m 500km/h
Sidewall suspension	3.82	7.05	0.19	0.15
Bottom suspension	2.7	2.7	1.9	3.8

Aerodynamic Braking

RTRI has made important progress in the use of aerodynamic braking for supplementary braking of the maglev. Since a vehicle travelling at high speed experiences a large wind resistance, this resistance or drag force can be used to decelerate the maglev vehicle. Figure II - 12 shows the increased braking produced by aerodynamic drag for different sizes (areas) of braking panel as expressed in terms of the drag coefficient. The data was measured with the MLU001 at speeds up to 350 km/h.

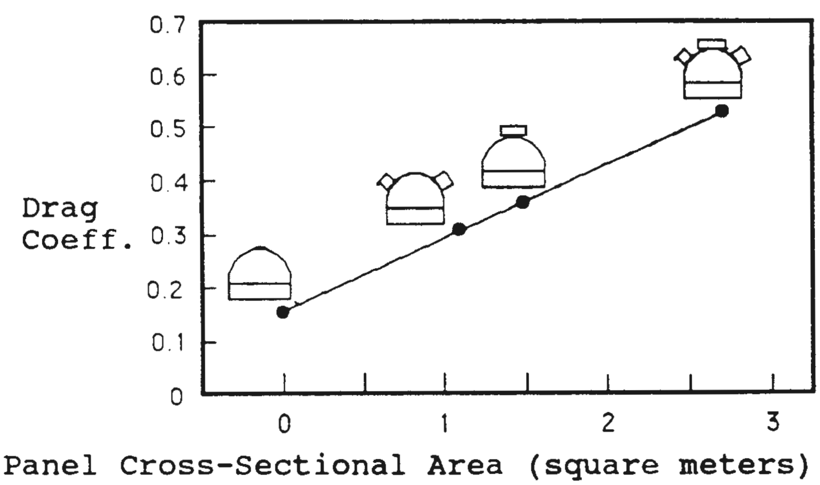


Figure II-12
Drag Coefficient for Different Brake Panels

Under emergency braking conditions (regenerative and backup dynamic brake failure), the aerodynamic brake would be deployed at 500 km/h and the emergency friction brake applied below 350 km/h. With no aerodynamic braking (but with friction brake applied below 350 km/h), the stopping distance is approximately 18 km (11.3 miles). With aerodynamic braking (4 m^2 brake panel area), the corresponding braking distance is just under 6 km (3.8 miles).

STATUS OF SELECTED EDS DESIGN ISSUES

The Japanese have made progress in a number of areas in improving the efficiency of their "linear train." The progress varies by area and by the pace of the progress. The status of that progress is briefly outlined below.

Vehicle Design

The new vehicle body design minimizes sectional area and uses lightweight materials to limit vehicle mass. Body construction uses carbon-fiber-reinforced-plastic (CFRP) [34] at the fore and aft ends of the vehicle and aluminum alloy at the vehicle mid-section. Vehicle mass will be reduced by 25 percent over the current MLU002 model.

SCMs will be located over the bogies. This will achieve two benefits: (1) it allows the vehicle passenger cabin to be lowered and thereby reduce the vehicle sectional area and aerodynamic drag; and (2) it reduces the level of magnetic field in the passenger cabin by removing the source field (SCM) from the immediate region of the cabin[35]. These benefits are offset by the increased point loading of the guideway due to the concentration of magnet mass at the bogies and the stronger vehicle structure required.

The aerodynamic drag force of the new revenue service train (14 cars, 7.0 m^2 cross section) travelling at 500 km/h was estimated at 170 kN in the open and 204 kN in a tunnel (Shinkansen type tunnel)[36]. On a per car basis, this is equivalent to 12.1 kN per car, a remarkably low drag force compared with similar drags reported for other high speed maglevs. It is reported that the drag force can be further reduced (10 percent) by increasing the width of the train and reducing the length of the train, keeping passenger load constant.

Maglev Safety and Health Issues

Maglev operational performance is critically dependent on maintaining the magnet in the superconducting state during operation. A sudden transition to the normal state (transition from zero resistance to high resistance state) could generate heat which could melt the magnet conductor resulting in permanent damage.

Status of Progress

High magnetic field levels in the passenger cabin remains a potential safety issue for the SC train. Attempts to assess the health risk is clouded by the lack of standards on what constitutes an unacceptable level of magnetic field for human exposure. Generally, fields in the 5-20 gauss range have been considered to impose minimal risk, but the difficulty of confirming this leaves the issue unresolved. Studies by the Japanese National Circulatory Medicine Laboratory showed that Type DDD pacemakers exhibited malfunctions at 11 gauss and recommended that individuals using pacemakers not be exposed to magnetic fields in excess of 3-5 gauss [37], while others set this limit at 1 gauss [38]. Still others state that setting the upper limit of allowable field strength at 5 gauss [39] is unacceptable from an engineering standpoint.

RTRI believes the revenue service vehicle design will effectively eliminate the magnetic field safety issue. Magnetic shielding will be placed in the immediate region of the bogie to protect the vehicle occupants from high fields. The final word on this important issue will likely await testing of the future revenue service vehicle.

Power Distribution and Control

The new service will require utilities with large power capacity. Estimates of the peak power demand vary from 27 MW in flat open areas to 60 MW in areas with grades and/or tunnels. RTRI estimates the high speed superconducting train will require about three times the electrical power needed by a train on the Tokaido Shinkansen.

Table II-5 lists the estimated power and energy consumption (measured at the substation input from the utility) for the "Linear Train" (14 cars) for a trip distance of 400 km (312 miles) and passenger loading of 900. Average energy consumption for the 500 km trip (with 50 percent in open and 50 percent in tunnel) is 40 MWh or 90 Wh/seat-km. This compares with an estimated energy consumption for the Tokaido Shinkansen of 30 Wh/seat-km at 220 km/h[40].

Table II-5. Maglev Power and Energy Consumption

	Open	Tunnel
Power demand	27 MW	60 MW
Energy Consumption	55 Wh/seat-km	125 Wh/seat-km

Assumptions:
Open: Drag force - 150 kN
Tunnel: Drag force = 202 kN; 4 percent gradient (4:100)
LSM efficiency - 90%; Converter efficiency = 95%

High capacity power converters (peak rating 100 MVA) are also required. RTRI is studying two types of power converter, the first using cycloconverters to generate the variable frequency power for the guideway propulsion and the second using converter-inverters for the variable voltage, variable frequency power. RTRI favors the second alternative because of its increased operational flexibility. Unfortunately, the converter-inverter requires higher power GTO (gate-turn-off) inverters than are presently available.

A major concern associated with the high power requirements of the superconducting train is the generation of electro-magnetic interference (EMI) as the train passes from one feeder block to another. This can also cause line voltage fluctuations, particularly if the short circuit capacity of the utility is small. RTRI is actively pursuing solutions to this problem[41].

Vehicle Stability

Vehicle travel around curves, and up and down hills can cause the maglev to experience unequal forces in fore and aft sections and result in yawing, pitching and bouncing. A destabilizing side force results when the vehicle negotiates a curve due to the increased drag force on the side closer to the guideway [42]. Similarly, a vehicle entering an incline experiences a destabilizing drag force due to the increased drag force on the fore section which is closer to the guideway horizontal surface. High speed tests have not been run on guideways with curves and changing track gradients so that the magnitude of this instability problem is not known.

Maglevs passing at high speeds will be subjected to sudden side forces resulting in vehicle roll. Non-linearity of the levitation force can excite bouncing and pitching oscillations[43]. Japanese scientists are aware of these instability problems and are conducting studies to assess them, including the development of active suspensions which will help to stabilize the vehicle[44].

To improve stability, RTRI intends to use sidewall null-flux suspension as an alternative to the normal repulsive force (horizontal ground coils) suspension. Sidewall null-flux levitation has important advantages and some disadvantages. The advantages include increased magnetic coupling between the SCM and sidewall ground coils, stiffer suspension, and lower energy loss. The stiffer suspension could also be a disadvantage and give poor ride quality, as confirmed from recent tests at Miyazaki with a retrofitted section of guideway with sidewall null-flux coils. RTRI is currently developing a new secondary suspension system to improve ride quality.

Reports of the superconducting train ride quality are subjective and vary depending upon the test conditions at the particular time. A Japanese survey taken in 1988 of 4,400 passengers who rode the MLU002 reported its ride quality was similar to the Shinkansen[45]. The most recent reports from those who rode

MLU002 (January, July 1989) indicate a problem in ride quality at low speeds during deceleration[46]. Below 30 km (19 mph) during braking, strong longitudinal buffeting (back and forth oscillation) was observed which continued until the vehicle came to a stop. The buffeting problem was attributed by RTRI to an odd number of magnet poles (3 poles/magnet) in the revenue service vehicle design.

Advanced SCM and Refrigeration Engineering

The revenue service vehicle will include a major change in the superconducting magnet design and placement as discussed above. The new SCM design has two coils per magnet instead of three coils and a longer pole pitch, thereby reducing magnetic field exposure of passengers.

The principal cryogenics problem concerns the liquid helium compressors used in the closed-cycle on-board reliquefication system. The problem relates to excessive wearing of the teflon piston "O" rings as they rub on the cylinder walls. Compressor life time has been about 700 hours which is regarded as unacceptably short. This reliability of the helium compressors is identified as an important problem remaining to be solved.

Japanese EMS Maglev System Development

Japan's EMS maglev effort began in the mid 1970s as two parallel R&D programs, one supported by the Ministry of Transport (MOT) and the other by the Japan Air Lines (JAL). MOT's involvement proved short-lived and in 1981, it terminated all maglev efforts. JAL continued to maintain an active program of development. However in October 1985, after having invested about $40 million in the maglev, JAL transferred all R&D to the High Speed Surface Transport (HSST) Corporation under whose auspices the EMS research programs continue today.

Japan's technology approach differs from the German Transrapid EMS approach in several respects: (1) it uses the short stator linear induction motor (LIM) for prime propulsion; (2) the propulsion motor is housed on-board the vehicle; and (3) power to the motor is supplied through power pickup from wayside rails. The short stator approach has certain advantages, the greatest being the low cost of guideway construction. But it has the disadvantage of a higher vehicle weight and a less efficient propulsion system (higher operating costs).

The commercialization of EMS maglev required a decade and a half of R&D. This comparatively short time (compared with the superconducting train) was due in part to the mature state of EMS technology and the access to past research data on linear induction motors and EMS technology.

Japan's EMS program, under the auspices of the HSST Corporation, envisioned the development of four maglev versions, each with a different operating speed in the range 100 - 400 km/h. Actually, all the test vehicles except the first (HSST-01) which used rocket boosters, were limited to peak speeds under 110 km/h. These speeds are not a limitation of short stator maglevs. The short stator maglev has been shown to be adaptable to higher speeds as evidenced by the recent efforts to advance the STARLIM maglev [47].

Five test vehicles were constructed and tested as part of this HSST program. Each used an on-board LIM powered by contact wayside power rails. Lateral stabilization was achieved by lateral offset of levitation magnets on the vehicle.

HSST REVENUE SERVICE TRAIN

The HSST revenue service train is based largely on the HSST-05 test vehicle which was certified for commercial operation at Yokohama City in April 30, 1988 by the MOT. The certification followed the passage of two ordinances, No. 6 and No. 19, which sanctioned electromagnetic levitation and LIM propulsion for public transport. The specifications for the revenue service train include the following: [48]

- System capacity - 30,000 passengers/day
- Train capacity - 158 seats/train (2-cars/train)
- Primary power voltage - 750 dc
- Rail gauge - 2.0 meters between rails
- Track structure - single beam, prestressed concrete
- Track form - elevated single line

Table II - 6 lists the design specifications for two recent test vehicles [49].

Table II - 6 HSST System Design Parameters

PARAMETER	HSST-03	HSST-05
VEHICLE	(1-car train)	(2-car train)
Dimensions(L*W*H)	13.8*2.95*3m (45.2*9.7*9.8ft)	36.5*3.0*3.6m (120*9.8*11.8ft)
Weight(empty)	12.3 t (27060 lbs)	39.5 t (86900 lbs)
Weight(loaded)	18 t (39600lbs)	54 t (118,800 lbs)
Passengers	50	160
SUSPENSION		
Type	6 modules	8 modules/car
Secondary	air spring	air spring
PROPULSION		
Thrust (total)	11.16 kN (2508 lbf)	42.34 kN(2-cars) (9515 lbf)
BRAKING	phase rev.	phase rev.,regen.
POWER SUPPLY		
Line voltage	40-550 vdc	750 vdc
TRACK		
Length	340m (Tsukuba) 450m (Vancou.) 180m (Okazaki)	568m

Suspension and Lateral Guidance System

The suspension system for the HSST-05 maglev has eight magnet modules per car (2-car train) with 4 modules distributed lengthwise along the underside of each car [50]. The modules are grouped in pairs, one on each side of the car and linked to each other by anti-roll beams so that each module is rigid in rolling motion. Each module is equipped with four magnets, a linear motor coil, a mechanical brake, and two skids. The separation between successive magnet modules along each side of the car is reduced to a minimum to limit 'end effects' which might otherwise increase magnetic drag.

The maglev (2-car) train is equipped with secondary suspension comprising 32 air springs, 4 air springs per module, to support the cars in the vertical and lateral directions. Hydraulic cylinders equalize the lateral forces between the car body and the magnet modules and ensure the modules are in an adequate position when traversing a curved track.

The lateral stability of the vehicle initially presented a problem when the vehicle negotiated curved guideway sections. Due to the technique adopted for lateral stabilization, i.e., lateral offset of suspension magnets, the levitation and lateral guidance forces become coupled so that the levitation airgap decreases as the vehicle traversed a curve. Studies [51] showed that for vehicle speeds up to 100 km/h, extending the width of the guideway ferromagnetic rail provided sufficient lateral stabilization without reducing the vertical levitation force. For higher speed vehicles, more sophisticated control systems are required to ensure lateral stabilization.

Vehicle Body Design

The vehicle body is made of aluminum alloy with the nose section fabricated from fiber-reinforced-plastic (FRP). Welding is used throughout. The cabin floor panels are made of aluminum honey-comb sandwich structure which combine high strength with low component weight. The vehicle is designed to house the major components such as VVVF inverters, magnet drivers, emergency batteries, etc., below the floor panels.

Guideway Design

The HSST guideway comprises a single elevated beam with girder span distances of either 12 m (39.3 ft) or 16 m (52.5 ft), depending upon the span requirements of the specific geographic location. A typical support column height is 4.5 m (14.8 ft). The ferromagnetic rail (to which the vehicle electromagnet is attracted) is attached to the girders by tie bars installed on the girders. HSST conducted tests on the dynamic characteristics of the guideway girders to quantify the girder deflection with loading. Typical girder beam deflection with 'live' load was 3.4 mm (.134 in.) at 45 km/h (28 mph) for a 16 m (52.5 ft) girder with a natural girder frequency of 8.75 Hz [52].

The soft nature of the soil bed at the Yokohama Exposition site which would result in settling of the guideway support columns presented a unique problem for the HSST-05. To avoid the added cost of installing piles (which would have been up to 50 m in depth) to provide adequate support, base slabs were fitted to the support columns and an adjusting mechanism was introduced to adjust the column height to compensate for any sinking of the column.

Maglev Guideway Switch

HSST Corporation avoided the problem of switching vehicles between parallel guideway tracks by restricting vehicle operation to single track guideways. NKK Corporation and Nippon Engineering Company have, however, developed a maglev switch for use with dual track guideways. The switch is hydraulically powered and has an alignment accuracy of less than 1 mm between the switched rails. It is reported that NKK & Nippon Engineering have delivered a similar switch to Las Vegas for installation[53].

Magnet Supply and Converter

The suspension magnet is powered by pulse width modulated (PWM) converters fed by a 280 VDC source. A backup battery pack provides emergency power in case of power failure during running. The currents to the levitation magnets are controlled by signals from the levitation control circuit in response to signal inputs from airgap and accelerator sensors attached to the magnet assembly. The operating performance of the magnet supply and driver was adequate to maintain the vehicle in stable suspension; however, the (2 kHz) chopper frequency of the PWM converter produced objectionable noise at audio frequencies. This noise was almost completely eliminated by replacing the transistor units in the chopper circuit with static induction (SI) thyristors and operating the chopper at 10 kHz. The higher chopper frequency has the additional benefit of reducing the capacitor size in the filter circuit. The LIM propulsion supply onboard the vehicle is fed from a 750 VDC power rail. The onboard PWM inverter generates 3-phase, variable-voltage, variable-frequency (VVVF) power with maximum output frequency of 70 Hz based on a design frequency of 200 Hz.

Control Signal and Communication System

The signal communication and control system used with the HSST-05 was developed to meet safety standards for future revenue service. The operating control system is composed of automatic train operation (ATO), train automatic stop control (TASC), system operation unit, and a monitoring system. During normal operation, the programmed operational procedure includes door open/close, levitation on/off, and acceleration/deceleration. Should a failure occur, the failure is monitored and a pre-programmed failure mode procedure is invoked.

The signal control system must insure against the possibility of train overrun at the terminal stations. The ATO/TASC equipment assures continuous control throughout the trip. An inductive radio system provides signal communications between the vehicle and the control room on the ground and also serves as a telephone system. The ATO equipment limits train speeds to a predetermined value with speed detection devices located at 3 m (9.8 ft) intervals to monitor vehicle speed. The terminals at the end stations are equipped with a'honeycomb' structure which provides vehicle stopping should all braking systems fail.

Automated control of the train begins as soon as the train departs from the station. Information is continuously transmitted to and from the vehicle (cab) control equipment to monitor and control the train speed. The specifications for the train operation are: [54]

Control modes: ATO control, Step control
Target speed: ATO -3 km/h
Speed control accuracy: ATO target speed +/-2 km/h(1.3mph)
Stopping accuracy: +/-50 cm (+/- 20 inches)
Programmed acceleration: 2.7 km/h/s (1.7 mph/s)
Programmed deceleration: 2.7 km/h/s (1.7 mph/s)

HSST PERFORMANCE

LIM Propulsion Efficiency

The linear induction motor has low efficiency compared with either the rotary induction motor or the linear synchronous motor. Compared with vehicles powered by rotary induction machines using VVVF power, the LIM consumes 40 percent more energy. It also requires 30 percent more power to feed the auxiliary equipment.

Figure II-13 shows LIM efficiency measured with the HSST-05 between 20-60 km/h (13-38 mph)[55]. The specifications for the LIM propulsion system are given in Table II-7. LIM power is provided by two VVVF inverters each having 762 KVA capacity. LIM slip frequency (12.5 Hz) is maintained constant to minimize the normal force and to operate the LIM at near constant propulsion force.

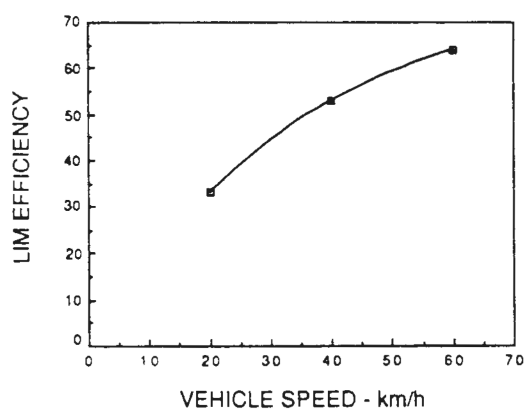


Figure II-13
HSST LIM Efficiency

The specifications for the propulsion system are given in Table II-7.

Table II-7 HSST Propulsion System

LIM:	
Input Power	32 kW
Rated Voltage	183 volts
No. Poles	10/LIM
Rated Frequency	72 Hz
Inverter:	
Output Frequency	0-55 Hz
Rated Slip Frequency	12.5 Hz

The energy consumption of the linear drive for the trip length of 568 m was 51 Wh/ton-km for 100 percent occupancy (80 pass/car). On a basis of full-load weight of 27 tons/car, the consumption per kilometer-seat is 17.2 Wh/km-seat.

Vehicle Specific Mass

Table II-8 lists the specific mass parameters (metric tons) for the HSST-03 and HSST-05.

Table II-8 HSST-05 Specific Mass Parameters

Train mass (loaded)	54 tons
Mass/length	1.48tons/m
Mass/seat	0.34tons/seat

Vehicle Ride Quality

Individuals who have ridden the HSST-05 [56] at Yokohama City say the ride is smooth and quiet during cruising. The acceleration was uniform and comfortable during the speedup but during deceleration, abrupt changes in acceleration were observed which produced an uncomfortable ride. The cause for this was not explained, but could be due to poor computer control.

Figure II - 14 gives the measured vertical spectral power density for the HSST-05 at 45 km/h (28 mph) along with the U. S. Urban Tracked Air Cushion Vehicle (UTACV) standard. The data confirms the good ride quality of the HSST-05 at cruise.

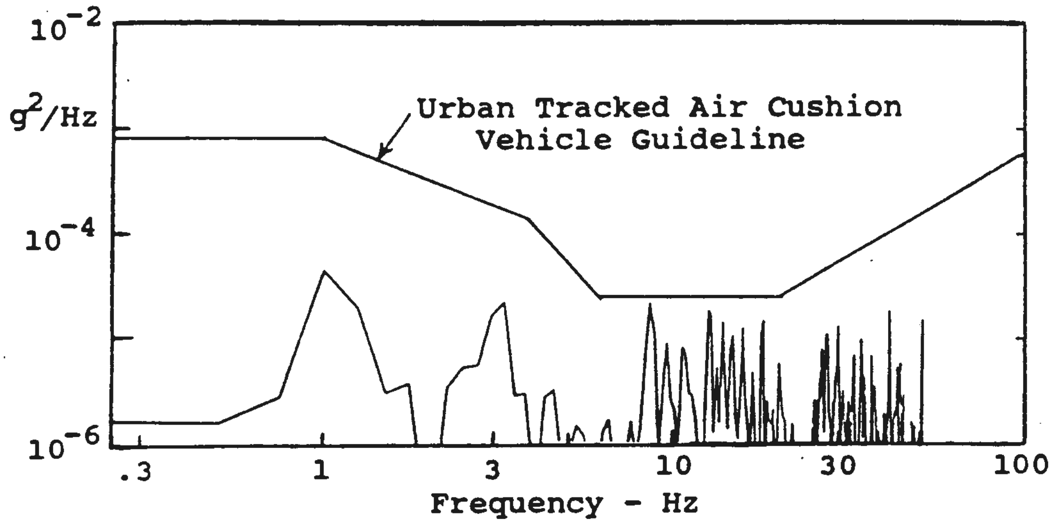


Figure II - 14
HSST-05 Vertical Spectral Power Density

TECHNICAL ASSESSMENT

The HSST maglev system, based on electromagnetic suspension, was conceived as a low to medium speed maglev for short distance travel in urban areas. Being restricted to relatively low speeds, it adopted many of the characteristics of a modern people-mover system.

The first HSST vehicle was tested at speeds above 300 km/h using booster rockets for added propulsion. It proved that LIM technology could operate in the high speed regime. The four later test vehicles were run at speeds below 110 km/h (69 mph). This was not so much a limitation in vehicle design as insufficient track distance to support tests at higher speed.

The unique feature of the HSST maglev is its LIM propulsion system and use of passive guideway. This simplifies guideway construction and reduces the cost considerably. Since the LIM vehicles run at speeds below 300 km/h, they can be fed by contact power rails (3-phase AC) or catenaries (dc power). A distinct disadvantage is its low top speed.

Maglev LIM Efficiency

Test runs of the HSST-05 at the Yokohama Exposition showed that the LIM has a low efficiency compared with both the linear synchronous motor and the rotary induction motor. The peak efficiency was 60 percent as measured at 60 km/h. This low efficiency (rotary induction motors typically have efficiencies of 90 percent) was attributed to the large air gap. Other factors contributing to low efficiency are heating losses in the secondary conducting rail and end-effect losses. Low propulsion efficiency is likely the penalty incurred for the advantage of having a lower cost guideway.

Maglev Mass Optimization

The vehicle specific mass for the HSST-05 (revenue service train) is 1.48 tons/meter and 0.34 tons/seat. The high mass-per-length (1.48 t/m) reflects the heavier weight of the vehicle due to the on-board LIM and power conditioning equipment. Interestingly, the mass-per-seat is a respectable 0.34 tons/seat which compares favorably with the advanced design of the Japan's superconducting train.

LIM Normal Force

Large attractive normal forces generated by the LIM during operation can be a problem. In the case of the HSST-05, the normal forces were limited by operating the LIM at the high (fixed) slip-frequency of 12.5 Hz. This reduced the freedom to independently adjust frequency and voltage or to operate at constant volts-per-Hz. This problem of generation of normal force with propulsion is inherent with electromagnetic propulsion/suspension systems which share a common magnetic flux circuit. (Transrapid has a similar problem of the propulsion circuit interacting with the suspension circuit.) While operating conditions can be adjusted to compensate for this interaction, it limits the design options for the operation of the converter circuit.

The LIM has reactive inductive power which does not contribute to propulsion but adds to the apparent power rating of the converter. Unlike the linear synchronous motor, this reactive power can only be removed by introducing line compensation (capacitance) at the input to the motor. Harmonic reactive power contributing to the total apparent power cannot be eliminated. This means that the converter will require higher ratings for the same active propulsion power.

Low Cost Guideway

The ultimate tradeoff on the HSST approach of active vehicle, passive guideway involves guideway construction cost, vehicle cost, and operating cost. The HSST approach minimizes guideway cost which by itself can be a major advantage for urban systems, especially where the choice of guideway routes and decisions to alter routes at a later time can rule out a high investment in an active guideway system. The use of contact power rails to supply power to the vehicle provides a low cost solution to the power distribution problem.

The real cost advantages of the passive guideway are offset by the higher costs of vehicle construction and operation. The vehicle cost now must include the cost of the LIM and its power conditioning equipment. Vehicle operating costs are higher since in addition to the passenger payload, the system must now transport the added weight of the propulsion system. This could make the passive guideway approach less attractive from a long-term operational standpoint.

Magneplane System Description

SYSTEM DESCRIPTION

The Magneplane system concept, developed in the U.S. in the mid 1970s, is a superconducting EDS vehicle which operates 150 - 250 mm above a trough shaped guideway. The Magneplane concept is based on the magnetic analog of flight where superconducting coils on-board the vehicle induce currents in a continuous, aluminum sheet guideway when moved over the guideway and repel the moving coils. The vehicle is supported resiliently at a height above the guideway of about 250 mm. Therefore, the vehicle is free to follow a smooth trajectory governed by its inertia. The vehicle is relatively unaffected by the manufacturing and installation imperfections which are perceived by the vehicle as high frequency undulations, since the height of these guideway discontinuities are much smaller than the vehicles levitation height. A magnetic drag force is also produced as a result of the coil passing over the sheet guideway. Thus, both lift and drag are produced just as in aerodynamic flight [57][58].

Magneplane is propelled by a linear synchronous motor, and is automatically controlled. The superconducting coils use a hollow conductor within which the supercooled helium is circulated to maintain them at their cryogenic operating temperature. Each coil is enclosed in its own vacuum envelope together with its thermal shield, persistent switch, and necessary structural support. A closed cycle refrigeration system is used to maintain the helium at 4.5 K [59][60]. Magneplane's system characteristics are summarized in Table II-9.

Table II-9
Magneplane System Characteristics (1975)

Vehicle length	50 m
Vehicle width	3.8 m
Vehicle height	4.35 m
Vehicle empty weight	30.5 t
Payload weight	14 t
Wt of cryogenic system and coils	20.7 t
Vehicle capacity	140 passengers
Min headway	20 s
System Capacity	25,000 passengers per hour each way
Operating speed	300 - 500 km/h
Guideway - steel, prestressed concrete,	and aluminum
Stations	off-line
Switches	on-board vehicle vert. arrangement
Operational control	synchronous auto via linear synchronous motor
Power Demand Rating	6 MW/block

<u>Vehicle</u>

The shape and structure of the vehicle is similar to commercial jet aircraft but it is articulated. The Magneplane configuration concept (1990) is shown in Figure II - 15. Note that the vehicle is articulated. The vehicle is propelled by a linear synchronous motor. The aluminum continuous sheet levitation strips are located on either side of the propulsion winding which is located in the center of the guideway. This trough configuration allows the vehicle to roll which theoretically permits tighter radii to be negotiated within human comfort limits. Smaller turning radii are possible because the vehicle is able to assume a coordinated turn trajectory. That is, rather than apply maximum permissible lateral loads to passengers allowed with small superelevation angles, Magneplane may bank as much as 45° and thus achieve a higher superelevation to keep the resultant of the horizontal centrifugal and vertical gravitational forces acting vertically through the passengers. This is a maneuver which passengers commonly experience in commercial aircraft. The balanced forces of coordinated turns are also the reason that drinks are not spilled during tight banking maneuvers.

The superconducting coils are wound from a hollow conductor, eliminating the need for liquid helium space. The cryostat, therefore, is reduced to a vacuum envelope. Each coil is independent to protect it from failure of another envelope. Supercritical helium is circulated through the coils to keep them cryogenically stable. The supercritical helium continuously passes through the hollow conductors in at least three parallel paths. It is recooled in the heat exchanger and its pressure is boosted to make up for friction losses. The stability of the conductor under anticipated operating conditions was analyzed, and a coolant flow rate was selected which allows a certain portion of the coil to become resistive, and remain so for a limited time duration, without forcing the entire coil to quench. The behavior of the normal zone propagation as a function of coolant flow rate, pressure drop, and frictional heat generation through the conductor were studied for this geometry [61][62]. The stabilized conductor in the design configuration includes aluminum to temporarily share current with the niobium-titanium. As long as the transition temperature of the superconductor is not exceeded during its normal excursion, the conductor remains stable and the normal zone will not propagate.

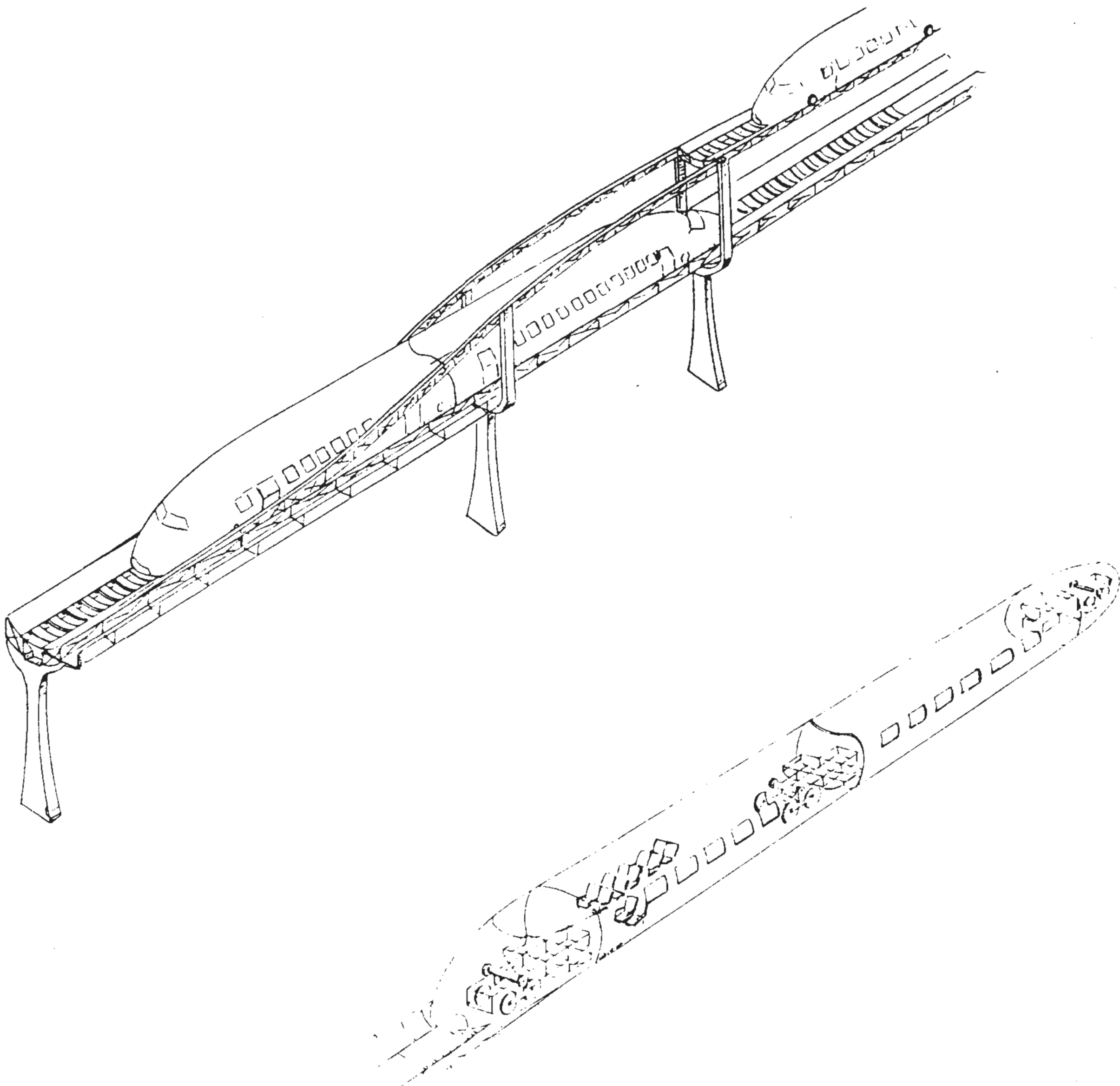


Figure II-15
Magneplane Configuration (1990)

Vehicle Switching

Two methods of switching have been considered. Both are initiated by extending the landing gear on-board the vehicle to engage either passive or active switching ramps. Passive switching is achieved by fixed ramps which engage the extended landing gear and carry the vehicle vertically to an off-line station located above the guideway. This method requires the vehicle to decelerate to a landing speed of about 100 mph prior to switching. The second method moves the guideway horizontally, bending it elastically into a gentle banked curve which diverts the vehicle at full crusing speed to an alternate guideway. Several actuators bend and bank a one-mile length of the guideway by moving a series of cradles laterally along curved track.

Technology Assessment

Magneplane is a result of significant theoretical studies, preliminary design studies and scale model tests and represents the most advanced American concept to date [63][64][65][66]. A fifth generation vehicle is presently being designed. It differs from the 1975 version in having its magnets concentrated onto three bogies, one at each end and one at the articulation. This eliminates the need for shielding the cabin and lowers both the profile and the center of gravity. The system uses hollow-conductor and supercritical (high pressure) closed-loop helium cooling system that differentiates it from other systems which surround each coil by a dewar reservoir of boiling helium.

M-BAHN Maglev Transit System Description

System Description

M-Bahn is a low speed permanent magnet suspension (PMS) system designed for short distance urban rapid transit. The fully automated system has centrally controlled automatic train operation via automatic train control subsystems at substations. The basic M-Bahn approach uses passive vehicles and active wayside equipment to control the short headways. At the same time, passive vehicles reduce the weight of vehicles and the associated cost. However, there is a concomitant rise in the cost of wayside equipment. The system is propelled by a synchronous long-stator linear motor[67]. This systems characteristics are summarized in Table II-10.

Table II-10
M-Bahn Maglev System Characteristics

Vehicle length	12 m
Vehicle width	2.3 m
Vehicle height	2.4 m
Vehicle empty weight	9.0 t
Vehicle bogies	3.7 t
Payload weight	9.0 t
Max. vehicle capacity	130 passengers
Min. headway	60 s
System capacity	5,000 - 15,000 pass/hr-dir
Train consists	1 - 3 vehicles
Maximum speed	80 km/h
Operating speed	30 -40 km/h
Max. gradient	15 %
Max. acceleration	1.3 m/s^2
Operational control	synchronous automatic via linear synchronous motor
Stations	on-line
Mean station spacing	600 - 1200 m

Vehicle

The type M 80/2 vehicle (shown in Figure II-16) which is 12 m long and 2.3 m wide has 28 seats and can carry a maximum of 130 passengers. The vehicle fabricated from welded aluminum is carried by two bogies. The primary suspension is by hybrid permanent/electromagnets. The empty weight of the vehicle is carried by the permanent magnets, and the payload is carried by the electromagnets. The rare-earth permanent magnet is an integral part of the laminated iron core of the control magnet. In effect, the control magnet reduces the system to a hybrid small air gap EMS system. A secondary suspension system consisting of air springs is provided for ride comfort considerations. Guidance is achieved by pairs of horizontal guide wheels running inside the guiderails. Switching is accomplished by wheels.

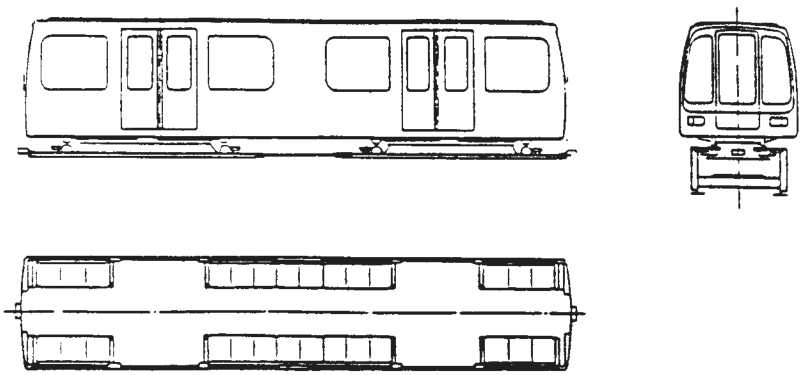


Figure II-16
M-Bahn Vehicle Type 80/2

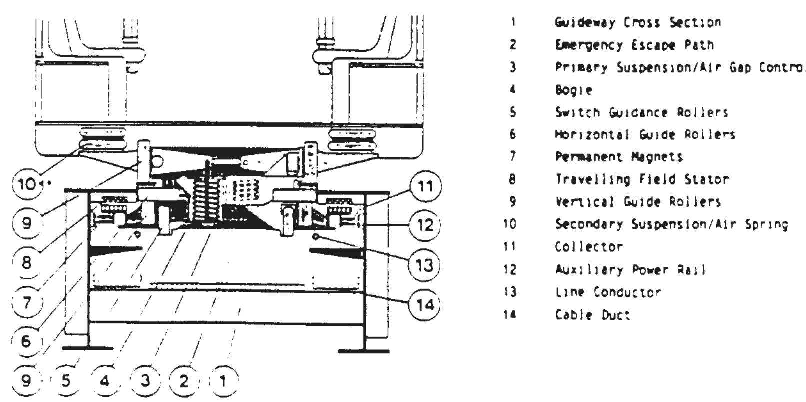


Figure II-17
M-Bahn Vehicle Cross-section

The permanent magnets which are mounted in the upper part of the vehicle bogie are attracted to the iron core of the long-stator linear motor which is installed in the guideway (see Figure II-17). A mechanical air gap sensor provides feedback to control the current in the electromagnets as a function of the payload weight. In this way, the attractive force of the electromagnet is maintained equal to the payload weight at all times. Therefore, the vertical guide wheels do not carry any significant load. However, they are used to counteract small nonlinear residual forces and dynamic forces due to guideway inaccuracies. The primary purpose of the vertical guide wheels is to maintain contact with the guiderails thereby providing a reference for air gap control[68][69][70].

Technology Assessment

Although the M-Bahn system was designed for low urban speeds and as such it was practical to provide guidance and switching via wheels, it nonetheless represents a technology which can be applicable to high speed systems. Work is being done at Braunschweig University on hybrid permanent magnets which have applicability to high speed systems. The M-Bahn implementation offers significant promise for a significant improvement in suspension performance.

Other U.S. Maglev Proposed Designs

Limited information is available on the following. Although this concept design proposal is not discussed in detail in this report it is listed below for future reference.

Knolle Magnetrans - Ernst G. Knolle, inventor.

> The Knolle Magnetrans is described by the inventor as a continuous transportation system like an escalator. Riders get into small cars that are then accelerated to very high speed to travel long distances.
>
> The purported costs of this system are an order of magnitude less than currently accepted costs for systems such as the Transrapid. If this concept is to be taken seriously, the basis for these cost reductions must be established. In addition, the acceleration, deceleration and station lengths imply some unusually high forces being applied to the passenger. More information is needed in this area. Finally, the short headways cited point to a potential safety problem. Again the details of how this headway is to be implemented and what the safety criteria will be is required.

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III. TECHNICAL FEASIBILITY

Congress has asked whether commercial maglev is technically feasible for the U.S. At this point there is no question that maglev is a feasible transportation technology. Both the Germans and the Japanese have convincingly demonstrated that passenger-carrying, magnetically levitated vehicles can operate at speeds beyond 240 mph. It is very likely that a high-speed maglev revenue system, employing a German technology and Japanese financing, will be built between the Orlando airport and a nearby resort complex with construction beginning as early as this fall.

A related issue is whether there is a role for U.S. industry in magnetic levitation technology. This analysis suggests that there are many opportunities for U.S. industry to participate in the future development of maglev technology, and that there is the potential for the U.S. to regain a leadership role. As discussed in Chapter II, a variety of maglev system concepts have been developed, with the German Transrapid system the closest to implementation. It is possible, however, that the least developed system, or even one that is yet to be proposed, will turn out to possess the best combination of performance and economics for use in the U.S. Even if a demonstration Transrapid system is built, it does not preclude the possibility of a second or third generation maglev design becoming the predominant system in the U.S. and elsewhere. At this time, decisions on what form maglev system development in the U.S. should take would be premature.

AREAS OF OPPORTUNITY FOR U.S. MAGLEV

There appear to be at least seven important endeavors which the U.S. could emphasize in order to recapture the initiative in maglev development:

1) Guideway construction cost reduction.
2) Rights-of-way acquisition cost reduction.
3) Propulsion system cost reduction.
4) Development of high temperature superconducting magnets.
5) Elimination of magnetic field hazard.
6) Safety and reliability.
7) Operational considerations.

GUIDEWAY COST REDUCTION--Fixed facilities account for about 90 percent of total maglev capital costs (exclusive of land). The guideway structure represents by far the largest single element of these fixed facility costs. Any significant reduction in these costs would have a proportional effect on maglev economics. In the recent Government/Industry Maglev Forum, a number of ideas were presented for improved materials and designs for the beams, bents and foundations which comprise an elevated guideway. New stronger and lighter space-age construction materials, new computer-aided design and manufacturing procedures and new ideas for lighter weight vehicles, versus those built in Germany and Japan, could have a major influence in reducing guideway costs.

RIGHT-OF-WAY COST REDUCTION--Because the U.S. has already invested in an extensive network of Interstate Highways linking major population centers, the opportunity exists for employing these existing rights-of-way for a dual purpose, without unduly interfering with their original function. It must be emphasized that the technology for doing this does not exist; it must be worked out, because the Interstate Highways were designed for maximum speeds of 70 mph and have curvatures and clearances which may not be suitable for much higher speeds. Strategies for coping with these limitations are needed. Many central city areas are not served by expressways, so strategies must be developed for achieving this critical access at acceptable economic and social cost. This represents an important technological opportunity.

PROPULSION SYSTEM INNOVATIONS--The long linear synchronous motor stator windings employed by the Transrapid and MLU maglev systems run the length of the guideway, and are an important element of system cost. There exist significant opportunities for reducing this cost by novel magnetic design involving both the vehicle magnets and the guideway windings. Alternative propulsion concepts using on-board prime movers such as the ducted turbofan engine or short stator linear induction motor (LIM) might be more cost-effective and should be re-evaluated. Ways must be found to mitigate environmental effects in the case of the fan, and weight problems in the case of the LIM.

HIGH TEMPERATURE SUPERCONDUCTING MAGNETS--Although low temperature superconductors do not pose the feasibility problems that were feared before the Japanese made significant strides in cryogenic systems, high temperature superconductors would certainly be used in all EDS systems if they become available. Hence, maglev represents a very important market for these materials, a market which the U.S. has the technological capability to exploit.

MAGNETIC FIELD EXPOSURE--Maglev systems employ large magnetic fields to suspend the vehicle. Although these fields attenuate rapidly with distance, fringing fields can reach the passenger compartment. Static magnetic fields have not been shown to pose any health hazard, but the issue is not closed and could affect the feasibility of certain maglev designs. Fields can be reduced to inconsequential levels by magnetic shields, but they are complex and add weight. At the Government/Industry Maglev Forum, a concept was presented for designing efficient magnets which confine the magnetic field to the suspension region.

SAFETY AND RELIABILITY--Safety and reliability are not so much opportunities as they are absolute requirements in any system that can hope to compete with other forms of transportation. The Transrapid developers in Germany, for example, have taken elaborate steps to assure safety, and any U.S. effort must be able to demonstrate to the public that safety and reliability are inherent features.

OPERATIONAL CONSIDERATIONS--The importance of operational considerations cannot be overemphasized. The ability to switch vehicles safely at high speeds and the related possibility of serving intermediate stations without impeding traffic on the main line can greatly increase the attractiveness of maglev relative to air service. The opportunity of using single cars vs. trains in the context of U.S. demographics has been addressed in the Magneplane system, but needs further analysis.

ADVANCED MAGLEV SYSTEMS FOR THE U.S.

The success of any effort to establish U.S. leadership in maglev technology will depend on the technical sophistication of existing systems, opportunities for developing improved components and subsystems, and the effectiveness of U.S. efforts to exploit those opportunities. Three types of activities will be important for assessing and exploiting these opportunities: first, a series of maglev system tradeoff studies to identify possible improvements and their costs; second, research work in major components or technical issues; and third, non-maglev-specific advances, such as in the area of superconducting technology, cryogenics and construction technology.

MAGLEV SYSTEM TRADEOFFS

Within the resources available for this report, it was not possible to conduct tradeoff studies to establish the potential for technological improvements. Such studies are an essential part of the Department's FY 1991 budget and will provide valuable insights into whether and how maglev systems can be designed to be integrated into the American transportation system. Such studies include an analysis of operation and construction issues, such as the most cost-effective and efficient train length to provide safe and flexible service; the feasibility of constructing guideways above or along Interstate Highways; the effect of lateral and vertical curvature on guideway construction and vehicle performance; and the optimal speed for maglev systems, considering the desirability of attractive trip times as well as noise, energy, topographic and other possible constraints. Technology tradeoff studies would also provide insight into how to improve either the performance or economics of existing components and subsystems, and would address issues related to design options for guideways, vehicles and power systems, including alternative suspension, propulsion and stabilization systems and magnet configurations to produce an integrated design that provides superior passenger comfort.

On-line Versus Off-line Stations

Tradeoff studies are required to determine the most effective way to serve intermediate stations--using single cars with off-line stops or full trains with station stops on-line. Studies should determine construction implications of on-line versus off-line stations and short versus long trains, assess safety implications of short headways (40-90 seconds) with single cars, and determine the impact of short headways on system configuration, including power system requirements, such as guideway coil length, feeder section length, converter requirements, power consumption with varying power distribution parameters, etc. Performance characteristics of the short train versus the long train, including average trip time, and frequency and capacity of service, should be assessed, as well as the capital and operating costs of each system approach.

Route Topography

The impact of route topography on maglev operating speed should be assessed and should include an analysis of selected Interstate Highways that are possible candidates for maglev routing. The tradeoff studies should provide an understanding of the impacts of lateral and horizontal curves on speed, acceleration and passenger comfort. This study should be coordinated with the following analyses of Magneplane.

Magneplane is an innovative design which would employ the kind of coordinated turns used by aircraft to handle horizontal and vertical curves. Further study is required to assess its approach to vehicle stabilization.

Vehicle Speed

Tradeoff studies of maglev operating speeds should be conducted. The reduction of maximum maglev speed from 300 mph to a lower speed could provide significant savings in energy while maintaining a high level of performance. Studies are needed to assess the tradeoff between short trip times to attract large numbers of passengers, versus cost and energy requirements, topographic constraints and other considerations.

RESEARCH IN COMPONENTS OR TECHNICAL ISSUES

Several major components of maglev systems and several technical issues require research which is important in developing advanced U.S. technology.

Propulsion Systems

A number of advanced systems are possible for propelling maglev vehicles. Some of these are described below.

Linear Induction Motors (LIMs) are commonly used in conjunction with short stator systems which permit lower cost passive guideway construction. LIMs have lower electrical efficiency and power factor than linear synchronous motors. However, an American firm (PSM) at the government industry forum reported the development of significantly higher power factor and efficiency as a result of reduction of "end effects." LIMs require an on-board power supply which adds to the vehicle weight. LIMs produce attractive normal forces when operated at low slip. These normal forces can be reduced by operating the motor at low slip, however this may result in lower LIM operating efficiency. Research may improve propulsion and operating efficiency and reduce manufacturing and operating and maintenance costs.

Linear Synchronous Motors (LSMs) are more efficient and have higher power factor than linear induction motors. LSMs work best with an active guideway and use frequency and torque angle or excitation current for controlling vehicle speed. If necessary, the propulsion excitation current can be used to adjust the motor impedance for unity power factor. Normal forces are generated during motor excitation and are either attractive for under-excitation or repulsive for over-excitation. Depending upon the propulsion circuit, these normal forces can cause problems when coupled to the vehicle levitation circuit. Further research could lead to the improvement of this technology.

A linear synchronous reluctance motor was recently proposed [2] which uses a slotted magnetic rail to produce salient-poles. Efficiency and power factor are reported to be good enough for practical use. The linear reluctance motor offers the potential for a passive guideway operation. Also, research on superconducting permanent magnets should provide future applications for medium speed maglev.

Maglev Vehicle Improvements

Research in specific features of the maglev vehicle constitutes an important part of the work needed prior to development. The implications of placing superconducting magnets (SCM) lengthwise along the vehicle versus on bogies should be studied to assess the vehicle mass, effective cross-sectional area of the vehicle and its impact on vehicle weight, vehicle drag, energy consumption, and propulsion circuit efficiency, as well as magnetic field shielding requirements.

The aerodynamic noise at high vehicle speeds should be examined to determine its level under various design and operating scenarios. The question of possible restriction of upper speed range due to excessive maglev noise should be reviewed. Speed and frontal area are the most important determinants of vehicle aerodynamic drag, but it is also affected by the clearance between vehicle and guideway. The Japanese repulsive maglev has a large clearance, which reduces drag, but is nearly half surrounded by its U-shaped guideway, which increases drag. The German attractive force maglev has a small clearance, but only over a small area. These factors require careful optimization, which could lead to a significant reduction in aerodynamic drag. Special consideration must be given to operation in tunnels where drag is substantially greater than in the open. In Japan, tunnels comprise half or more of the mountainous routes; most of the routes under consideration in the U.S. involve few tunnels.

Vehicle stability of electrodynamic suspension maglev is a complex, 3-dimensional problem. It involves the coupling of the fields of superconducting magnets with the fields induced in guideway ground coils. Improving vehicle stability requires tradeoffs of power converter characteristics, i.e., output waveform, harmonics, frequency flexibility, with the optimization of superconducting magnet design, and vehicle ride comfort. Oscillations in pitch, heave, sway, yaw, and roll can be excited under certain conditions, particularly by coupling through non-linear force interactions.

Studies of the EDS vehicle stability should include the impact of guideway curves on induced pitching and rolling instabilities. The study should treat the effect of magnetic field variations on vehicle stability and should determine whether increasing the variable-voltage, variable-frequency (VVVF) converter upper frequency range would minimize harmonic problems.

Guideway Design Optimization

Innovative schemes for guideway construction, including active and passive switch-design should be examined for possible use with high speed, low mass superconducting trains.

Power System Engineering

Tradeoff studies should be made of power utility, substation, converter, distribution line, switching gear, and propulsion coil section length to establish minimum cost. The studies should also address equipment reliability and probability of system failure.

Magnetic Field Levels

Magnetic fields in the EDS system have the potential for being unacceptably high. The high levels of magnetic field in the passenger cabin of the EDS system are reduced either by placing the superconducting magnets on bogies at the vehicle ends, or through shielding or cancelling coils. What constitutes a safe magnetic field level, however, remains to be established. Research is needed both on what constitutes a safe magnetic field and options for reducing field intensity in the passenger section of the vehicle.

TECHNOLOGY ADVANCES

Non-maglev-specific technology advances can have a significant impact on an advanced maglev system. Among the most important are further development of high temperature superconductors (HTSCs) and advanced manufacturing methods.

Impact of High Temperature Superconductors (HTSCs)

HTSCs would be very useful in EDS systems. On the other hand, the viability of repulsive force maglev is probably not dependent on the availability of HTSCs. Current state-of-the-art superconductors, cryostats and refrigerators are adequate for the purpose; HTSCs would result in economies and simplification, but would not, by themselves, tip the scales in favor of the repulsive force maglev system. This should not be taken to mean that HTSC technology should not be supported. In the event that maglev employing superconductors becomes the system of choice, and HTSCs are available, the market for maglev-related HTSCs would be substantial, and the maglev-related benefits of this research could become an important factor in deciding whether to pursue it.

Computer Integrated Manufacturing (CIM)

As noted previously in this report, one of the most important issues in the development of maglev is guideway construction cost. One underlying premise of the large air gap electrodynamic suspension (EDS) system is that it requires lower construction tolerances and allows construction at reduced costs compared with the small air gap, electromagnetic suspension system (EMS). The Transrapid development approach which uses Computer Integrated Manufacturing (CIM) can reduce the guideway construction cost and thereby remove some of the cost advantage previously associated with the electrodynamic suspension. The problem of requiring more substantial foundations in order to reduce settlement in the small air gap system would still remain.

CIM also opens the opportunity for its application to other transit system requirements and to manufacturing as a whole. The machine tool industry would get a boost from the development and integration of design with numerically-controlled machining processes, integration of flexible robotics in manufacturing and assembly, and integration of quality control and service.

The introduction of this technology into the field of transportation could assist U.S. industry to become more competitive.

POTENTIAL FOR U.S. ROLE IN MAGLEV DEVELOPMENT

After nearly a decade and a half of extensive maglev research, development and testing, Germany and Japan have achieved the status of world leaders in electromagnetic suspension (EMS) and electrodynamic suspension (EDS) technologies, respectively. The German Transrapid TR-07 is currently near the state of commercialization and Japan's superconducting train is fast approaching its final stages of development. In view of these developments and the opportunities described, the question is how the U.S. should proceed to gain the maximum advantage for its transportation system from maglev technology while having U.S. industry participate in its further development.

U.S. MAGLEV PROGRAM ALTERNATIVES

Several options are available for the U.S. to pursue to assume a leadership position for developing an advanced maglev system. Developing an American design and system is one of the options. Test facilities would be desirable under all options and essential under two of them. These could include a guideway and facilities for the design and testing of magnets. Each option is discussed below.

Accelerated Design of American System

One option is the independent U.S. development of high speed (350-500 km/h) maglev technology. Design and trade-off studies would establish the most promising system concepts and validate their viability. Prototypes would be developed, tested and demonstrated.

Joint Venture of Existing Systems and American Development

A second option is an international cooperative program to develop an American system using selected components of Japanese or German systems. This approach would pair American industrial strengths in magnet technology and control systems construction technology with the best of the existing systems to reduce development time and minimize costs.

Construction, Operation and Maintenance of Existing Systems

As a third option, if it were determined to use existing foreign systems for implementation, U.S. leadership in maglev could still be achieved over time as U.S. industry could perfect the technologies through detailed understanding gained through production and operational experience. Ultimately, this experience and knowledge could translate into the development of superior construction methods and improved vehicles and sub-system design.

Each option has certain advantages. Developing a unique American design concept would appear to produce the most dramatic benefits, but this approach also entails the largest development cost and risk. By contrast, implementing an existing system would appear to produce the least benefit for U.S. industry, but such a strategy would present the lowest risk and shortest development time. Each option also has different implications on requirements for skilled personnel. For example, it may be necessary to encourage the development of research fellowships and scientific and engineering studies in advanced magnet technology, power systems engineering, and related fields under the first two options. A decision on the appropriate option should await further investigations proposed earlier in this chapter and in Chapter IV in order to evaluate potential benefits versus risks.

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IV. ECONOMIC FEASIBILITY

This analysis of the economic feasibility of constructing commercial magnetically levitated transportation systems in the United States over the next 20 years takes into account the broad economic implications as well as the financial feasibility of their development, construction, and operation.

The economic implications of building a system include considerations of public benefits in addition to costs and revenues strictly internal to the system and realizable by a private company which may build and operate it. For example, in addition to revenue paid by the users, benefits may include benefits to society, such as safety and environmental benefits, and avoidance of the costs of expanding facilities of other modes, as well as the adverse environmental effects associated with such expansion. Public expenditures for maglev systems may be justified by these broad economic benefits.

CONCLUSIONS OF THE FINANCIAL AND ECONOMIC ANALYSIS

It cannot be emphasized enough that most of the conclusions drawn in this chapter are highly tentative. Indeed, the end of the chapter contains a discussion of the additional economic studies and data collection that need to be performed in order to obtain more reliable answers to many of the questions.

With the above caveats, the preliminary conclusion is that it will be economically feasible to construct a limited number of commercial maglev systems in the United States, starting in this decade. Specific conclusions are listed below:

- Relying purely on net user revenues, and assuming the availability of adequate rights-of-way at little or no cost, it appears possible to finance from 500 to 2,600 route miles (1,000 to 3,500 miles of single track guideway and passing tracks) of maglev lines in the U.S. on a project-by-project basis, without recourse to public finance, excluding right of way cost and assuming access to tax-free bond financing for a substantial portion of the capital. (See Chapter V on the availability of tax free bond financing under current law.)

- The construction of these lines would represent \$15.2 to \$54.7 billion worth of expenditures on fixed facilities, including basic structures as well as the more sophisticated equipment needed to power and control the trains.

- About \$1.2 to \$3.2 billion worth of vehicles would be needed to carry passengers on these lines at the start of service (assumed to be around the turn of the century). This number would grow to $1.8 to $5.2 billion over the initial 20-year period of operation, if only those lines were built.

- Some form of external revenue generation, such as enhanced real estate value capture or public financing, is needed for projects beyond this initial mileage. For example, it is estimated that about 1,500 to 5,000 route miles (2,300 to 6,300 miles of single guideway) would have net revenues sufficient to cover all operating costs and repay at least 50 percent of capital costs. These projects would represent from $35 to $97 billion of fixed facility expenditures and $2.3 to $4.2 billion worth of vehicles ($3.7 to $6.8 billion over 20 years).

- A substantial amount of savings in public sector infrastructure cost (avoided highway and airport capacity needed to serve increased travel demand) could be used to justify public investment in maglev projects. Other public benefits are available from lessened dependence on petroleum energy sources and air pollution reduction.

- Other significant public benefits accrue from reduced dependence on petroleum energy sources and reduced air pollution.

The remainder of this chapter describes in further detail the methodology, the projections, the assumptions and the results of the analysis.

APPROACH

Whether one is trying to determine broad economic feasibility or financial feasibility, it is necessary to reduce all benefits (or revenues) and costs to a common time period. Usually this is done by discounting future benefits (revenues) and costs to a given base year, typically the year when the largest share of capital costs are expended, or the midpoint of the construction period, using discount rates related to the cost of capital. That approach was chosen in this report, using a discount rate of 8-1/2 percent per year, and discounting 30 years worth of future revenues and costs back to the midpoint of construction, assumed to be two years prior to the start of service. The rate of 8-1/2 percent was chosen to represent the "real" rate of return that is likely to be required to convince an investor to participate in a maglev project assuming the availability of tax-free interest for a substantial portion of the investment. Since constant 1988 dollars are used in all calculations, it is necessary to use the real rate of return, i.e., the market rate of return minus an adjustment for inflation. Thus the 8-1/2 percent real rate of return is the equivalent of a 12-1/2 percent market rate in a world of typical 4 percent inflation. While 12-1/2 percent may seem high for a tax-free interest rate, it is not considered high for a project involving large capital outlays and new technology. A time period of 30 years was chosen as the likely minimum economic life of the maglev investment.

Specifically, the approach included the following steps:

(1) Identifying specific city pair markets of 500 miles or less separation with particularly heavy air travel.

(2) Identifying a series of routes or networks serving one or more such city pairs.

(3) Projecting the number of person trips likely to be attracted to each such network if served by maglev in different future years and assuming certain fares (see Appendix IV-A).

(4) Determining financial feasibility by calculating revenues and costs in such future years, discounting them to the common base year, and comparing the capital cost to the value of the net revenues (i.e., revenues minus operating costs).

(5) Assessing economic feasibility by identifying and, if possible, quantifying external benefits and costs and include these in the comparison of revenues and costs.

(6) Calculating the effect of changes in assumptions on the results of the analysis.

In conducting this analysis, the following questions were most important:

- o What is the extent of possible maglev routes where net passenger revenues (i.e., net of operating costs) are likely to be sufficient to cover total capital costs?
- o Where capital costs cannot be covered by net passenger revenues, are there external benefits on some routes which may justify public financing of capital costs?

The analysis did not attempt to quantify non-user revenues from private or quasi-private sources such as from "value capture" of adjacent land development or from impact fees levied on nearby property owners to finance a maglev project. These methods are discussed in a legal and institutional sense in Chapter V. As is now evident from the financing methods available through the Florida High Speed Rail Transportation Commission Act, for example, such sources could ultimately represent the difference between profitability and inability to raise sufficient private capital.

MAGLEV MARKETS

CRITERIA FOR CITY PAIRS AND ROUTES/NETWORKS

The initial list of city pairs considered for hypothetical maglev service was derived by examining primarily the size of the air travel market for each city pair separated by distances of 500 miles or less. Added to this list were certain city pair markets which had in the recent past been the subjects of high speed rail feasibility studies, and certain other markets which, though they might not be ranked in the highest air volume categories, nevertheless represent important regional travel markets. This initial list then formed a basis for constructing routes or networks consisting of adjacent city pair markets that could be connected in such a way that maglev users from more than one city pair market could use components of the same network. The networks identified through this process are shown in Figure IV-1 as solid lines. They include the following routes:

Corridor or Network	Principal Cities Served
California/Nevada	San Francisco*, San Jose, Los Angeles*, San Diego, Sacramento, Reno, Las Vegas.
Pacific Northwest	Seattle, Portland
Texas	Dallas/Ft. Worth*, Houston, Austin, San Antonio
Chicago Hub	Chicago*, Detroit*, Toledo, Cleveland, Indianapolis, Cincinnati, Springfield, St. Louis, Milwaukee, Twin Cities
Ohio/Pittsburgh	Cincinnati, Columbus, Cleveland, Pittsburgh*
Pennsylvania/Cleveland	Philadelphia, Harrisburg, Altoona, Johnstown, Pittsburgh*
Atlanta Hub	Atlanta*, Nashville, Chattanooga, Birmingham, Columbia, Charlotte, Macon, Savannah, Jacksonville
Florida	Miami*, Ft. Lauderdale, Orlando, Tampa, Jacksonville
New York State	New York City*, Albany, Utica, Syracuse, Rochester, Buffalo
Northeast Corridor	Richmond, Washington, Baltimore, Philadelphia, New York*, New Haven, Providence, Boston

*Service to airport and city.

The routes shown as solid lines in Figure IV-1 do not necessarily represent the top ranking potential maglev routes or networks. However, the list does represent a range of potential maglev markets of varying density concentrated at the high end of possible commercial viability, and is unlikely to exclude routes which have great promise of commercial viability over the next 20 years. In effect, it represents a basis for further analysis leading to a preliminary assessment of economic feasibility of constructing commercial maglev systems in the U.S. After initial systems are in place, other links may become viable.

EXAMPLES OF MAGLEV NETWORKS

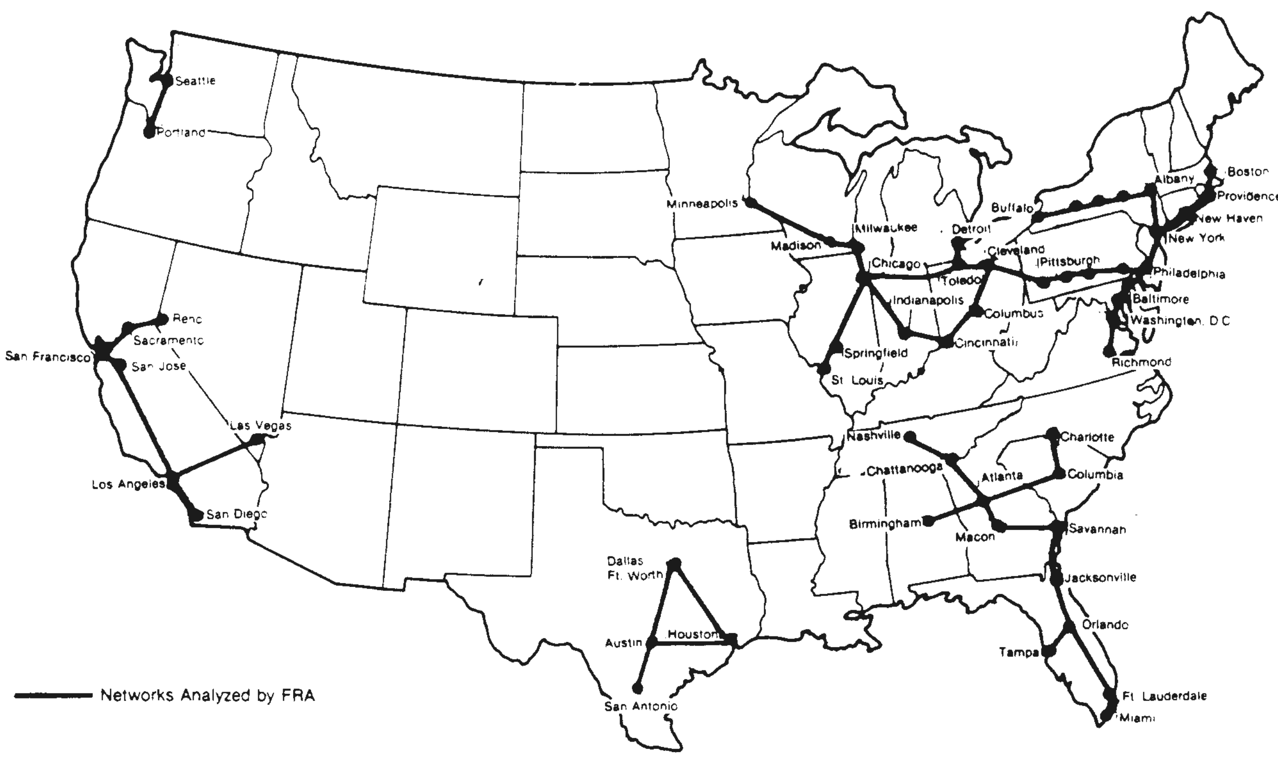


Figure IV-1

POTENTIAL FOR INTERREGIONAL AND NATIONAL LINKAGES

The quantitative analysis in this section of the report is focused on the regional systems mentioned above since maglev systems are most likely to evolve on a corridor or regional basis. In the longer term it may be desirable to link these regional networks. Both the Interstate Highway System and the nation's airport systems are examples of infrastructure systems built largely by the public sector but effectively financed by fees raised from users--essentially private companies and their customers (passengers and shippers) and private vehicle owners, with some Federal general fund contributions. In the very long term, an even more extensive system of national scope might even be possible. A more careful study would be needed to determine routings and priorities.

BASE YEAR (1988) TRIPS IN EACH MARKET

The first step in projecting future trips between each pair of cities (i.e., pair of metropolitan statistical areas) is to estimate the number of trips in the base year of 1988. The number of trips by air in 1988 was obtained from the Department of Transportation's 10 percent sample of airline tickets. The number of trips by rail was obtained from Amtrak's count of tickets sold for travel between stations. Information on trips by automobile is not available on a city pair basis from a nationwide sample. However, survey data were available for some city pairs in the Northeast Corridor, Texas, Ohio, California, Michigan, and Florida, and these data were used to estimate trips by automobile. Where auto data were not available the proportion of auto trips vs. air plus rail trips was estimated as a function of distance between city centers. Two functions were used--one for the Northeast Corridor and another for all other locations--derived from city pairs where the data were available (see Appendix IV-A).

In addition to trips between each pair of cities, a separate estimate was made of air trips moving between one city and a large hub airport in the other city, but not having that airport as a true origin or destination airport. These were derived from information reported by the airlines to the Department. They will be referred to as "air transfer" trips.

ASSUMPTIONS AND METHODS USED IN THE ANALYSIS

FUTURE MAGLEV TRIPS

Projection of Base Year Trips

Future trips by all modes of travel were projected through the year 2030 in proportion to the growth of real income of residents of the two cities over time. Projections of real income by metropolitan statistical area were available from the National Planning Association (see Appendix A for details).

Proportion of Future Trips Using Maglev

The percentage of future trips using maglev, if maglev were available, was estimated as a function of distance separating the cities. (See Figure IV-2.) This function was developed using a technique which took into account the comparative attractiveness of maglev vs. air and auto modes--as measured in terms of door-to-door travel times, out-of-pocket costs, and frequency of service, assuming maglev had fares and frequency of service comparable to those of the air mode. The relationship between this relative attractiveness and the percent of people choosing the "rail" mode was derived from data on travel in the Northeast Corridor, based on a recent survey. This same relationship was extended to apply to the use of maglev, including travel between cities outside the Northeast Corridor, in such a way that the higher average speeds (at least 200 m.p.h. for maglev vs. current rail average of about 80 m.p.h.) would attract a higher percentage of traffic than today's Northeast Corridor rail service at the same distance.

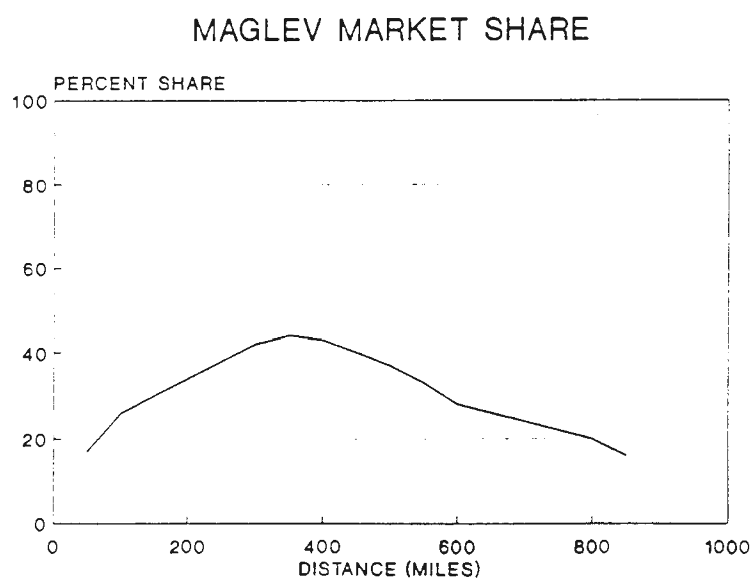


Figure IV-2

By way of explanation, consider, for example, travel between Washington and Philadelphia, where a high percentage of trips moves by rail today, at a distance of 140 miles. Today, the ratio of terminal-to-terminal trip time by Metroliner vs. by air is 1.65. If maglev service were available on the Northeast Corridor assuming a conservative 200 mph average speed that same ratio would hold for travel from Washington to Boston, a trip of 440 miles. Thus, we would expect the relative competitiveness of maglev vs. air between Washington and Boston to be as good as it is today for rail vs. air between Washington and Philadelphia. It can be shown by similar reasoning that maglev vs. auto competitiveness between Washington and Boston would be dramatically better than rail vs. auto between Washington and Philadelphia is today. The rail market share has been correlated with these relative competitiveness relationships and applied under the improved competitiveness conditions of maglev vs. other modes. (See Appendix IV-A for details.)

<u>"Induced Trips"</u>

In discussing projections of travel using a new mode of transportation, a distinction is made between "diverted" travel and "induced" travel. Thus far this report has discussed only diverted travel, which consists of maglev users who would travel via other modes of transportation if maglev service did not exist. Induced travel consists of maglev users who would not have made the trip at all without maglev. It includes trips resulting from users increasing their frequency of travel as a result of maglev service. While techniques have been developed for estimating diverted travel based on the relative attractiveness of competing modes, the techniques for estimating induced travel are not nearly as well developed.

For lack of a better source of data on this phenomenon, one can turn to the French experience when the TGV service was introduced between Paris and Lyon. French officials have stated that half of the <u>increase</u> in rail trips was from induced demand, the other half being partly trips diverted from other modes and, to a lesser extent, partly increased overall travel due to economic conditions. This would imply that estimates of trips diverted from other modes, as derived above, should be substantially increased--perhaps by almost 100 percent--to account for induced trips. For purpose of this analysis, the diverted trips were increased by a much lower percentage of 22 percent (see Appendix IV-A).

Air Transfer Trips

The air transfer trips (trips which transfer to or from maglev as part of longer distance air trips) were included as part of total trips, projected into the future, and subjected to the same estimated proportion using maglev, but they were treated in a different manner from the other trips in the following two ways. First, they were multiplied by two thirds, a factor representing the judgment that it would be more difficult to divert to maglev one leg of a trip already committed to air travel. Second, they were not subject to the induced travel factor.

Summary of Maglev Trip Estimates

Tables IV-1 and IV-2 provide an illustrative summary of the results of the above-described estimating process, showing air, air transfer, rail and auto trips estimated in the base year (1988), as well as future total trips and maglev trips estimated for years 2000 and 2030 in selected major city pair markets. The tables are illustrative only of the magnitude of the number of trips involved and projected growth assumptions used in this study, and should not be used to estimate individual city pair traffic. As explained below, the results of these projections should be considered only in an aggregate sense until more accurate data and better estimates can be made.

Table IV-1: Examples of Estimated Base Year Trips by Mode

	Annual Passengers in 1988 (000)			
City Pair*	Rail	Auto	Air	Air Transfer
LA-San Francisco	61	4,761	5,091	2,129
Seattle-Portland	96	2,686	351	0
Dallas/FW/Houston	5	2,970	2,020	1,589
Chicago-Detroit	29	3,484	1,347	840
Cleveland-Cincinnati	0	460	66	0
Phil.-Pittsburgh	33	485	324	360
Atlanta-Nashville	0	485	183	485
Miami-Tampa	2	2,065	467	747
NY City-Albany	454	4,540	112	0
NY City-Washington	1,182	4,921	2,992	330

*Note: These are only for one selected city pair in each network and do not include other city pair trips.

Table IV-2: Examples of Projected Future Annual Total Trips and Estimated Trips by Maglev

	Year 2000 (000)		Year 2030 (000)	
City Pair*	Total	Maglev	Total	Maglev
LA-San Francisco	20,700	7,900	39,300	14,900
Seattle-Portland	5,000	1,700	10,500	3,600
Dallas/FW-Houston	14,000	4,300	30,700	9,600
Chicago-Detroit	9,200	3,500	17,100	6,600
Cleveland-Cincinnati	800	300	1,500	625
Phil.-Pittsburgh	2,300	800	4,600	1,500
Atlanta-Nashville	2,800	700	6,400	1,600
Miami-Tampa	6,800	2,400	14,900	5,200
NY City-Albany	7,000	2,400	13,700	4,700
NY City-Washington	13,900	5,700	26,300	10,700

*Note: These are only for one selected city pair in each network and do not include other city pair trips.

FUTURE MAGLEV REVENUES

Fare Strategy

A key factor in forecasting passengers and maximizing revenues is the fare strategy, and what average fare should be assumed. Airlines and Amtrak have practiced the technique of "yield management" to maximize revenues. That is, a variety of fares is available on all routes, but the number of seats available in each price range varies according to the degree of competition from other carriers, and the extent of demand for tickets by season, day of week and time of day. A maglev operation could adopt similar strategies, but it is difficult to tell what the average fare is likely to be.

As a first approximation, it has been assumed that the average maglev fare in any given city pair would be the same as the 1988 average airline fare--that is, the average fare taking into account all the discount fares used by air travelers.

Revenue

Once the average fare is assumed, it is a simple matter of multiplying that fare in each market (the actual average 1988 airline fare) by the number of estimated maglev passengers in that market. See discussion of net revenue, below.

MAGLEV OPERATING AND MAINTENANCE COSTS AND NET REVENUE

Operating and Maintenance Costs

Maglev operating and maintenance costs used in this report were taken from reports prepared by The Canadian Institute of Guided Ground Transport (CIGGT) under contract to the Department of Super-Speed Train Development, City of Las Vegas, Nevada. CIGGT undertook a detailed review, analysis, and validation of operating and maintenance costs for the Las Vegas-Southern California TRANSRAPID maglev system submitted by the Budd Company and others to the City of Las Vegas in January 1983. CIGGT was authorized to make revisions as either new information or their own judgments dictated. In June 1987 the City of Las Vegas submitted its Final Report to the FRA on the feasibility of providing Super Speed Train service between Las Vegas and Southern California. The CIGGT analysis was a major component of this submission.

Cost Per Passenger Mile

CIGGT estimates maglev operating and maintenance costs at $.045 per passenger mile in 1984 dollars, or $.052 in 1988 dollars. While this figure was rigorously developed by CIGGT, it is, on the surface, surprising because it is so much less than Amtrak's short-term avoidable cost of approximately $.162 per passenger mile and fully allocated cost of $.36 per passenger mile (excluding depreciation and taxes) for Metroliner service--the only existing high speed rail service in the U.S. In an attempt to identify and better understand this cost differential, selected comparisons have been made between Amtrak's high speed service in the 226 mile New York-Washington market and the proposed maglev service in the 230 mile Las Vegas-Southern California (Ontario Airport) market. Precise comparison is not possible because detailed cost data are not provided and it is likely that certain costs are included in the summary data for one service but not the other. Rough comparisons are, however, valid.

Much of the disparity is accounted for by the greater productivity of maglev train sets. Operating at an average speed of 184 mph, versus 82 mph for Metroliners, maglev trains would be able to provide over two times as many train miles as Metroliners. In addition to faster average speed, other advantages enjoyed by maglev over Metroliner operations include better equipment utilization, wage rates and crew assignments more typical of the airline industry, and equipment and right-of-way maintenance practices that reflect manning levels consistent with commercial aerospace/avionics programs and technologies.

Crew Costs

Estimates of maglev crew costs are one-third those for Metroliner service. A typical maglev crew on a six-car train is one operator and six on-board service employees (1 per 100 seat car). A crew was assumed by CIGGT to make 2 round trips each day and work a 10-hour day and a 4-day week. Metroliner crews include an engineer, conductor, trainmen, and on-board service personnel. This crew would make one round trip each day. Typically a crew works 40 to 48 hours per 5-day week.

Sales and Marketing

Maglev sales and marketing costs are approximately 15 percent of similar costs for Metroliner service. A significant cost savings for maglev is realized because a relatively simple reservations system can accommodate a two terminal non-stop operation, such as Las Vegas to Southern California, while the multi-stop Metroliner service requires much more sophistication. CIGGT estimates the direct labor content for a maglev reservation at 1.67 minutes or about 60 percent of the amount of time it takes Amtrak to complete a Metroliner reservation. On a cost per reservation made basis, available data suggest the average cost of an Amtrak reservation is nearly five times the $2.00 cost estimated by CIGGT.

Vehicle Maintenance

Estimated maglev vehicle maintenance costs per passenger mile are approximately one-sixth of Amtrak's Metroliner maintenance costs. Again, the greater productivity of maglev equipment explains some of the difference. For Las Vegas - Southern California service, a fleet of 72 cars would be sufficient (60 in daily service and 12 as backups). In Metroliner service, Amtrak operates 76 cars and 18 locomotives. How quickly equipment is turned after arriving at its destination and made ready for a return trip is a critical component of productivity. The CIGGT analysis "turns" maglev train sets in 45 minutes; Metroliners are rarely turned in less than 2 hours. On average there were assumed to be 48 total daily departures (eastbound plus westbound) in maglev service. Currently Amtrak offers a total of 33 daily departures.

The other difference in maintenance costs relates to the technology itself. Maglev does not have the rotating parts a train has, since it has a linear motor and either no wheels or wheels used only in starting and stopping the vehicle.

Summary of Operating and Maintenance Cost

The maglev cost data relate to the TRANSRAPID 06 test train operated at Emsland, West Germany. Since publication of these studies, TRANSRAPID 07 has gone into testing. Changes incorporated into this latest test model include a 46 percent weight reduction in levitation magnets, reduced aerodynamic drag from a smaller vehicle cross-section, the addition of aerodynamic flaring to the vehicle underside, and improved operational reliability through a redesigned magnet control system and associated gap sensor. Each of these changes is expected to reduce operating and maintenance costs.

Cost increases are also possible. Test track operations are no substitute for revenue service. Meeting published schedules, adjusting to weather and climatic changes, and a host of other challenges that accompany serving the traveling public can lead to unforseen cost penalties. For this reason, although $.05 per passenger mile based on the CIGGT analysis is used in this report, it is important to consider the impacts of higher costs. Therefore, calculations based on $.10 per passenger mile are shown in a subsequent section of this chapter entitled Sensitivity to Varying Cost Assumptions. The lower cost of $.05 per passenger mile reflects the CIGGT analysis and the higher cost contains an allowance for factors which are likely to increase the cost.

Net Revenue

The net revenue in any given year is defined as the difference between the revenue and the operating cost as calculated above. Net revenue for each maglev network was calculated by summing up the net revenues associated with each city pair over all city pairs served by the network. For any given city pair the revenue is equal to the fare (same as the average 1988 air fare) times the number of maglev passengers. The operating cost equals the operating cost per passenger mile ($.05) times the distance, times the number of maglev passengers. In order to get a sense of the magnitude of the cash flows, Table IV-3 has been prepared showing net revenues by year for the same selected city pairs for which numbers of passengers was illustrated in Table IV-2. As with the passenger estimates, it is emphasized that the numbers are for illustrative purposes only and should not be used to make city pair comparisons.

Table IV-3 - Net Revenues for Selected Maglev City Pairs for Future Years

City Pair	Net Revenue ($000,000; 1988 Dollars) Using $.05/mile Operating Cost Year 2000	Year 2010	Year 2020	Year 2030
LA-San Francisco	422	527	652	801
Seattle-Portland	76	98	126	160
Dallas-FTW-Houston	155	204	265	341
Chicago-Detroit	117	145	178	218
Cleveland-Cincin.	40	50	62	76
Phil.-Pittsburgh	62	79	100	125
Atlanta-Nashville	65	87	114	148
Miami-Tampa	87	145	140	192
NYC-Albany	130	163	203	251
NYC-Washington	332	414	513	630

CAPITAL COSTS

Capital costs were considered to be in three categories in this report: fixed facilities, vehicles, and land. Only the fixed facility and vehicle costs have been quantified. Land is discussed briefly along with an analysis of the use of Interstate Highway and other existing rights-of-way.

High speed ground transportation systems are very capital intensive, particularly in terms of the costs of fixed facilities. The capital costs of maglev systems are incurred in order to provide the very high speeds which are difficult to sustain with other modes of ground transportation. As seen in preceding sections of this chapter, the payoffs for these high speeds are found in the traffic attracted to maglev and the consequent passenger revenues and external benefits.

It is particularly difficult to project the capital costs of a technology that has not yet been developed, such as a maglev system based on a U.S.-designed and built product. As a starting point, cost estimates furnished by the Transrapid Corporation with regard to Germany's Transrapid maglev system, along with independently derived estimates of the cost of certain guideway components based on their size and weight, were used to estimate capital costs. Two points cannot be emphasized enough in this regard:

- Capital costs--especially guideway costs--are highly dependent on the particular projects, the nature of the terrain, the soil conditions, and the degree of urbanization. For example, the cost of building a system alongside a flat straight Interstate highway in a rural area is likely to be far less than the cost of building in mountainous terrain or through an established urbanized area.

- The cost of a U.S.-designed system could be significantly different from the cost based on existing technology. In particular, a major emphasis is likely to be placed on ways of reducing the guideway costs in any U.S. development program, and this could reduce the capital cost significantly.

With these caveats, the following assumptions were used as a basis for the cost estimates.

Fixed Facilities Costs

The cost of fixed facilities was assumed to be $15 million per single guideway mile. In most of the routes examined, it was estimated that service could be provided using single (i.e., "single track") guideways with passing sidings provided at intervals sufficient to accommodate headways of 30 minutes between vehicles. Information provided by Transrapid Corporation indicates that passing sidings of a length equal to only 10 percent of the route would be sufficient, provided that schedules were adhered to rigidly. Thus, for most potential maglev corridors a fixed facility cost of $16.5 million per mile was used, taking into account the sidings.

In maglev routes amounting to about 850 miles in total length, it has been estimated that a double guideway would be needed because of the need to schedule departures at less than 30-minute intervals in each direction during the first year of operation. Fixed facilities on these routes, primarily in the Northeast Corridor and on the West Coast, would cost an estimated $30 million per route mile, reflecting the cost of double guideway.

Along another 780 miles of route, approximately, it was estimated that double guideway would be required at some point during a 30-year period after the first year of operation and the fixed facility cost was made to reflect the net present value of the future capacity expansion cost.

The cutoff volume for single vs. double guideway was estimated at 12.6 million passengers per year, in both directions combined, on a given route segment, using a train capacity of 800 (10 car trains with 80 passengers each) and an appropriate distribution of traffic by time period.

It should be noted at this point that representatives of the Transrapid Company believe that the estimated unit cost of fixed facilities should be at least 25 percent lower than $15 million per single guideway mile used as the basic assumption in this report. It has already been noted that such costs would vary greatly with the site and that one cannot necessarily assume that the cost of a Transrapid system would be the same as that of a new U.S. system. Therefore, it is important to consider a later section of this chapter entitled Sensitivity to Varying Assumptions, in which the effect of reducing fixed facility cost by 25 percent is noted.

Vehicle Costs

The cost of vehicles in the first year of operation equals the cost of a vehicle times the number of vehicles needed to serve a given route or route segment. Information provided by Transrapid puts the cost of a vehicle of 80 to 100 seats at approximately $3.6 million. Assuming a conservative 80 seats per vehicle, an average speed of 200 m.p.h., a typical one-way vehicle trip of 200 miles, and a 45-minute turnaround time at each end of the trip, a typical vehicle seat will "produce" 9,120 seat miles per hour when the vehicle is in service. Assuming a typical vehicle must be in service 15 hours/day for 340 days, but that only 90 percent of the vehicles are available for service at a given time, then a vehicle will produce 42 million seat miles per year. At a 63 percent load factor (typical of Metroliners and domestic air carriers), this means a maglev vehicle produces about 26.4 million passenger miles per year.

Thus the number of vehicles necessary for the first year's operation can be approximated by dividing passenger miles by 26.4 million and the cost of this by, in turn, multiplying by $3.6 million. A correction of 28 percent was added to this cost to represent the net present value of the cost of vehicles required in subsequent years during a 30-year project life. An approximation of the total net present value of the cost of vehicles over the life of a project, in 1988 dollars, comes to .174 times the number of passenger miles expected in the first year. This would vary depending on growth rates and vehicle utilization rates.

It is worth noting at this point that for most highly used routes the vehicle capital cost as a percentage of total capital cost is estimated at only about 11 percent. The percentage is less for the less heavily used routes.

Land Costs

Land costs have not been explicitly included in this analysis. Even more than guideway costs they are highly dependent on particular circumstances of the route, including the extent to which it is possible to use existing right-of-way without compromising average speed. For example, about 13 percent of the cost of building the Interstate Highway System represented land acquisition. In the case of maglev, today's greater extent of urbanization and relatively higher land costs could increase that percentage. However, the availability of existing rights-of-way and the relatively narrower right-of-way needed for maglev could lower the land cost. In reviewing this economic analysis, it is necessary to recognize that this cost has been omitted.

Use of Interstate Highway System rights-of-way for maglev systems has been advocated as a way to minimize the amount of new rights-of-way and cost required for a maglev system and to avoid environmental disruption that could result from the creation of a new transportation corridor. Many Interstate Highways were built on rights-of-way that included margins of land between the roadway and the right-of-way boundary which would be sufficient to accommodate a maglev system. In many locations, however, such as rapidly growing urban areas, any originally unused rights-of-way have been committed to highway expansion or other transportation use. The availability of highway rights-of-way, therefore, must be assessed on a case-by-case basis.

Data were obtained from the Federal Highway Administration's Highway Performance Monitoring System (HPMS) to consider the suitability of using Interstate highways for the potential maglev route segments identified in Figure IV-3. It was found that a curve causing various speed restrictions at or below 227 mph would be expected to occur on an Interstate highway every 1.37 miles. This frequency of curves could significantly lower the average running speed of a maglev system, if it were to use an Interstate highway right-of-way exclusively. The HPMS does not record curves of less than .5 degrees, but such curves could limit maglev speeds to a level between 227 and 300 mph. Based on HPMS data, grades found on the Interstate Highway System are not likely to be a basic constraint to maglev use. The HPMS does not record data for vertical curvature, and it is difficult to determine this condition from topographic maps. However, the vertical curvature on the Interstate System could produce either a speed restriction or an unacceptable ride experience, especially while cresting a hill. To avoid minor dips, and for security reasons, maglev alignment would be likely to be elevated. In some locations, long span bridges across the highway or excursions from the right-of-way could become necessary to avoid sharp curves.

One specific route, the approximately 126-mile San Diego/Los Angeles route, was analyzed in some detail, using the HPMS data and U.S. Geological Survey topographic maps. An existing railroad alignment was also reviewed. Given the degree of curvature and other limitations, it was found that speeds above 200 mph would be difficult to achieve on these routes and that the average speed would be considerable below maglev's potential in a less constricted environment.

To put the matter of potential right-of-way costs in some perspective, a hypothetical 60-foot wide double track maglev corridor equals approximately 7.5 acres per mile. A cost of $10,000 per acre (a very high figure for strictly agricultural property) equates to only $75,000 per mile, which is small in comparison to fixed facility and vehicle costs. Exurban/suburban values of $100,000 per acre for raw land would still equate to only $.75 million per mile, or less than 5 percent of fixed facility costs. Estimating the cost of acquiring improved property in an urban setting is a case-by-case matter. In general, the dominant force regarding right-of-way costs in urban areas will be the presence or proximity of buildings, not the land area to be acquired.

Decisions on right-of-way use can be made only on a case-by-case basis. Clearly, in most cases, the exclusive use of Interstate highway or any other existing right-of-way will not permit maglev systems to reach their full operating potential. Judicious combinations of existing rights-of-way, with new alignment where necessary, can provide access to city centers and other destination points, may limit capital costs of new systems and limit the need for new right-of-way acquisition. A more complete discussion of Interstate and rail rights-of-way is contained in Appendix IV-B.

ECONOMIC ANALYSIS

NET REVENUES VS. CAPITAL COSTS

The revenue and cost estimates described above were used to analyze each of the routes and networks shown in Figure IV-1. As a further refinement, each network was divided into a series of links, each connecting major adjacent city pairs and carrying on it trips between several different city pairs which must use that link as part of the total trip. In this way it was possible to assign to each link a portion of the revenue for each relevant city pair, in proportion to the distance traversed on that link, an operating cost dependent on passenger miles on the link, a fixed facilities capital cost dependent on the length of the link and whether single or double guideway, as well as a vehicle capital cost dependent on passenger miles. Using this approach, net revenue (revenue minus operating cost) and capital cost were calculated for each link, with all revenues and costs discounted to a common base year, assumed to be 1998, or the midpoint of construction if all facilities were opened simultaneously in year 2000. Realistically, such an event would never occur, but the assumption was made to put all links on a common basis.

Associated with each link are estimates of the present value of net revenue and capital cost, as well as physical measures of the magnitude of fixed facility construction and related vehicle manufacturing. In the aggregate these estimates provide an approximation of the size of the market for maglev facilities and vehicles in the United States. Such aggregate approximations, as shown in Figures IV-3 and IV-4 provide a comprehensive picture of the size of this market subject to further refinement when better estimates become available.

For example, Figure IV-3 illustrates that about 850 route miles (1,400 miles of single guideway) could be built to accommodate the first year's traffic on maglev links which are estimated to be self-sufficient, i.e., links where the net revenues exceed capital cost. Similarly, Figure IV-3 shows that about 3,000 route miles (4,000 miles of single guideway) are associated with links whose net revenues cover at least 50 percent of capital costs.

In following the discussion regarding net revenues vs. capital costs and public benefits, particularly Figures IV-3 through IV-6, one should recognize that single point estimates such as the above 850 route miles should really be considered as ranges, dependent on estimates of the costs and revenues associated with providing maglev service. The ranges are illustrated in Figure IV-7 and Table IV-4.

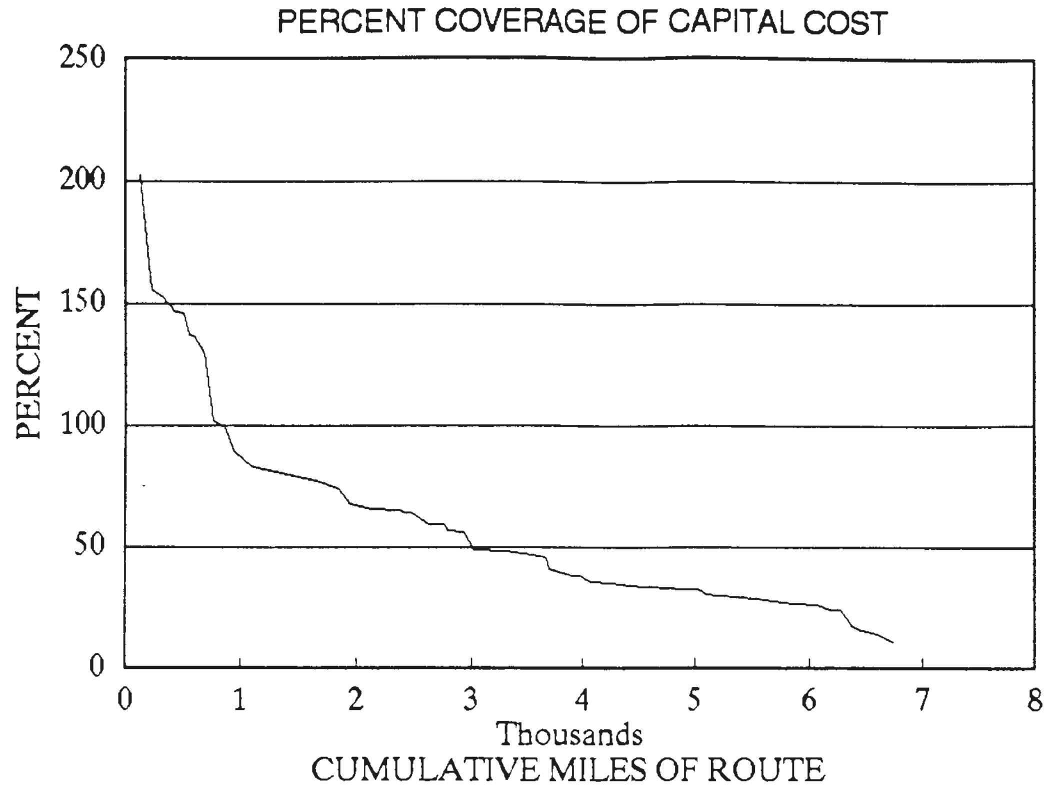


Figure IV-3

Figure IV-4 shows that about 415 vehicles of 80 seats each would have to be manufactured to accommodate the first year's traffic on maglev links in the U.S. where net revenues cover at least 100 percent of capital costs, while 925 would be required for links with net revenues covering at least 50 percent of capital costs. Since we can expect traffic to increase by over 50 percent during the first 20-year period of operation, then the overall market for vehicles for the first 20 years would be at least 50 percent higher.

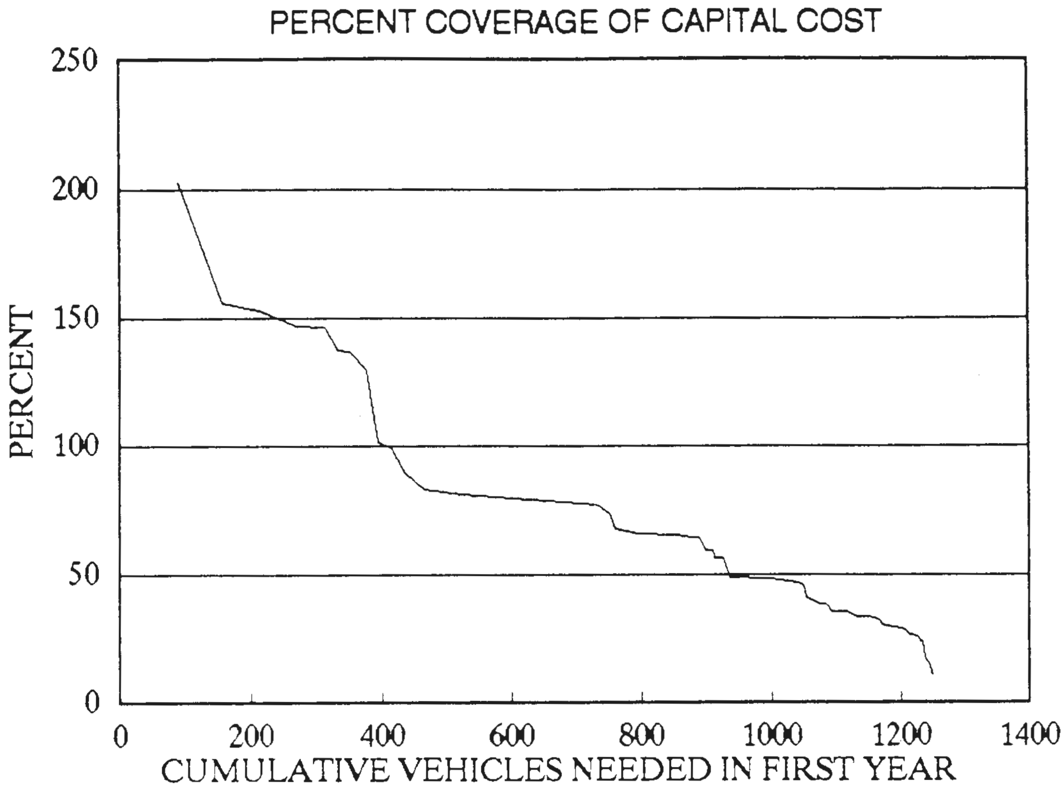


Figure IV-4

Figure IV-5 illustrates aggregate capital requirements in terms of the value in 1988 dollars discounted to year 1998. For projects covering at least 100 percent of capital costs, $24 billion would be needed. For projects covering at least 50 percent of capital costs, $66 billion would be needed. Figure IV-6 can be used to illustrate another point--namely, if all user revenues were pooled into a fund to help finance projects which covered less than 100 percent of capital costs, about $66 billion worth of projects could be built and operated which, <u>in the aggregate</u>, would cover 100 percent of capital costs. While a private operator would be unlikely to invest in these lower ratio projects without some public sector capital contribution, a public entity could do so. An analogy to this is the example of the Interstate Highway System whose "weaker links" are, in effect, cross-subsidized by user fee revenues (gas tax) from the more heavily traveled segments.

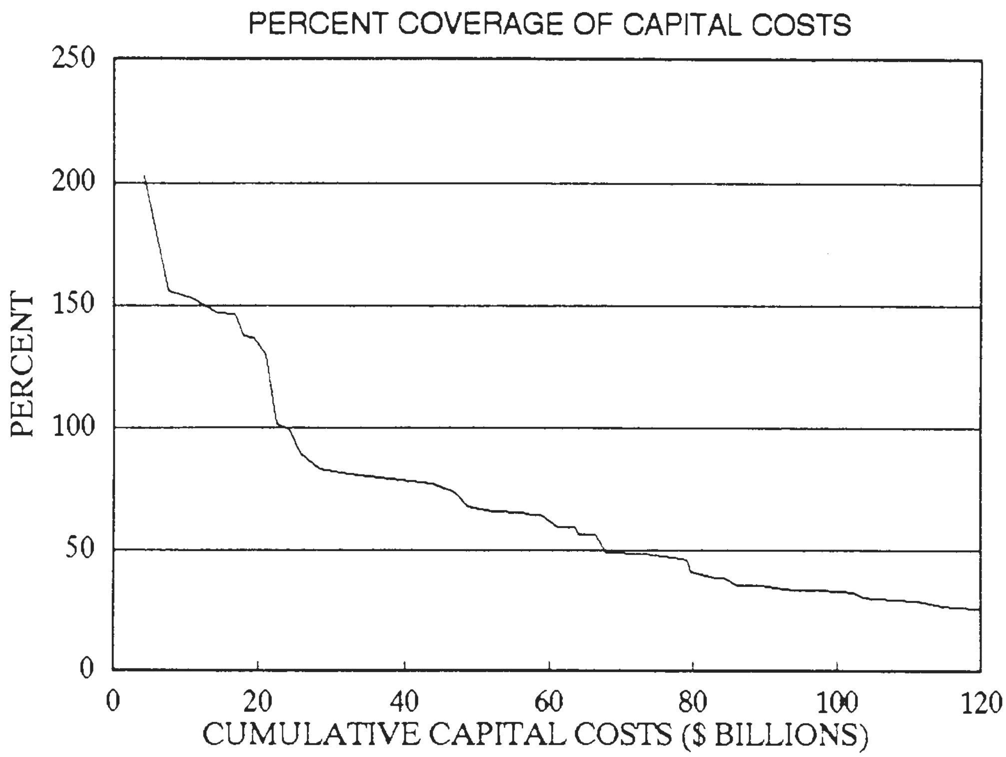


Figure IV-5

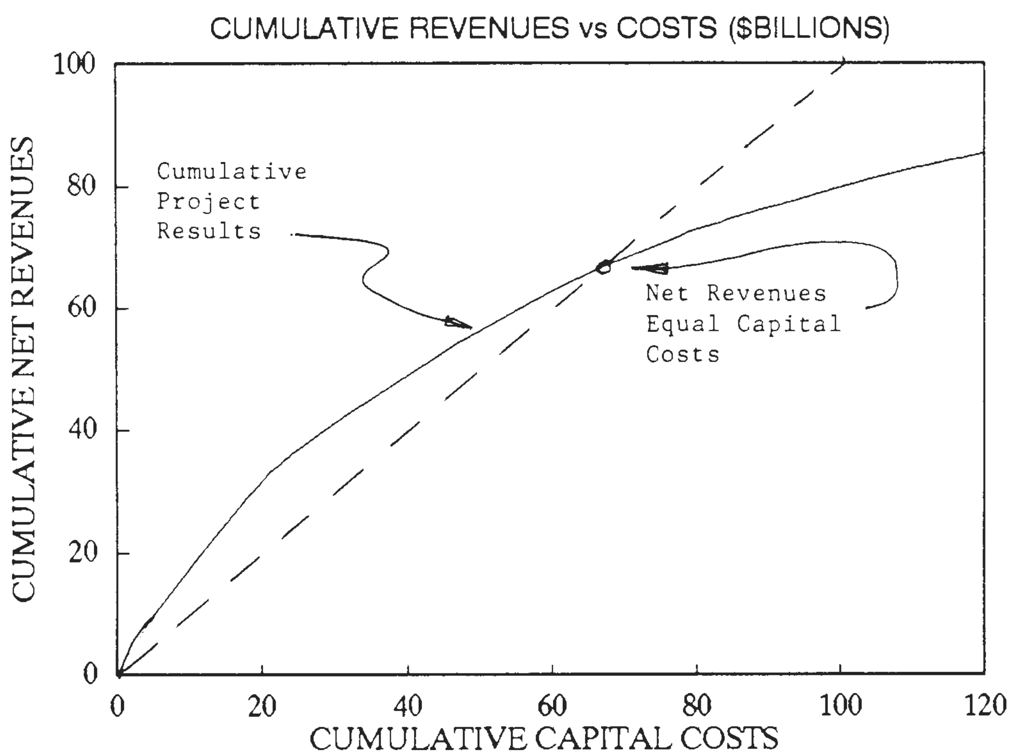


Figure IV-6

EXTERNAL (PUBLIC) BENEFITS AND COSTS

Major capital projects, particularly those that expand transportation facilities, result in external costs and benefits to the community, the region, and the nation that are difficult to calculate, but that cannot be ignored when analyzing transportation options. New transportation facility construction requires massive amounts of land, usually entailing considerable environmental disruption. Also, affected communities can be expected to raise strong opposition if operations are perceived as noisy, dangerous, and likely to further crowd local streets. The current reliance on energy intensive highway and air travel results in substantial external cost, reflecting the fact that transportation accounts for nearly 30 percent of all energy consumed annually in the U.S. As a percent of petroleum products supplied to end-use sectors of the U.S. economy, transportation accounts for over 62 percent, a 10 percent point increase in share since 1970. The cost is further compounded by the increasing share of petroleum that is imported. Land use, noise and air pollution and energy conservation are all identifiable external factors that must be analyzed when considering transportation alternatives.

A maglev service would not escape external costs. Even if existing highway and railroad rights-of-way, many of which have been in place for years, could be spliced together to form the right-of-way for a maglev guideway, a considerable amount of new land might be needed. The absence of contact friction during operations would reduce, but not eliminate, noise for maglev. At high speeds aerodynamic resistance is the primary source of noise. A net decrease in oil imports is expected because, unlike air and highway vehicles, maglev relies exclusively on electricity for power, and only about 5 percent of BTU output of the nation's public utilities is accounted for by oil. Air polluting emissions caused by maglev trains would occur at generating sites, where they are more easily controlled than at the numerous scattered and mobile locations of airplanes and cars.

The following section of the report discusses external benefits and costs of existing transportation options and how maglev service could impact each. Quantification is presented wherever existing data are available. Where data are not available, benefits and costs are identified and an attempt is made to evaluate their importance in relation to other benefits and costs.

Petroleum Consumption

One benefit of a maglev system would be to divert travelers from energy intensive modes that are entirely dependent on oil, much of it imported, to a system that makes more efficient use of energy with virtually no demand for oil, domestic or imported.

Argonne Laboratories, under contract to the U.S. Department of Energy, compared energy intensities for a 300 mile trip in 2010, for maglev, air and auto modes. A 60 percent load factor was used for maglev and air service. Energy consumption per passenger mile of maglev and air service is estimated at 3,450 and 10,300 BTUs respectively. Auto BTUs of 2,750 are calculated on 1.9 passengers per vehicle and 27.03 miles per gallon.1/ Using these estimates, assuming about half of the passengers diverted to maglev from other modes come from air and the rest from auto, and assuming that about 15 percent of maglev passengers are new trips (not diverted) lead to the result that the typical maglev trip represents an energy saving of about 2,100 BTUs per maglev passenger mile.

The above information can be used to estimate the first year energy saving associated with maglev systems of different extent. For example, a maglev system consisting of only links covering total costs and costing about $24 billion (see Figure IV-5) could carry 11 billion passenger miles in the first year and save 23.1 trillion British Thermal Units (BTUs) of energy. The savings in petroleum energy would be greater, at about 59 trillion BTUs, or about 10.2 millon barrels of petroleum per year, since virtually all air and auto energy comes from petroleum while only about 5 percent of maglev energy comes from petroleum. Though this is a substantial amount, it represents only a very small portion of U.S. petroleum consumption.

Air Pollution

Maglev's contribution to cleaner air would result from travelers selecting it as the preferred transportation mode and abandoning more polluting auto and air modes. Notwithstanding significant progress in cleaning the exhaust of aircraft and auto engines since the Clean Air Amendments of 1970 and 1977, these modes are singularly responsible for a large fraction of carbon monoxide (CO) and ozone pollution in urban areas. Between 1970 and 1988 vehicle registrations in the U.S. increased at an annual rate of nearly 3 percent to 184.4 million, while population increased only at slightly more than 1 percent per annum over the same period. The Environmental Protection Agency (EPA) reports that two-thirds of the nationwide CO emissions are from transportation sources, with the largest concentration coming from highway vehicles.

Research into the likely reduction in air pollutants from the introduction of maglev service has been conducted by the staff of the Florida High Speed Rail Transportation Commission.2/ Estimates are expressed as net reductions after taking into account increased demand for electricity resulting from maglev service. The work focuses on central Florida utilities and their unique mix of energy sources for the generation of electricity. Using Florida data to estimate reductions in air pollutants would probably provide a different estimate than if one were to look at the U.S. as a whole because of the different mix of power plant fuels. For example, less than 24 percent of kilowatt hours generated in Florida use coal as an energy source, while for the U.S. as a whole 57 percent of kilowatt hours are supplied by burning coal.

The Florida work, in its published form, combines auto and aircraft pollutants when calculating net pollution reductions resulting from maglev service. The report estimates that carbon monoxide (CO), produced by the incomplete burning of carbon in fuels, would be reduced .0136 pounds for each passenger mile of maglev service that replaced air or auto travel. Based on the 11 billion passenger miles forecasted for the maglev links, which cover costs, a total of 75,000 tons of CO emissions per year would be eliminated. For nitrogen oxides (NOx) and volatile organic compounds (VOC) the reductions are 19,000 and 13,000 tons respectively. On a nationwide basis, these represent very small percentages of pollution from transportation sources.

Sulfur oxides pollution would increase very slightly with maglev because of the widespread use of coal in electric power generation.

<u>Congestion and Avoidance of Investment in Highway and Airport Capacity</u>

A newly constructed maglev line can provide external benefits by diverting traffic and lowering congestion levels on highways and at airports and avoiding the construction of new highway and airport facilities.

<u>Highways</u>

Congestion on the nation's highways, including virtually all segments of the Interstate in urban areas, has reached alarming levels. A report prepared for the Federal Highway Administration (FHWA) in October 1989 calculated a roadway congestion index (RCI) for freeways and principal arterials in 39 urban areas, and presented trends in RCI levels between 1982 and 1987 3/. In 1982 the average RCI for cities in the west and south stood at .87; by 1987 the measurement had increased to 1.00. For cities in the north and midwest the measurement increased from .91 to 1.00 over the same five years. Not surprisingly Los Angeles, with a congestion index of 1.47, led all cities studied, while Washington, D.C. at 1.25 led northeast and midwest cities. The congested cities of New York, Boston and Chicago were not included in the analysis. The report states that congestion index values "greater than 1.0 indicate undesirable mobility levels within the urban area."

The report estimates (1987 dollars) the economic impact of traffic congestion by taking into account the cost of travel delay, excess fuel consumption and higher automobile insurance premiums. For the 39 urban areas studied the economic impact was estimated at $41 billion annually. Inflation alone raises the amount to $44 billion by 1989, or over a billion dollars per city per year.

Using a slightly different measure of congestion--volume over service flow (v/sf)--the Federal Highway Administration reported in Highway Statistics 1988 that over 50 percent of the urban Interstate network had v/sf ratios greater than .71. Travel speeds decreased and congestion increased at ratios over .77. FHWA also reported that between 1985 and 1987 the percentage of peak-hour travelers experiencing congestion rose from 61 to 65 percent. Productive hours lost due to highway congestion now exceed 2 billion annually, and cost the national economy approximately $80 billion per year. By the year 2000, 70 percent of peak hour travelers will experience congestion, while the cost will exceed $100 billion.

Airports

Airport congestion may be worse than highway congestion, although, of course, fewer people are affected. The Federal Aviation Administration (FAA) has identified 21 airports which experience air carrier delays of at least 20,000 hours per year, including three with over 100,000 hours. By 1997, 34 airports are projected to experience this level of congestion delay. These projections anticipate all planned improvements. In terms of traffic volumes, these 34 airports would account for approximately 70 percent of all enplaned passengers.

The nation pays a large price for such delays. Airports that experience more than 20,000 hours of annual flight delay cost the airlines and U.S. businesses over $5 billion. By 1997 when approximately 34 airports will be congested, the cost is expected to reach $8 billion in today's dollars.

These data, as disconcerting as they may seem, could understate the problem. The FAA will publish in the summer of 1990 its "Terminal Area Forecasts FY 1990-2005." It will rely heavily on recent traffic forecasts of air passenger travel.4/ Between 1989 and 2001 passengers boarding on U.S. airlines (major commercial carrier and commuter) are expected to increase from 451.6 to 741.7 million, a 4.2 percent per annum growth rate. Estimates of delay and severe congestion are expected to be revised based on current growth expectations that exceed earlier estimates.

Airport and Highway Investment Cost Saving Implications

The construction of each maglev link between cities will have different implications with respect to the amount of highway and airport capacity for which it can be said to substitute. For example, if a maglev link were put into service between a pair of cities with no congestion problem either at the airport or on the connecting highway, then there would be no external benefits to be gained from the avoidance or deferral of new airport and highway capacity construction. Also, it is difficult to generalize about the cost of an increment of capacity. In some locations, capacity expansion may be just a matter of adding an already planned runway or adding a lane of highway which had already been provided for in current highway and bridge designs, or perhaps enhancing the capacity of existing runways or highway lanes using technology which may permit closer spacing of vehicles. Finally, it may be that a new highway or airport expansion project is justified for reasons not directly related to a new maglev link and would be built in any case, independent of the maglev project.

Having stated these points, it is nevertheless instructive to attempt to quantify--and cost out--the airport and highway investment, in aggregate terms, which maglev systems of different extent would permit the public sector to avoid. The benefits of avoiding or deferring these investments could be attributed to the maglev project and thereby could provide a large part of the economic justification for a project which may not be capable of paying back all its capital costs.

Consider, for example, the 11 billion passenger miles (representing approximately 62 million trips) which would occur on the maglev links covering at least 100 percent of cost (Figure IV-5) if all were available for service in the year 2000. Assuming 15 percent of these are new trips (not diverted from other modes) and that half of the remainder came from auto and the rest from air, this would represent a diversion of 4.7 billion passenger miles from highways and 26.5 million enplanements from airports. Assuming a temporal distribution of auto traffic (by month, by day of week, by hour) typical of intercity trips, the auto diversions would equate to the need to provide 400 lane miles less of capacity. The air diversions amount to about the capacity of one top ranking airport such as Atlanta's, or the equivalent of about two airports that accommodate fewer enplanements per aircraft operation, such as Boston's. One and a half airports will be assumed. It was assumed further that only about 65 percent of this capacity equivalency would actually require new construction (the remainder, as discussed above, being absorbed by existing capacity or new technology, or being built for other reasons). Assuming the cost of new highway construction at $3.2 million per lane mile, and airport construction at $4 billion per equivalent airport of 450,000 annual operations, the one time savings can be calculated at $4.5 billion, thereby providing a considerable additional benefit, relative to the estimated $24 billion cost of the maglev systems which cover costs.

OTHER ECONOMIC IMPACTS

It is outside the scope of this report to estimate the aggregate economic impact of maglev investments beyond the transportation costs, revenues and external benefits and costs already discussed. Such phenomena as the multiplier effect on GNP and jobs are often relevant only in situations of less than full employment and sometimes only on a regional basis. Care must be taken in such estimates not to count as national benefits what in reality are regional shifts and not to attribute to maglev, in particular, benefits which in periods of less than full employment could also accrue as a result of other forms of investment. However, one economic benefit is worth mentioning, even though quantification is elusive, that is, the effect of investment in a new technology on the diffusion of the components of that technology, often in unforeseen ways, into other fields. This phenomenon is sometimes known as "spinoff."

Any investment in a maglev transportation system will be aimed at increasing traveler mobility, decreasing congestion, conserving energy, and reducing harmful emissions. An important early decision will be selecting either an electro-magnetic or electrodynamic system to raise maglev vehicles off their guideways. If an electrodynamic system is chosen, significant advances can be expected in superconductivity--the development of materials that, when cooled to extremely low temperatures, conduct electrical current with no resistance and no energy losses. Recent breakthroughs in materials composition have demonstrated that superconductivity can be achieved at much higher temperatures than in the past. If these materials can be practically applied to the maglev systems, it could mean that liquid nitrogen could be substituted for liquid helium as a coolant at significant cost savings. As newer materials are developed, commercial application of superconductivity will become more and more attractive. Maglev transportation could both be an application of the latest superconductivity technology and an opportunity to advance the technology in a real world environment.

Superconducting materials have the potential for wide application in computers and advanced electronics, medical diagnosis, electric motors, and magnetic separators. Electric motors, for example, using superconducting coils could be one third the size and weight of conventional copper coiled motor and deliver more power at greater efficiency.

Another industry, now relatively underdeveloped in the U.S. relative to other countries is the use of semiconductors in the delivery of large amounts of power, as required in maglev systems and high speed rail applications. Improvements in this technology for maglev could find applications in power plants, other transportation systems and other areas where large amounts of energy are consumed or transmitted.

Still another spinoff area could involve advances in computer integrated design, fabrication, and assembly of maglev vehicles and guideways. Transrapid International has indicated that this concept can produce significant construction and manufacturing cost savings and could be extensively used in building a new Transrapid system.

While spinoff considerations are to some extent common to other high tech investments, maglev would appear to offer particularly significant opportunities, and these should not be discounted in any decision to invest in the technology.

SENSITIVITY TO VARYING COST ASSUMPTIONS

Fixed Facility Costs

The cost of fixed facilities represents a very high percentage of the total estimated cost of providing maglev transportation. It has already been stated that even for the more heavily used facilities, the cost of vehicles represents only about 11 percent of the capital cost, exclusive of land acquisition. Also, even for heavily used facilities, capital costs represent as much as 80 percent of total capital plus operating costs. The cost of fixed facilities for the more heavily used maglev links would then be about 70 percent of the total maglev cost exclusive of land. The percentage would be even higher for the less heavily used links. Therefore, it is extremely important to have the most accurate possible estimate of fixed facility costs.

Fixed facility costs are also highly dependent on terrain and soil conditions. In particular, the cost of $15 million per single guideway mile contains only a nominal allowance for earthwork costs. Requirements for earthwork, tunnels, and long span structures in mountainous terrain and for bridges over waterways could easily increase the fixed facility costs by a significant margin. The high cost of construction and utility avoidance in urban areas could have a similar effect. At the same time, it is also possible that a new U.S.-based design that paid particular attention to guideway cost reduction through lighter weight construction could actually produce a lower cost. The same result might be achieved if it were found to be feasible and practical to run the maglev guideway along the ground instead of on structures. In the economic analysis, it was assumed to be on structures.

If, for example, the fixed facility costs were 25 percent higher than assumed ($18.75 million per single guideway mile instead of $15 million) then the number of route miles whose costs are covered at least 100 percent would be about 700 instead of 850, and the number whose capital costs are covered at least 50 percent would be reduced to 2,500, instead of 2,900. If fixed facility costs were 25 percent lower, then 1,300 route miles would have costs covered 100 percent and 3,700 would have capital costs covered 50 percent.

Vehicle Costs

A corollary to the importance of fixed facility costs is the relative unimportance of vehicle costs when they represent only 11 percent or less of total capital costs. The assumed cost of $3.6 million per vehicle, or $45,000 per seat of capacity, is already about twice as high as for a typical intercity rail passenger car and it is unlikely that vehicle cost inflation (or vehicle cost decreases) would have a significant impact on the results of this economic analysis.

Operating Costs

As already noted, there is enough uncertainty about the operating cost assumption of $.05 per passenger mile that an alternate calculation based on $.10 should also be made. If this is done, then the net present value of the net revenues (i.e., revenues minus costs) would decrease by between 11 percent and 33 percent, depending on the particular corridor, with an overall average decrease of 23 percent.

Decreasing net revenues by about 23 percent would have an effect on coverage of capital cost similar to the effect of a 25 percent increase in fixed facility costs mentioned above. That is, it would reduce the number of route miles on self-sufficient links from 850 to 700 and on links with 50 percent coverage of capital costs from 3,000 to 2,500.

SENSITIVITY TO OTHER TRANSPORTATION MODE ASSUMPTIONS

Aviation and Highway Congestion

The potential for significant airport/airway and highway congestion has already been discussed. Yet, in the basic economic calculations of maglev usage it was assumed that travel times by auto and commercial air would be about the same in future years as they are today. Actual levels of congestion and their effects on intercity travel times are difficult to predict because of the uncertainty regarding the ability of capacity to keep up with growth either through new construction or through technological improvements such as avionic devices to reduce safe aircraft spacing or devices to reduce automobile spacing on highways.

A rough idea of the effects of congestion on the relative attractiveness of maglev vs. highway and air travel can be gained by recalculating the relationship between the maglev market share and distance between cities (Figure IV-2) using plausible travel time increases in the air and highway modes that could result from congestion. That was done by making the following two travel time related changes in the basic assumptions underlying the relationship:

(1) 15 minutes was added at each end of the air trip, for a total 30-minute increase in air travel time for each trip.

(2) Average speed via highway was reduced from 50 mph to 45 mph.

The result of these assumptions was to change the shape of Figure IV-2 in such a way that it produced a 21 percent to 30 percent increase (with an average increase of 27 percent) in the net present value of net revenues. This would increase by about 27 percent the ratio of net revenues to capital cost and result in a larger number of projects being capable of covering capital cost with revenues. For example, at least 100 percent of capital costs would be covered on 1,300 miles of guideway instead of the 850 with the basic assumptions.

Competitive Behavior

One of the key assumptions in this analysis was that maglev would have to compete with airlines for its customers and that the maglev fare charged in each city pair market would be equal to the average air fare for that market in 1988 taking into account all the discount and premium fares offered and the relative use of each fare by airline travelers. This assumption influenced both the average revenue collected for each maglev trip and the relationship between maglev market share and distance.

In reviewing the data on 1988 average air fares, it was clear that there is a wide variation in average air fares even among city pair markets with roughly the same distance between cities. This finding is not surprising since average fare levels can be expected to vary according to the cost of serving different airports, the size of the market, and the degree of competition with other air carriers and other modes. The finding suggests that an air carrier serving a maglev market, particularly one which has above average air fares for its distance range, could well decide to depress its fares in order to meet the maglev competition. The extent to which an airline can charge low fares indefinitely is of course limited by its costs, but if this type of competitive reaction is widespread it could lead to financial difficulties for maglev sponsors and fewer systems being capable of covering 100 percent of capital costs with their revenues.

Just as airline competition could pose problems for maglev, particularly in the startup phase, it is also possible for airline cooperation to enhance the prospects for maglev, particularly if airline companies had a financial stake in maglev lines. It has already been noted that maglev could, by absorbing short haul airline travelers, provide more takeoff and landing "slots" for more lucrative airline long haul business. In such a case, an airline which operates both long and short haul service might be willing to "cede" the short haul market to maglev and even to make special through ticketing arrangements to accommodate transfers from its long haul flights to the short haul maglev service. Such actions would improve financial performance and thus increase the number of systems covering 100 percent of capital with revenues.

Investment in Other High Speed Ground Transportation (HSGT) Systems

The preceding several paragraphs have discussed alternative assumptions and their effects on the economic analysis. In that analysis, maglev was assumed to be in competition with air and auto travel for its share of the travel market in those corridors where a maglev system could exist. It was also assumed that maglev would not be in competition with high speed rail or even another parallel maglev route, in the sense that there would not be two or more parallel high speed ground transportation carriers splitting up the market. Such an assumption is certainly reasonable since it is unlikely for some time that there would be enough traffic to support a competing system on any U.S. route. However, in deciding whether to develop a new U.S.-based maglev technology, it is logical to ask the question whether the existence of other technologies (high speed rail and other maglev) might lead to selection of these other technologies for some of the routes that are attractive for maglev implementation. In other words, while the market on any given route is unlikely to be split among two or more high speed ground transportation technologies, at least initially, there is certainly a possibility that the U.S. market as a whole could be split among different technologies--each one getting one or more routes or networks.

The likelihood of choosing a particular technology for implementation on a given route depends on several factors:

(1) Availability of that technology within a reasonable time frame.

(2) Performance advantages of that technology as perceived by potential users and interpreted by those making the implementation decision.

(3) Cost.

Availability

Certainly, a U.S. maglev has a disadvantage at this point since it is likely that an 8 to 10-year development program would be required before the U.S. system could be available for revenue service. The Transrapid maglev has already undergone its development program and now has only to be proven in a demonstration project, which could occur as early as 1994 or 1995 in Orlando, Florida. Transrapid technology is being given serious consideration for implementation in at least one location--Los Angeles-Las Vegas. Should this happen, that market could be lost to a U.S. system for many years. High speed rail systems can be considered off the shelf technology, for all practical purposes, and there is a good likelihood that one will be installed to serve Miami, Orlando and Tampa.

Performance

It is very probable that a U.S. maglev would offer a maximum speed superior to that of high speed rail. Although the French TGV train, during a series of test runs has set the world speed record for passenger trains at 320 mph, the technology using steel wheels on steel rails is unlikely to achieve such speeds in revenue service. High speed trains are not expected to operate in revenue service at much beyond 200 mph and yet maglev designers--even with present maglev technology--fully expect 300 mph speeds in regular service. At the same time, it is necessary to keep the importance of maximum speed in perspective. The practical limitations of the right-of-way and the need for enroute stops will result in smaller differences in average speed between maglev and high speed rail.

A U.S. maglev can also provide other superior performance characteristics, including lower noise output, somewhat lower energy consumption and pollution, faster acceleration and, at very high speed, potentially better ride quality. There is one disadvantage, although it might be overcome if overcoming it is explicitly included in the development program as a goal. That is the fact that it is likely to be much more difficult to permit maglev vehicles to share existing railroad tracks within cities in order to avoid the high costs of new rights-of-way or underground facilities.

Cost

Several studies have made comparisons between high speed rail and maglev on specific potential routes. The most detailed of these was the previously cited study by the Canadian Institute of Guided Ground Transportation (CIGGT) for the Las Vegas/Los Angeles route. That study, based on comparisons between Transrapid and TGV, concluded that the operating costs per passenger mile for a maglev vs. a high speed rail system would be slightly lower and that maglev would attract more traffic, but that the capital costs would be about 24 percent higher. Capital costs are of major importance as already noted since they represent a large proportion of total costs. One of the major reasons for a higher capital cost is the fact that the entire maglev guideway is assumed to be mounted on a steel or concrete structure above the ground, while much of the high speed rail guideway can be essentially at ground level with grade separation. One of the major areas of maglev research is likely to be in guideway cost reduction.

Conclusions on Implications of Other HSGT Technologies

A detailed comparison of U.S. maglev vs. high speed rail or existing maglev technology is beyond the scope of this report and can, in any case, be done only in the context of the specific physical characteristics of individual routes. Nevertheless, the following conclusions can still be drawn with regard to the probability that these other technologies will be implemented instead of a U.S. maglev in a number of locations.

- There is a very real possibility, indeed a probability, that states, localities and the private sector would implement a high speed rail system or the Transrapid maglev system in some corridors simply because of the availability of these technologies in advance of a potential U.S. product, thus delaying implementation of a U.S. maglev system in these locations when available.

- At the same time, along some of the routes best suited to maglev, including the Northeast Corridor and San Diego/Los Angeles, there appears to be an institutional commitment to near-term incremental improvement to existing rail systems. In these cases, it is plausible that the incremental approach would "hold off" more intensive investment in HSGT and until a U.S. maglev would be implemented when it becomes available.

- It appears likely that a U.S. maglev system could deliver performance characteristics significantly superior to those of high speed rail. It also appears possible that improvements can be made in relation to existing maglev technology.

- Although it also appears that the cost of providing maglev transportation with existing technology--largely dominated by capital costs--is likely to be somewhat higher than for high speed rail, nonetheless, there appear to be opportunities for lowering the cost of a U.S. product.

- The potentially superior performance and potentially equal or lower cost of a U.S. maglev compared to existing HSGT technology suggest that it could be the system of choice in U.S. markets.

SUMMARY OF SENSITIVITY ANALYSIS

The amount of maglev service where revenues would cover costs varies depending on assumptions for future scenarios. Results are summarized in Table IV-4 and Figure IV-7. Under unfavorable assumptions (a 25 percent increase in fixed facility costs and a doubling of operating costs) the amount of service projected to cover all operating and maintenance costs decreases substantially. Still another, more pessimistic, scenario can be constructed using the unfavorable assumptions and assuming that ridership is 25 percent below expectations. In that case, even the best route segment would fall just short of covering costs.

On the favorable side, improved guideway design or construction methods resulting in a 25 percent reduction in fixed facility costs and increased air and highway congestion would result in a much larger self-sufficient network. This result serves to underline the need for further technical and economic investigations to narrow the range of uncertainty.

Table IV-4 - Miles of Route Covering Operating Cost Plus Different Percentages of Capital Cost

	Unfavorable Scenario	Base Scenario	Favorable Scenario
100 Percent of Capital Cost	< 500	850	2,600
50 Percent of Capital Cost	1,500	3,000	5,000

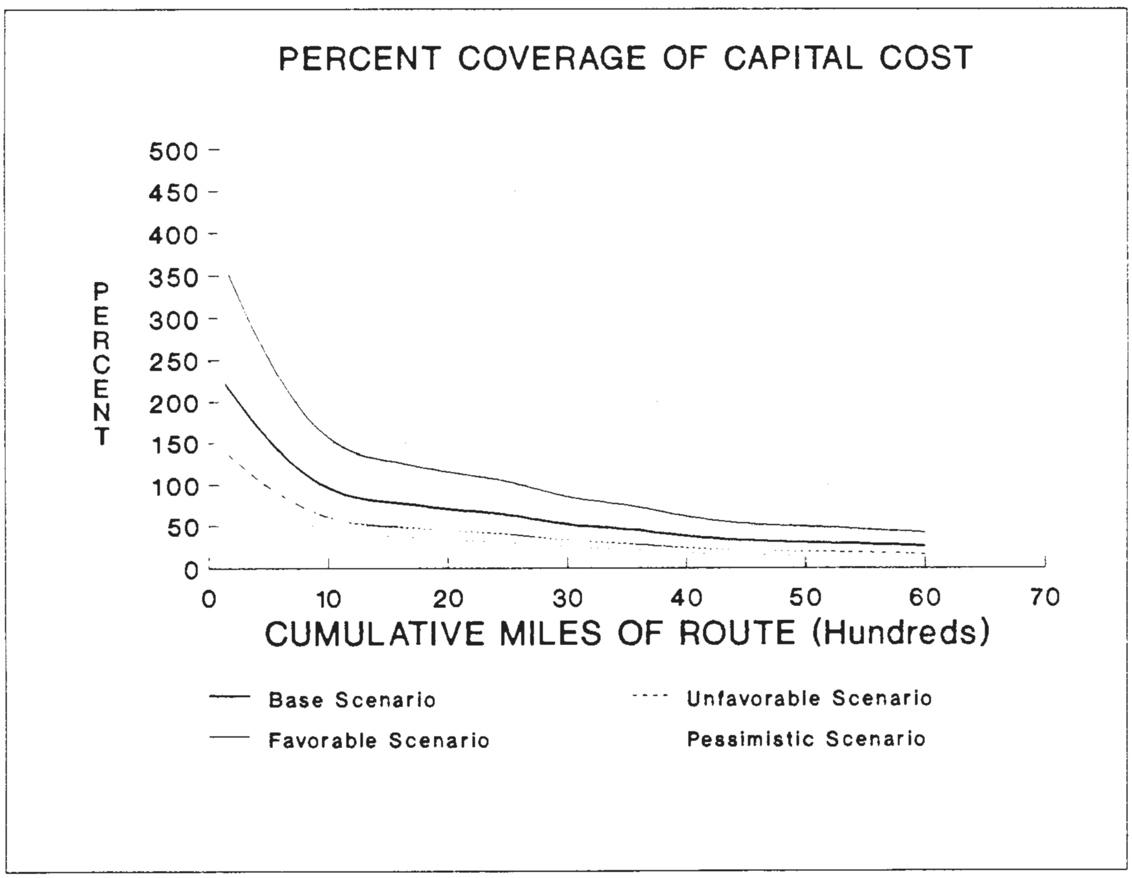


Figure IV-7

DISCUSSION OF UNCERTAINTIES AND NEED FOR FURTHER INVESTIGATION

During the course of this economic analysis it has become evident that there are numerous uncertainties involved in estimating costs, revenues and other benefits that require further investigation before definite conclusions can be drawn regarding the economic feasibility of commercial maglev systems, particularly as it relates to a new U.S. maglev development program. A list of the major uncertainties and the further investigation needed is given below.

CURRENT TRAVEL IN MAJOR MARKETS

Though it is known with reasonable accuracy how many people travel by air and rail between all major city pair markets, automobile trip data are much more spotty. Surveys are needed to determine this in certain key locations. For smaller markets where surveys may not be cost-effective, a better method is needed for estimating auto trips on the basis of information on other trips and related data.

FACTORS INFLUENCING MARKET SHARE

Better understanding is needed of the relationship between the service attributes of intercity travel modes and their market shares, as well as "induced trips" stimulated by the presence of a new mode of travel. Further research is needed on how consumers will react to maglev, as well as how they would react to high speed rail if either of these systems were introduced.

FUTURE TRAVEL GROWTH

In this study, future intercity travel, based on past trends, was assumed to grow in proportion to real income. Further research is needed into travel by socio-economic and demographic characteristics of passengers and business/non-business trips, together with projections of composition of the population in the future.

FREIGHT AND COMMUTER USE

Although it is likely that maglev systems would be justified primarily in terms of intercity passenger markets, it is possible that both time sensitive freight shipments, including mail, and some commuter service on intercity routes could contribute significant net revenues without impeding the intercity operation. This report did not attempt to quantify such contributions and research is needed on the potential.

COSTS

As a component of further research to be conducted on the technical characteristics of what could become a U.S. maglev technology, attention must be given to the probable costs of building and operating such a maglev system. The cost relationships should be derived in such a way that costs can be calibrated against actual cost experience on existing HSGT systems, and that the relationship can be used to compare the costs of alternative new U.S. maglev system designs.

COST/PERFORMANCE/RIGHT-OF-WAY TRADEOFFS

Because of the importance of fixed facility costs a more detailed investigation is needed on a site-specific basis. This must be coupled with analysis of potentially available rights-of-way, particularly Federal-aid highways, and their suitability for maglev use.

NETWORK AND MARKET CONSIDERATIONS

The analysis in this report focused on serving major air travel markets of less than 500 miles in distance between cities. Theoretical networks were formed by connecting some major markets. Further analysis is needed of the network concept, the effects of a more extensive network, and the possibility of attracting longer trips of say 800 miles to the network. Further study is needed of the dynamics of building a network over time and how it can be incrementally connected to the existing air and surface transportation system.

ENDNOTES:

1/ Automobile BTU's per passenger mile based upon assumptions in America's Challenge for Highway Transportation in the 21st Century. FHWA 11/88.

2/ "Energy, Environmental, and Economic Benefits of Florida's High Speed Rail and Maglev Systems Proposals," Tim Lynch, Ph.D., Deputy Director of FHSRTC, January 1990.

3/ "Roadway Congestion in Major Urban Areas 1982-1987," Texas Transportation Institute, October 1989.

4/ "FAA Aviation Forecasts FY 1990-2001," March 1990.

APPENDIX IV-A

NOTES ON METHODS USED FOR ESTIMATING MAGLEV PASSENGERS

Base Year Trips in Each Market

As explained in Chapter IV, estimates of auto travel were not available in most city pair markets. Relationships between the percentage of trips using auto and the distance between cities were derived using data for city pairs where auto travel estimates were available from recent origin/destination studies. The first such relationship, derived from Northeast Corridor data, was used to estimate auto usage only for those Northeast Corridor city pairs lacking auto data. This relationship is described by the equation:

$$P = .97 - .00136D$$

where P = percent of market using auto

D = city pair distance in miles

Outside the Northeast corridor, the following equation was derived and applied:

$$P = 1.165 - .00177D$$

In no case was the calculated value of P allowed to exceed 99 percent.

These relationships are shown in Figure IV-A-1. Auto trips were then calculated using the formula:

$$\text{Auto trips} = \frac{P}{1-P} \times (\text{Non-auto trips})$$

Auto Share as a Function of Trip Length

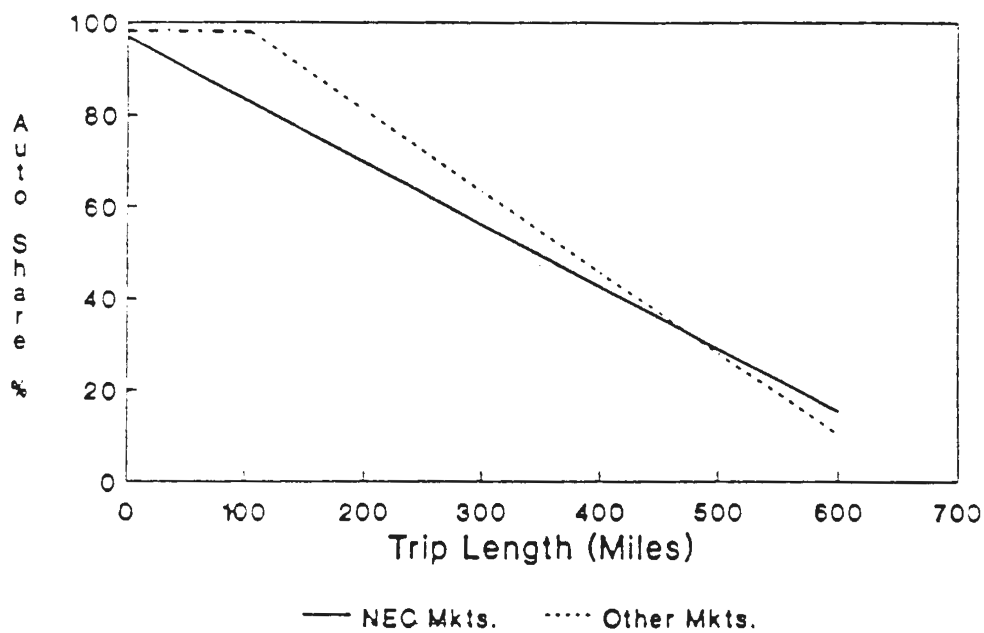


Figure IV-A-1

<u>Projection of Base Year Trips</u>

Amtrak's Market Research Department has derived a relationship between per capita passenger miles nationwide and real per capita personal income using historic time series dating back several decades. This relationship is shown in Figure IV-A-2. It shows that per capita passenger miles is virtually proportional to real per capita income, and implies that total passenger miles is proportional to total personal income. In this report, that relationship has been used to expand trips by city pair in proportion to the percentage growth in income (as projected by the National Planning Association) averaged over the two metropolitan areas comprising the "city pair."

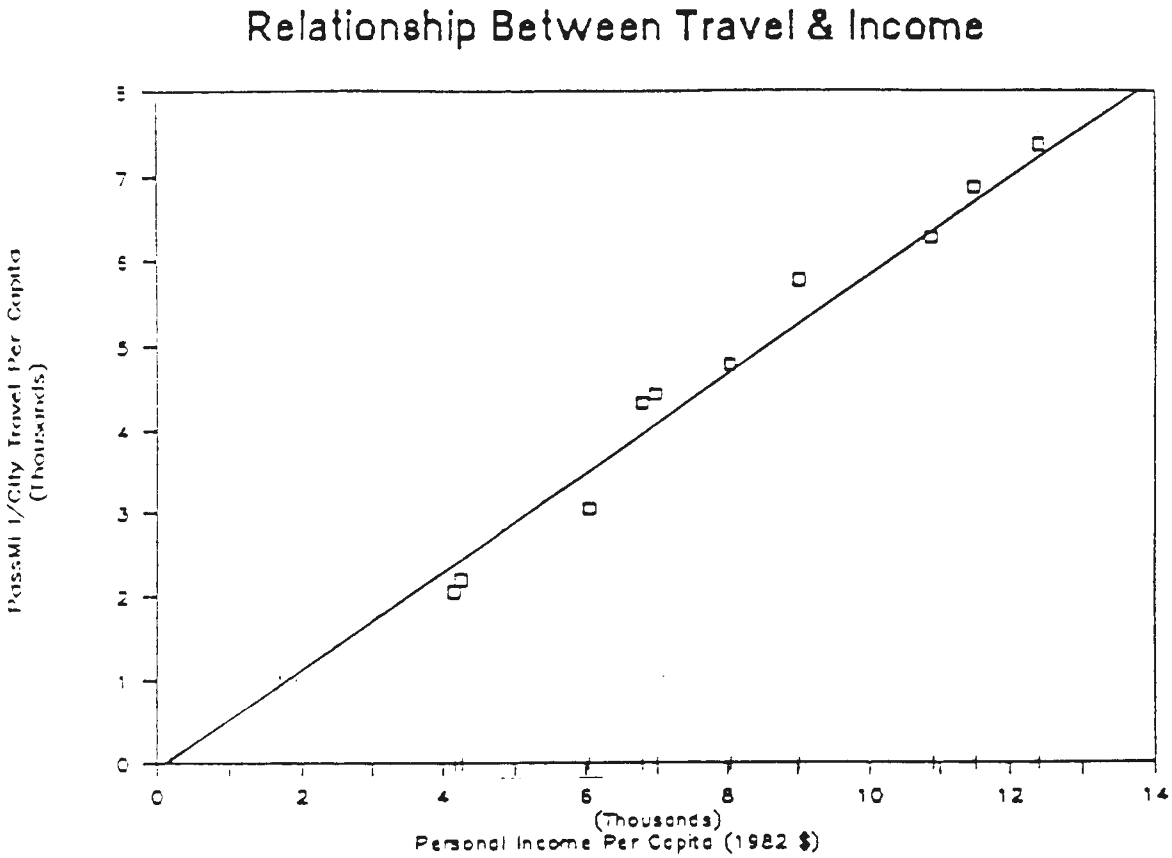


Figure IV-A-2

The growth in passenger miles per capita in the past is a combination of the growth in the number of trips per capita and in the average length of trip. By assuming that <u>trips</u> in the distance ranges considered in this report (50 to 500 plus miles) are proportional to real income it is implicitly assumed that the growth in trip length will "average out" in that trip length range, i.e., some shorter trips will move into the range while longer trips move out of the range.

III. Proportion of Future Trips Using Maglev

Using information obtained from a series of surveys conducted in 1987, Booz Allen Hamilton derived a model relating the percent usage of different modes (market share) to their competitive service and fare characteristics. This model is described in exhibits IV-A-1 and IV-A-2, as taken from Exhibits 7 and 8 in Demand Model Estimation, a report submitted to Amtrak by Transportation Consulting Division of Booz-Allen & Hamilton, Inc.

The model was "calibrated" by Booz-Allen so that it would reproduce current travel patterns in the Northeast Corridor (market shares of each mode) when calculated on the basis of current competitive service characteristics for each mode, in terms of average door-to-door travel time, out of pocket costs, and frequency of service.

For this report, a spreadsheet was calculated using typical times, costs, and service frequencies in the Northeast Corridor as functions of distance in order to calculate the rail market share. Changes were made to represent a scenario where maglev would be in service instead of rail. These changes were:

- Use 200 mph average speed for "rail" instead of about 80 in the Northeast Corridor.
- Use a frequency of service of 20 per day for "rail" as well as air instead of the wide variety of frequencies in the Northeast Corridor.
- Use air fares for "rail" as well as air, instead of the typically lower rail fares in the Northeast Corridor.

The resultant calculated value of "rail" (maglev) market share as a function of distance became Figure IV-2 in the report, which was used for each city pair, both inside and outside the Northeast Corridor to calculate the maglev market share. Figure IV-2 actually represents a modified version of this calculation for distance beyond 400 miles because the unmodified calculation yielded results which were believed to represent unrealistically high maglev percentages for the longer distance ranges, in view of the market shares attributed to air, rail and auto under present circumstances in the Northeast Corridor. In particular, the unadjusted auto market shares for the long distances seemed too low, and the "rail"/air split did not seem realistic compared to rail/air splits in markets with comparable competitive characteristics today.

EXHIBIT IV-A-1

AMTRAK NORTHEAST CORRIDOR MODEL ESTIMATION PROJECT

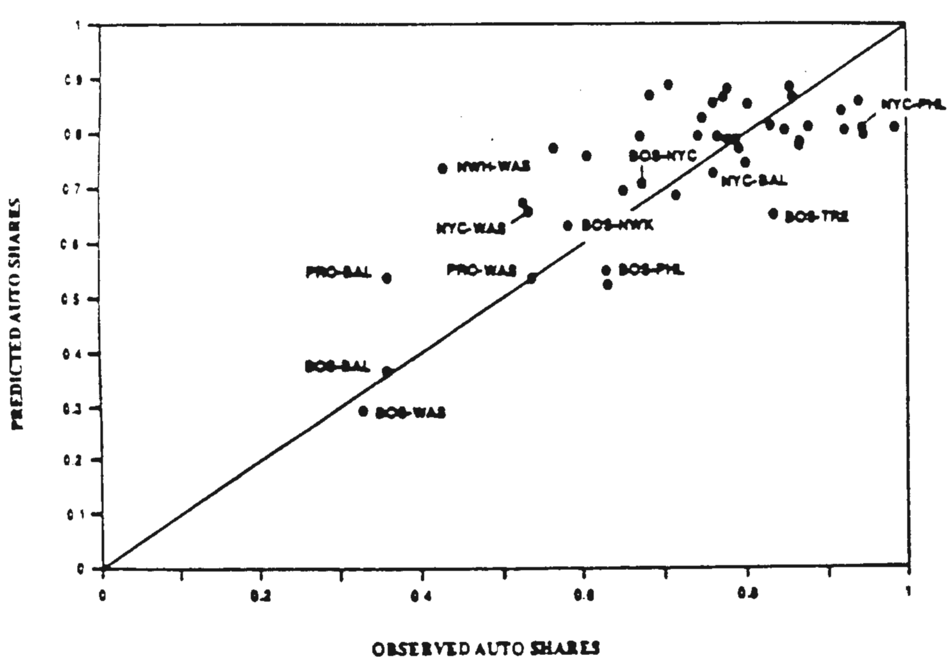
Auto Versus Common Carrier Split Model

$$\text{Auto Share} = \frac{\exp(-0.0067 * (TTA - WATCC) + 1.64)}{1 + \exp(-0.0067 * (TTA - WATCC) + 1.64)}$$

Where TTA = total time via automobile
WATCC = weighted average travel time common carrier modes (rail and air)

			Standard Error	Prob >|T|	
a1	=	-0.0067	0.0009	0.0001	F Value = 52.58
b	=	1.64	0.11	0.0001	
					r = 0.73

PREDICTED vs. OBSERVED AUTO SHARES



• NYC-WAS CITY PAIR (ONLY MAJOR CITY PAIRS ARE IDENTIFIED)

EXHIBIT IV-A-2

AMTRAK NORTHEAST CORRIDOR MODEL ESTIMATION PROJECT

Non–Stratified Common Carrier Mode Split Model

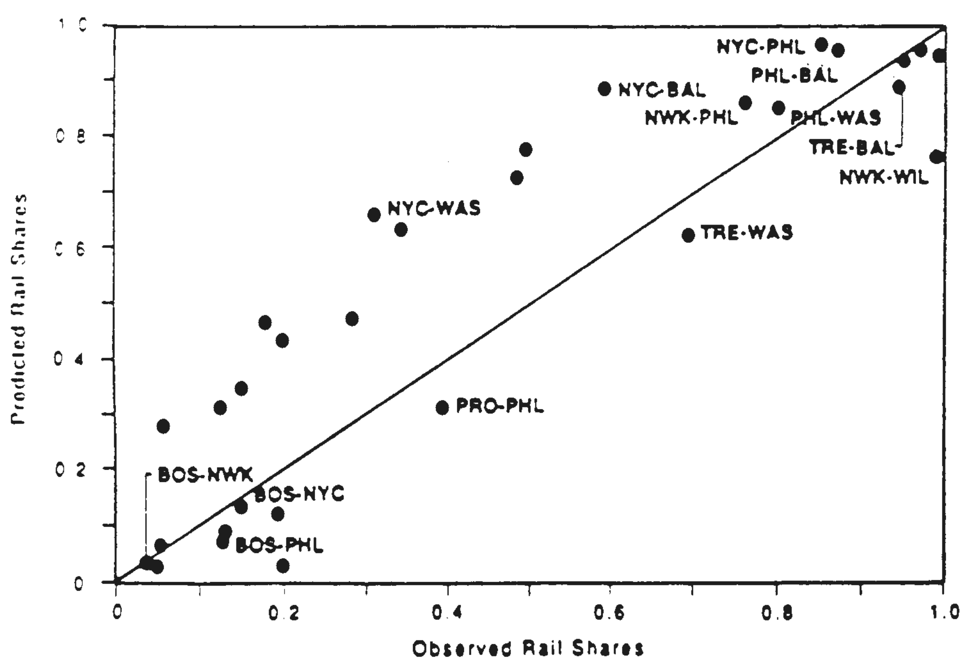
$$\text{Rail Share} = \frac{\Pi\,\text{rail}}{\Pi\,\text{rail} + \Pi\,\text{air}} \quad \text{and Air Share} = \frac{\Pi\,\text{air}}{\Pi\,\text{rail} + \Pi\,\text{air}}$$

$$\text{where } \Pi\,\text{rail} = \begin{pmatrix}\text{linehaul}\\ \text{time}\end{pmatrix}_{\text{rail}}^{a2} \begin{pmatrix}\text{excess}\\ \text{time}\end{pmatrix}_{\text{rail}}^{a3} \big(\text{frequency}\big)_{\text{rail}}^{a4} \begin{pmatrix}\text{linehaul}\\ \text{cost}\end{pmatrix}_{\text{rail}}^{a5}$$

$$\text{and } \Pi\,\text{air} = \begin{pmatrix}\text{linehaul}\\ \text{time}\end{pmatrix}_{\text{air}}^{a2} \begin{pmatrix}\text{excess}\\ \text{time}\end{pmatrix}_{\text{air}}^{a3} \big(\text{frequency}\big)_{\text{air}}^{a4} \begin{pmatrix}\text{linehaul}\\ \text{cost}\end{pmatrix}_{\text{air}}^{a5}$$

	Standard Error	Prob > |T|	
a2 = −2.20	0.41	0.0001	F Value = 36.43
a3 = −2.74	0.86	0.0024	
a4 = 1.44	0.25	0.0001	r = 0.912
a5 = −1.58	0.50	0.0024	

PREDICTED vs. OBSERVED RAIL SHARES



● NYC-PHL CITY PAIR (ONLY MAJOR CITY PAIRS ARE IDENTIFIED)

IV. "Induced Trips"

The induced trip estimates were influenced by a presentation given by Michel Walrave, Deputy Director General of SNCF (French Railways) in Seoul, Korea, in October of 1979. Walrave states that half of the increase in rail traffic brought about by the Paris/Lyon TGV was induced traffic. Rail traffic in this corridor increased from 12.2 million passengers in 1980 (pre-TGV) to 21.3 million in 1988, for an increase of 9.1 million. Half of that would represent 4.5 million induced trips, and the other half would represent primarily diverted trips. Induced trips could then be estimated by adding another 100 percent of diverted trips. A more conservative 22 percent of diverted trips was used in this report partly because some of the trips may be accounted for by growth in income and population and partly because the transportation market in France is more highly regulated and less subject to competitive reactions such as lower air fares which would tend to reduce induced demand for maglev.

The phenomenon of induced trips cannot be neglected. It was shown in France, for example, that firms with offices in Lyon increased the number of business trips to Paris when it became more convenient and less expensive, in some cases eliminating an overnight stay. For maglev in the U.S., the situation is not exactly comparable since many city pairs already have inexpensive and convenient air service.

Multiplying estimated diverted trips, not including "air transfers" (maglev leg of a longer distance air trip) by 22 percent, was believed to be a reasonable method for estimating induced trips.

APPENDIX IV-B

USE OF INTERSTATE HIGHWAY AND RAILROAD RIGHTS-OF-WAY

THE INTERSTATE HIGHWAY SYSTEM

Interstate Highways have been considered as potential rights-of-way for maglev systems. There are nearly 45,000 miles of Interstate Highway in the United States. The Interstate Highway System has been built over the last 35 years to relatively uniform design standards which vary according to the degree of urbanization and the nature of the terrain.

Rights-of-way are generally 150 to 200 feet wide, but may be up to 300 feet wide if frontage roads are provided or planned. The rights-of-way are owned by States, not the Federal Government. Curves are designed for speeds of 50, 60 or 70 mph depending on terrain and cost of land in urban areas. Grades may generally be as steep as 3 to 5 percent, but up to 7 percent (i.e., 7 feet change in elevation per 100 feet of length) in mountains or other rugged terrain is permitted. Overhead bridges must generally have a clearance of 16 feet. Medians can vary from 4 to 36 feet, depending on local conditions and land costs. Shoulders, drainage ditches, signs, lights, fences, etc. take up additional space in many places along the Interstate System.

The Federal Highway Administration maintains a nationwide data base called the Highway Performance Monitoring System (HPMS) which covers Interstate and other highways. The HPMS is based on random sampling portions of routes so that general statistics of a route or the system as a whole can be obtained even though complete information may not be available for particular segments of interest. The HPMS system was used to assess the general feasibility of using Interstate rights of way for maglev routes.

Potential Maglev Routes and Characteristics of Interstate Route Segments

A total of 39 potential maglev route segments serving the markets shown in figure IV-1 were identified and data were obtained from the HPMS data base. Valid data were obtained on 35 Interstate route segments totaling 7,271 miles, approximately 16 percent of the Interstate system. The detailed sampling on these 35 route segments represented 3,200 miles, or 44 percent of the total. This rate of sampling is sufficient to provide a summary of general characteristics.

Particular concern has been voiced over the frequency of curves and their sharpness, as this could potentially restrict maglev speeds rather severely. It was assumed for this study that maglev vehicles could operate around curves with 12 degree banking angles (the limit for Germany's Transrapid system) while subjecting passengers to a lateral acceleration of no more than one tenth the acceleration due to gravity (0.1g). In order to maintain a 300 mph speed under these conditions, curves of about 3.5-mile radius would be needed, i.e., .3 degree curves. 80.4 percent of the sampled miles were tangent (straight) or on curves of less than 0.5 degrees, thus allowing a speed of 227 mph or greater. Table IV-4 summarizes the relative frequency of

Table IV-4

Curvature	Number of Curves	Average of Sample Miles	Percent Miles of Curve	Distance Between Curves	Speed Range MPH
Tangent -0.5 Deg.	3,243	2,575	80.4%	N/A	227-300
0.5 - 1.4 Deg.	1,253	359	11.2%	2.55 Mi.	135-227
1.5 - 2.4 Deg.	618	156	4.8%	5.18 Mi.	103-135
2.5 - 3.4 Deg.	288	70	2.2%	11.10 Mi.	87-103
Above 3.5 Deg.	172	45	1.4%	18.60 Mi.	Below 86

curves of increasing sharpness up to those above 3.5 degrees (86 mph or less). A curve causing varying amounts of speed restrictions at or below 227 mph would be expected to occur every 1.37 miles. This frequency of curves would significantly lower the average running speed of an Interstate oriented maglev, since it requires many miles to accelerate or decelerate from a potential cruising speed of 300 mph, and the fact that the HPMS system does not even record curves of less than .5 degrees which could limit speeds to a level between 227 and 300 mph.

The frequency of steep grades was the second major item checked through the HPMS system. Less than 2 percent of the route mileage sampled was on grades of 4.5 to 7 percent. Since current maglev propulsion systems can handle grades of up to 10 percent, grades found on the Interstate Highway System are not likely to be a basic constraint for use by maglev systems.

Another design attribute which is likely to be a constraint on some routes is the vertical curvature. HMPS does not record such data and it is also difficult to determine from topographic maps. However, it is known that the standards for maximum vertical curvature on the Interstate System, if applied to maglev, could produce either a speed restriction or an unacceptable ride experience, especially while cresting a hill. Thus, the maglev alignment in some locations would require considerable vertical separation from (either above or below) the highway alignment and consequent added expense.

Other data extracted from the sample in the HPMS data base included median width, right of way width, feasibility of widening the right of way, terrain, adjacent development, urban location and number of interchanges. The data showed what many would expect. Rural areas have wide, easily expanded rights of way with few interchanges, while urban areas have restricted medians and rights of way with little feasibility of expansion.

Example of a Specific Route - San Diego/Los Angeles

A number of questions can be answered only on a route specific basis. In an effort to see how the data from HPMS correlated with a specific route, the Los Angeles - San Diego Interstate Route 5 corridor was analyzed using 24,000 to 1 scale topographic maps from the U.S. Geological Survey. These 2,000 feet to the inch maps show all roads, bridges, streams, elevation contours, etc. It was noted that for this specific route the random samples of HPMS did not include major segments of the urban areas of Los Angeles. This random statistical omission on this particular route would have the HPMS data provide a more optimistic picture of the utility of the I-5 right of way than in reality, but other specific HPMS route samples would probably provide a more pessimistic picture. Even with the urban omissions, the HPMS data indicated the Interstate 5 route from Los Angeles to San Diego had more than 3 times the number of 1.5 - 2.4 degree curves (103-135 mph) than were found in the national average.

The topographic maps did reveal a significant number of overhead and under-grade bridges. There are 120 overhead bridges on the route; an average of one per mile, but several sections had 3 or 4 per mile. Overhead bridges would cause a Maglev system using an Interstate right of way to climb to an elevation of about 50 feet above the highway alignment in order to clear the vehicles using the overhead bridge. At this elevation a maglev system could also conflict with overhead telephone and electric power lines, possibly requiring relocation of these lines.

There were a total of 86 undergrade bridges counted in this corridor. These ranged in length from short bridges over country roads, which would have virtually no impact on construction costs, to significant viaducts in urban areas where space is at a premium and construction costs are high.

Simulation of Maglev Operation on San Diego/Los Angeles Interstate Highway and Railroad Routes

Using a mathematical model, vehicle operations on the rights of way of both Interstate 5 and the Santa Fe Railroad were simulated in order to calculate the performance of a maglev train capable of 300 mph top speed operating non-stop from Los Angeles to San Diego. The Santa Fe Railroad route is about 10 miles longer due to the slow, highly curved route through Soledad and Rose Canyons. Otherwise, much of the Santa Fe route is superior to the Interstate 5 route. Table IV-5 summarizes the performance of a maglev train on both routes.

Table IV-5

	I-5	Santa Fe
Distance	119.3 MI	129.5 MI
Travel time	51 MIN	61 MIN
Average Speed	140 MPH	127 MPH
Maximum Speed Attained	219 MPH	269 MPH

It is significant that the average speed on the Interstate 5 alignment for a maglev vehicle capable of 300 mph top speed is only 140 mph. Thus, strict adherence to this alignment significantly reduces the effectiveness of maglev in this corridor. As already noted, this portion of Interstate 5 has considerably more curves than other Interstate route segments that could accommodate maglev routes, and it is likely that a more typical Interstate alignment would produce less speed reduction.

A detailed review of the simulated runs was made for both routes, along with another check of the topographic maps to see if it would be feasible to create a route using the best portions of both routes. The route proposed by the American High Speed Rail Corporation in 1983 for high speed rail service between the two cities was also reviewed. The latter route used major portions of the Santa Fe right-of-way, replaced Soledad and Rose Canyons with a tunnel, used a few miles of a Southern Pacific Railroad line, and built on a totally new right-of-way in selected areas to avoid low speed alignment problems. A similar concept would probably work well for a maglev route between these two cities, but sustained speeds above 200 mph are likely to be the exception rather than the rule.

Conclusions Regarding Interstate Highway Rights-of-Way

The foregoing analysis leads to a conclusion that the exclusive use of Interstate Highway rights-of-way would not permit a maglev system to reach its full operating potential. The use of this right-of-way should be considered an opportunity for maglev use rather than a constraint. The same can also be said for other existing rights-of-way, such as railroad, pipeline, power line, etc. Judicious combinations of existing rights-of-way should be able to minimize the amount of new rights-of-way required to build a maglev system, thereby potentially reducing the cost of right of way acquisition and guideway construction, while at the same time minimizing the intrusion of the man made environment into virgin territory. Decisions on right of way use can be made only on a case-by-case basis.

V. MEASURES TO PROMOTE U.S. LEADERSHIP IN MAGLEV

Today, the leadership in maglev technological development belongs to West Germany and Japan. Building, in part, on technological advances funded by the FRA in the late 1960s and early 1970s and on concepts published by American scientists during the same time period, the maglev development programs in both countries have advanced to the point of commercial application. West Germany is actively marketing its Transrapid system in the U.S. and ground may be broken later this year on a Transrapid maglev system near Orlando, Florida. Japan is in the final stages of demonstrating its maglev system, committing over $2 billion (U.S.) to construction of a segment of maglev line for that demonstration which will become part of a commercial maglev link between Tokyo and Osaka early in the 21st century.

It will be a great challenge for the U.S. to now move to a position of world leadership in maglev technology and its commercial applications. That is not to say the task is impossible because, as Chapter III of this report shows, there are opportunities to develop a better maglev system than those currently available. This Nation's long history of scientific and technological breakthroughs are evidence that U.S. industry is capable of that development. But it will not be an easy challenge to meet.

The FRA has held extensive discussions with companies that might be expected to participate in a maglev development program. In addition, FRA, together with the U.S. Army Corps of Engineers and the Department of Energy, held a government/ industry forum on May 2 and 3, 1990, to discuss maglev development with a wide range of the private sector interested in maglev development. In these discussions, the companies, representatives of the academic community and potential developers of maglev systems expressed their opinions on what will be required for the U.S. to assume a leadership role in maglev. A consistent, underlying theme of all the suggestions that came from industry was that the Federal Government must make a major long-term commitment to maglev research and development. There were a number of suggestions on how this commitment might manifest itself, which are the subject of this chapter. These suggestions can generally be viewed as either issues involved in the research and development of an U.S. based maglev technology, or issues involved in the implementation of specific maglev systems.

MAGLEV RESEARCH AND DEVELOPMENT

The American private sector believes that there are significant legal and financial impediments to a program to develop a domestic maglev technology. These impediments are part of the "traditional" American way of doing business and it will be up to Congress and the President to determine if the potential for development of maglev justifies the legislative changes needed to eliminate them.

Antitrust

Significant questions have arisen whether traditional antitrust considerations of domestic market dominance and insuring adequate competition have been stressed to the detriment of other issues relating to U.S. competitiveness in world markets. Of particular concern are the foreign industrial consortia that are encouraged, and even subsidized, by their national governments to develop and market advanced products such as maglev. The magnitude of the maglev challenge is such that it is unlikely that one company, acting alone, will be successful. Under current law [section 7 of the Clayton Act, 15 U.S.C. s 18 (1976) and the so-called 1982 and 1984 Merger Guidelines] industry consortia such as those engaged in maglev development overseas would not be permitted in the United States.

The Department is exploring options under the National Cooperative Research Act for promotion of joint research and development ventures consistent with Administration policy.

Patents

Maglev development can benefit from public-private partnerships, with the public sector providing a long term vision of a common goal and with the private sector supplying the creative energy. A primary concern of private companies in such arrangements is the ownership of intellectual property rights that might result from maglev research and the ability to profit from these rights. The Congress attempted to address this issue in the Stevenson-Wydler Technology Innovation Act of 1980; however, companies likely to become involved in a U.S. maglev development program expressed serious reservations on this issue. They see the current arrangements concerning the ownership and exploitation of intellectual property as a disincentive to their involvement in a Federally sponsored maglev development program.

FINANCING MAGLEV RESEARCH AND DEVELOPMENT

Many interested in the development of maglev systems in the United States look for the development of an American maglev technology, or at the very least, an American improvement of the existing foreign designs. While there are no firm cost estimates, such a development program will be expensive. The Maglev Technology Advisory Committee's report to the Senate Committee on Environment and Public Works contained an estimate that it would take $750 million and six or seven years to develop an U.S. based maglev technology[1].

Funding the development of such a maglev technology in the private sector will be one of the greatest challenges facing maglev in this country. Private investors require a high degree of confidence that the ultimate market for research and development efforts will be sufficiently large and profitable to amortize the cost of R&D, plus recover carrying charges and a provide a reasonable profit on the R&D investment in a reasonable period of time. At this time, however, the private sector does not have sufficient confidence in the potential size and timing of the maglev market to commit to fund maglev R&D efforts and will look to the Federal Government for both leadership and funding.

Some states may contribute to such funding as a means to ensure that technological spinoffs from such research, in the form of clean, technologically sophisticated industry and relatively high paying skilled employment, develop in the State. As an example, Illinois has committed approximately $300,000 to the Argonne National Laboratory's efforts to develop a maglev research facility near Chicago. But the sums needed to develop and test a maglev system are so vast, that it is unlikely that such efforts will make significant progress without major involvement by the Federal Government.

The FRA's earlier maglev research activities were funded primarily through grants that covered most if not all costs. Such an arrangement may not be appropriate for a major maglev effort today. This is not just because Federal funds are limited. There are real advantages to private sector involvement, primarily those associated with crafting a system that can meet the unique requirements of the American marketplace. If the United States is to become fully committed to the development of maglev technologies and systems, one mechanism which should be considered is the formation of a consortium of manufacturers and suppliers directed at common research and development goals.

A model for this kind of effort is SEMATECH, the research consortium of U.S. semiconductor producers, and suppliers of semiconductor manufacturing equipment. This consortium is a jointly funded government -- industry response to the declining competitiveness in the U.S. semiconductor industry. The goal of SEMATECH is to: (1) conduct research and development on advanced semiconductor manufacturing techniques, (2) test and demonstrate the resulting techniques on a pilot production line, and (3) develop processes to adapt these proven techniques so that they can be applied to the manufacture of a wide variety of other products.

SEMATECH's operating budget of $200 million per year is funded 50 percent by the Federal Government, through appropriations to the Department of Defense. According to the General Accounting Office, Federal funding for SEMATECH has been beneficial and is justified on the basis of its public benefits, being the goal of making progress towards developing the next generations of manufacturing technology and helping the U.S. to regain world leadership in semiconductor manufacturing [2].

The SEMATECH model could be used to encourage an all-out research and development effort directed at regaining U.S. leadership in maglev technology. The SEMATECH experience suggests that in order for this to be successful, the Federal Government needs to be involved not only in the funding, but also in providing leadership and support to the consortium itself.

Another possible arrangement to undertake this development is demonstrated by is the Intelligent Vehicle Highway Systems (IVHS) project of the Department's National Highway Traffic Safety Administration (NHTSA). In this effort, NHTSA is supporting the cooperative venture. One component of the effort is development of a state-of-the-art driving simulator. It is NHTSA's intention to encourage private industry, primarily the "big three" automakers, to contribute one-third of the approximately $30 million cost of producing the simulator. The arrangement under consideration is a cooperative agreement with a research facility (probably a university) and a contractor to manage the simulator.

Several pieces of legislation have been introduced that attempt to address some of the issues associated with Federal financial support for public-private partnerships undertaking maglev R&D. Under several of these measures, including the Administration's Water Resources Development Act of 1990, Federal agencies are authorized to undertake collaborative research and development with non-Federal entities, including university research and industry organizations. Government funding may be 50 percent of the cost of each project. Cooperative research and development is defined to be consistent with Section 12 of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. § 3710a), which provides for cooperative research and development in Federal laboratories.

As part of the advanced maglev analysis proposed by FRA and the Corps of Engineers, the Federal agencies will determine the conditions and commitments that must exist to induce the private sector to undertake maglev R&D. One thing is clear from discussions held with corporations that would be expected to play a major role in maglev development. That is, industry believes that the Federal Government must make a major long term commitment to maglev development before the corporations are going to commit substantial amounts of their own resources. Several corporations have questioned the strength of the Federal commitment to maglev and pointed to other instances, such as Federally-funded maglev research prior to 1975, where the Federal Government has not pursued ongoing R&D to a conclusion, but, instead abruptly shut down an ongoing effort.

IMPLEMENTATION OF SPECIFIC MAGLEV PROJECTS

A key to U.S. industry's leadership in the commercial application of maglev technology is the presence of a domestic market for this technology. More specifically, U.S. industry leadership requires a market that is ready, willing and able to purchase this technology in sufficient quantity, and over a sufficiently short period of time to justify the investment of resources in the development of an U.S. maglev technology.

The FRA has had a long and close relationship with States and localities interested in promoting high speed ground transportation as well as private entrepreneurs interested in developing such systems as maglev. These States, localities and entrepreneurs have expressed their belief that certain legal and regulatory issues need to be clarified before the transportation and commercial potential of maglev can be realized. The most important of these will be summarized below.

USE OF INTERSTATE HIGHWAY RIGHTS OF WAY

It has been suggested that capital needs for a maglev system could be reduced by using a portion of the right of way of Interstate or other highways. Aside from technical issues of whether this is feasible, and economic issues of whether this is cost effective, there are important legal issues.

The most pressing legal concern is related to the cost of using the right of way. Interstate and other Federal-aid highways are owned by the states in which they are located, however the Federal Highway Administration must approve any non-highway use of this property. Under existing law, the FHWA must require the States to obtain fair market value for any commercial use of the right of way, such as by a private maglev system, even if the State wishes to encourage such use by making the right of way available at little or no cost.

Legislation has been introduced in both houses of Congress which, if enacted into law, would require the Department to issue regulations covering requests by states to permit maglev systems to use Interstate highway rights of way. The Department has not taken a formal position on any of these bills at the time of this report (June 1990). It can be noted, however, that the bills did not address all the issues concerning maglev use of highway rights of way such as the ability of states to offer use of the right of way at little or no cost to commercial maglev systems as an inducement to the development of maglev.

USE OF RAILROAD RIGHTS OF WAY

Almost all railroad rights of way are privately owned. Use of such rights of way is, therefore, strictly a matter of negotiation between the maglev entity and the transportation entity owning the particular railroad right of way which is being considered.

EMINENT DOMAIN

Assembling transportation corridors often requires the use of the eminent domain powers of the state. (Federal eminent domain powers are almost never used for transportation purposes.) In some states, the constitution or state law provides eminent domain powers to railroads (which might also be conferred upon maglev systems.) In other states, this power must be exercised directly by the state.

Even in such cases, it could be possible for states to assist the assembly of the maglev corridor right of way although this might require special state legislation. This has been done in Florida with respect to both the high speed rail and the maglev proposals. State legislation authorizes the Florida High Speed Rail Transportation Commission to exercise eminent domain authority on behalf of a private operating entity, upon application to the Commission. The grant of authority is broad. The Commission is authorized to acquire not only right of way which is required for transportation purposes, but also ancillary facilities in connection with stations for commercial development. Neither the Commission, nor the presumptive franchisee, however, anticipate the use of eminent domain for development-related purposes.

Since this project is still in the early stages of development, the State of Florida has yet to have any actual experience with these mechanisms. It is anticipated that the process will work as follows. The Commission will request the Florida Department of Transportation to carry out any required condemnation. The private entity must pay the total cost of carrying out the condemnation, including all state expenses. The state -- its Land and Water Board -- will hold title to all property thus acquired. An agreement will be entered into transferring operating responsibility back to the private entity.

ECONOMIC REGULATION

Section 306 of the Rail Passenger Service Act exempts the National Railroad Passenger Corporation (Amtrak) from most of the provisions of Subtitle IV of 49 U.S.C., formerly known as the Interstate Commerce Act. Except for this specific exemption, the Interstate Commerce Commission (ICC) continues to have authority to regulate the interstate transportation of passengers by rail.

How this latent authority would affect maglev development in the United States is unclear. First, it is unclear whether maglev would be considered rail transportation for the purposes of ICC regulations, particularly when recent expressions of legislative intent such as the Rail Safety Improvement Act of 1988 and the Technical and Miscellaneous Revenue Act of 1988 include maglev in their definition of rail. The ICC has not issued a formal decision on this issue, but both ICC staff and the California-Nevada Superspeed Train Commission expect the ICC to assert its jurisdiction over the proposed high speed project between Las Vegas and Anaheim regardless of whether traditional rail technology or maglev is proposed.

In addition, the ICC's definition of "interstate commerce" has at times included situations that others might view as intrastate. At the time of this report (June 1990) there is an ongoing proceeding involving a 21 mile long scenic railway in California in which the ICC is considering the extent of its jurisdiction over intrastate rail passenger service [3]. The Department's recent National Transportation Policy statement advocated elimination of all remaining ICC regulation of rail passenger service. This would include any ICC authority over maglev. Elimination of this authority could be done by the ICC itself by issuing an exemption under 49 U.S.C. 10505 of passenger service from ICC regulation. Alternatively this elimination of authority could be accomplished legislatively.

In the absence of Federal regulation of maglev systems, the states might choose to economically regulate these systems through their Public Utility Commissions. In some states, the definitional problem with the term "railroad" may create the same jurisdictional problem as with Federal law. Accordingly, state statutes may have to be updated, if it is deemed by the states to be in the public interest to regulate this form of transportation.

FINANCING IMPLEMENTATION OF MAGLEV PROJECTS

The FRA expects that the implementation of specific maglev projects will be funded largely in the private sector, with, perhaps some assistance or financial inducements from State and local governments. High speed rail projects proposed for Florida, Texas, California and Nevada are planning this type of project funding. The FRA does not foresee a major role for the Federal Government in providing direct financial support to specific maglev projects. Such a role would negate one of the important benefits of private sector participation, the ability to successfully assess profit potential and balance it against risks and uncertainties.

Two points must be emphasized with respect to financing strategies. First, no single financing mechanism, in isolation, will meet all of the financial needs for the implementation of maglev systems. These are large scale projects and will require financing tools to be used in combination with one another. Second, hybrid financial mechanisms may be necessary. Large maglev development projects, particularly if public/private partnerships are involved, are likely to be "atypical," and creativity and careful planning are called for.

PRIVATE SECTOR FINANCING

The analysis in Chapter IV estimates that there are a number of potential maglev projects that would be able to fund all capital and operating costs, plus generate a profit, from fares. Such projects could find financing through the traditional private sector financing tools of equity investment and debt. The following discussion identifies a number of mechanisms that may be available to finance implementation of specific maglev systems by the private sector.

Equity Financing

Equity investors are owners of the entity in which they hold stock. Such an investment is made in anticipation that the entity (in this case the maglev system) will be successful and either appreciate sufficiently in value, or pay sufficient dividends or a combination of both to justify the investment. Such investments have the most risk because they are unsecured and there value is directly tied to the success of the enterprise. Equity, therefore is usually the hardest capital to raise, particularly for innovative ventures such as maglev. For companies engaged in "traditional" transportation business, equity usually accounts for approximately 50 percent of total capitalization. For maglev, because of the greater uncertainties involved, the percent equity will probably be less.

Debt Financing

Debt is a less risky investment. In effect debt is money loaned to a company rather than an investment in that company. as a consequence most forms of debt do not participate in profits. Debt generally has an assured rate of return that is paid before any dividends and in the event of default or bankruptcy, is secured by a claim against the assets of the company. There are several mechanisms for raising debt financing that might be applicable to implementation of a specific maglev project. The most prominent are identified below.

Bond Financing

Bond financing allows large amounts of capital to be raised by the issuing entity through instruments evidencing either long-term or short-term debt. Long-term debt obligations involve repayment over a period of 5 or more years. Such debt is typically used to finance capital needs. Short-term debt normally involves a repayment period of 3 years or less and is generally used for operating needs, though it may also be used for capital requirements, such as for a construction loan arranged in advance of a long-term financing package.

Short-term debt could be employed by a maglev entity to cover temporary shortfalls in cash in anticipation of expected revenue. Such debt instruments might include revenue or grant anticipation notes, generally issued for a period of several months to a year or more.

Of particular importance is the response the bond market will have to participating in the financing a system which at present has no history in revenue service. Long-term debt financing is easier to secure after a technology has established a revenue track record. This raises the question of whether initial government support might be required to strengthen the credibility of the economic projections upon which subsequent borrowing in the bond market might be based.

Bank Consortia Financing

Although applicability is not limited to equipment financing, a successful financing strategy for maglev development is likely to involve a consortium of banking institutions. Each institution signs on for a portion of the total financing package. This approach has been used, for example, in the financing of the Channel Tunnel (Eurotunnel), presently under construction between France and Great Britain. Bank consortia financing has also been referred to as a necessary component in the proposed financing plan for the Las Vegas-Anaheim development project.

Equipment Financing

Whatever technology is ultimately implemented, a maglev system will require a heavy investment in vehicles and other necessary equipment. Regardless of whether the operating entity is public, private or a public/private partnership, an equipment financing plan will most likely have to be part of any proposal. And although equipment typically accounts for about 11 percent or less of the projected costs of maglev projects, these mechanisms might also be useful for financing guideway technology costs, exclusive of earthworks engineering.

Leasing

Leasing is attractive because it provides for the use of a capital asset without the necessity of a capital outlay. Among the many advantages of leasing are: (1) leasing allows entities to leverage their capital budgets; (2) leasing does not tie up valuable working capital or credit lines; (3) since leasing is not borrowing, there may be no accounting requirement to show leased equipment and the corresponding obligation to make future payments as a liability on the lessee's balance sheet; and (4) leasing may offer cash flow benefits.

Two specific leasing arrangements might be relevant to maglev equipment financing. Certificates of participation (also called "equipment trust certificates") are used to finance large purchases of equipment by spreading the cost among a number of investors. Each investor owns a share of the equipment, which is leased back to the using agency. A bank normally acts as trustee to the transaction by issuing the debt, holding title to the equipment, and handling periodic payments made by the using entity. From the using entity's perspective, this financing technique allows the cost of equipment to be spread over many years, usually corresponding with the useful life of the asset. Additionally, the interest component of the periodic payments may be tax-exempt if the entity qualifies as a political subdivision, under Section 103 of the Code, and the transaction is structured as an installment sales contract. Equipment trusts and other leasing arrangements are common means of financing passenger aircraft and freight railroad rolling stock.

Vendor Financing

In order to encourage the sales of its products, many manufacturers provide vendor financing to user organizations. In the case of maglev, where the competition among manufacturers may be intense, this form of financing may play an important part in the overall financial package for any proposed project. From the point of view of a maglev operating entity, such financing is extremely attractive, since it reduces capital outlays and provides for an "all-in-one" process for both the purchase and financing of equipment.

Two types of vendor financing are in use: in the first, a manufacturer accepts an extended payment schedule, thereby deferring sales revenue; in the second, a manufacturer arranges for financing with a bank or other financial institution and incorporates the financing in the sale.

The competition among manufacturers for sales of their products has caused many to offer below market financing rates. Particularly where foreign manufacturers have been involved, this has sparked protests by domestic companies that such financing constitutes an unfair business practice. Congress passed corrective legislation in 1986 prohibiting contractors from offering below market rates in vendor financing. A recent example of vendor financing is the acquisition by Amtrak in 1989 of 104 cars financed by Bombardier.

NON-TRANSPORTATION REVENUE SOURCES

A way for improving the financial performance of a maglev project so that adequate financing can be secured is to incorporate revenues from sources other than the operation of the transportation facility. These non-transportation revenues can either be a direct source of funds or serve as security to raise financing through the issuance of debt instruments. Perhaps the greatest potential revenue source in this regard is real estate development.

Real estate located at or near major transportation system access points (e.g. airports, train stations, and highway interchanges) increases in value as the transportation systems develop due to the increased accessibility of these properties. For many years, transportation planners have looked for mechanisms to capture part of this increase in value which could then be used to offset part of transportation system capital costs. Perhaps the most advanced efforts in "enhanced value capture" can be found in Florida as part of the Florida High Speed Rail Project.

The feasibility studies for high speed rail in Florida showed that a high speed rail system connecting Miami, Orlando and Tampa could cover all operating and most capital costs from transportation revenues. To make up the capital deficiency and to make the project attractive to the private sector without using public funds, Florida incorporated a mechanism that will grant the holder of the high speed rail franchise enhanced development rights for properties adjacent to the rail line or connected to it via public transit. The franchisee can then enter into joint development agreements with real estate developers who would compensate the franchisee, who in turn will use this compensation to provide capital for the high speed rail system. It is interesting to note that the presumptive franchisee for the Florida high speed rail line is a consortium organized by one of the largest real estate developers in Florida.

TAX BENEFIT FINANCING

Chapter IV of this report contains an estimate that a number of transportation markets would generate revenues from fares sufficient to cover all capital and operating costs associated with a maglev system. The rate of return on project financing used in this analysis (12.5 percent), however, may be inadequate to attract financing for some of these projects that might be considered unusually risky given the lack of experience of financial markets in dealing with maglev. A means to increase the effective yield, and therefore the relative attractiveness of an investment, is the use of tax benefit financing.

Depending upon their availability, the use of tax exempt financing tools might be part of the strategy for the financing package for many maglev projects. These may include the issuance of what used to be referred to as industrial development bonds ("IDB's"), that is bonds issued by a governmental unit which are used to finance operations employed in the trade or business of a private entity that produces pubic benefits. Because of changes in Federal tax laws, not all IDB's may be considered tax exempt.

<u>Effect of the Tax Reform Act of 1986</u>

The Tax Reform Act of 1986, Pub. L. 99-514, made sweeping changes to Section 103 of the Internal Revenue Code ("Code"), dealing with tax exempt bonds. Tax writers were concerned with many of the abuses in the issuance of industrial development bonds, in which tax exemption was given to essentially private activities with little public purpose.

The law established a new test for tax exemption. Under the Act, "non-essential function bonds" bonds determined to be not essential to the fundamental purpose of a state or local government, are fully taxable. The Act now refers to "private activity bonds," which may be tax exempt if they are issued for certain qualified purposes, such as airports, docks and wharfs, sewage disposal facilities or mass commuting facilities. (Note that maglev would not normally be included in the definition of "mass commuting facility" and is separately covered by a provision in the Technical and Miscellaneous Revenue Act of 1988. (See below.) "Private activity bonds" are those where more than 10 percent of the proceeds are used in a private trade or business and 10 percent or more of the debt service is secured by payments from such property. As a result of this provision, private ownership is no longer permitted for airports, ports and mass commuting transit facilities wishing to avail themselves of the tax exempt status.

The Act also subjects most private activity bonds to a new state volume cap, based upon population, and subjects bonds to the alternative minimum tax and revised depreciation rules. Additionally, the Act requires arbitrage profits to be returned to the U.S. Treasury and limits advance refunding. All of these changes have the effect of making tax exempt financing for maglev projects less desirable.

In addition to the specific changes to tax-exempt financing described above, it should also be remembered that the lowering of marginal income tax rates has made tax-exempt financing less desirable, from the perspective of a potential investor. Also, the Investment Tax Credit, which the Act eliminated, served as an additional incentive to the kind of investments for the development of maglev technologies and systems.

Effect of the Technical and Miscellaneous Revenue Act of 1988

Under Pub. L. 100-647 (November 10, 1988), Section 142 of the Code was amended to include as exempt facilities "high-speed intercity rail facilities," which is defined to include "any facility (not including rolling stock) for the fixed guideway rail transportation of passengers and their baggage between metropolitan statistical areas...using vehicles that are reasonably expected to operate as speeds in excess of 150 miles per hour between scheduled stops, but only if such facility will be available to the general public." The effect of the amendment is to accord to bonds used to finance maglev projects the same treatment as present law accords to bonds used to finance airports, docks and wharfs, with three exceptions. First, the high-speed intercity rail facilities financed with the proceeds of such bonds need not be governmentally owned. However, if the owner is a private entity, an irrevocable election must be made not to claim depreciation or other tax credits with respect to such property. Second, 25 percent of each issue must receive an allocation from the state's private activity bond volume, which has a dollar ceiling based upon state populations. And third, any proceeds of an issue not spent within three years of the date of issue must be used to redeem outstanding bonds.

The amendment makes bond financing of maglev projects more attractive. Of particular importance is the provision that the facilities need not be governmentally owned. The elimination of this restriction fosters public/private partnerships or other forms of ownership which would make certain maglev projects feasible. Nevertheless, the requirement of a partial allocation of state volume limitations and the fundamental disincentives to tax-exempt financing in the Tax Reform Act of 1986 (because of lower marginal tax rates, among other things) are still in place. In this respect, the amendment should be considered to be only a transportation services or the beneficiaries of the heavy capital investment and the associated economic activity such creates.

PUBLIC FINANCING OF MAGLEV PROJECT IMPLEMENTATION

The results of the analysis in Chapter IV show that there are many potential transportation markets that could cover all the estimated operating costs and a large portion of the capital costs of a maglev system. Public entities may choose to provide support for proposed private sector maglev systems unable to generate sufficient capital in the private sector, in order to avoid more costly infrastructure investments elsewhere or for other public purposes.

Federal financial assistance, in FRA's view, will not play the dominant role in any public financial support for implementation of specific maglev systems. States and local governments will be the primary focus of any public assistance for the implementation of specific maglev systems. These governmental entities may choose to provide direct financial assistance raised through any of the several taxes, assessments or other revenue sources available to state and local governments. Direct financial assistance to private entrepreneurs may be undesirable or impossible due to state or local statute, governmental policy or public opinion. In such cases, these entities may consider an offer of incentives to maglev system developers such as the enhanced real estate development rights that will be part of the franchise granted for a high speed rail line in Florida, or various forms of tax incentives.

Another means of providing indirect financial support would be to make rights of way available at little or no cost to the entity developing the maglev system. States own large amounts of transportation rights of way, in particular highway rights of way. States, through their transportation planning process, can also act to preserve rights of way or potential transportation corridors providing access to major urban areas when such opportunities exist. Use of these rights of way could then be made available to the maglev system developers eliminating what could be a major capital cost. An excellent example of this can again be found in Florida where the State Department of Transportation has an active program of acquiring abandoned railroad rights of way. One right of way acquired by the State connects the Florida east coast cities between Miami and West Palm Beach. Use of this right of way has been made available to the entity that receives the franchise for the high speed rail line.

SPECIFIC RECOMMENDATIONS

The study conducted by FRA and summarized above must be considered preliminary. As a consequence, this report does not contain any specific recommendations by the Administration for legislative action. The President's fiscal year 1991 budget request would fund a detailed examination of the issues that FRA has been able to identify in its discussions with companies, academic communities and entrepreneurs who would be expected to participate in maglev development and implementation. In the report on that effort, FRA expects to be able to offer the results of that detailed examination and formal recommendations for any legislative action needed to support U.S. leadership in the commercial applications of maglev.

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GLOSSARY

Aerodynamic braking - Method for decelerating a moving vehicle utilizing the aerodynamic resistance of the moving vehicle to achieve braking force.

Aerodynamic drag coefficient - Constant of proportionality relating aerodynamic resistance to vehicle speed and sectional area.

Air bag suspension - A type of suspension, usually secondary, using air compression for the resistance force.

Air gap sensor - A transducer used to measure the air gap between the moving maglev vehicle and stationary guideway.

Automatic train operation - Operational monitor and control whereby the speed and position of the train is automatically controlled.

Bogie - A low swiveled undercarriage at either end of a railway car used to support the car.

Catenary - A power line usually supported at short periodic distances and used for feeding power to rail vehicles by means of a sliding contact.

Claude cycle - A closed cycle cryogenic process developed by G. Claude in 1902 which utilizes both internal & external work expansion for gas liquefaction.

Computer integrated manufacture(CIM) - Manufacturing technology utilizing computers for automating and controlling the manufacturing process.

Cryogenics - The science that deals with the production of very low temperatures and their effect on the properties of matter

Cycloconverter - Power conditioner for bidirectional conversion of ac power having different input/output frequencies.

Eddy current brake - Nonfriction-type brake which utilizes induced eddy currents in secondary braking element.

Electromagnetic suspension (EMS) - Type of levitation derived from the attractive force generated by an excited (primary) electromagnet interacting with a secondary ferromagnet.

Electrodynamic suspension (EDS) - Type of levitation derived from the repulsive force generated by a static magnet field moving relative to a conducting secondary medium. The static magnetic field may be provided by either a superconducting magnet or permanent magnet.

Electromagnetic interference (EMI) - Electromagnetic noise generated by uncontrolled or random currents in electrical equipments.

Emsland Transrapid Test Facility (Transrapid Versuchsanlage Emsland,TVE) - Test facility at Emsland, Germany used for high speed maglev tests.

Fail-safe - Equipment and/or system operational state whereby performance interruption is prevented through system design and component redundancy or where a failure results in nonhazardous consequences.

Feeder block - Section of power distribution line along guideway used to feed power from substation to a length of propulsion winding coil.

Geotopia - Japanese-English term for describing underground commercial centers or complexes located at metropolitan maglev terminals in Japan.

Ground coils - Discrete electrical conducting coils attached to the guideway for producing vehicle levitation & lateral guidance.

Guideway - Physical structure along which the maglev vehicle is propelled and guided. The guideway may be either U-shaped as used with Japan's superconducting maglev, T-shaped as used with Germany's Transrapid maglev, or possibly some other form.

Headway - The time interval between successive trains travelling on the same guideway.

High temperature superconducting magnet - A magnet formed of conducting coils that remain superconducting at temperatures considerably higher than liquid helium temperature. High temperature superconducting magnets generally operate in the range of 20°K to 100°K (-423.4°F to -279.4°K).

Inverter - A device for converting direct current (dc) into alternating current (ac) by mechanical or electronic means.

Linear induction motor - Linear motor using induced currents in a secondary reaction member, usually a conducting rail, to generate propulsion thrust.

Linear synchronous motor - Linear motor which generates propulsion thrust by the interaction between a static (excitation) field and a moving magnetic field (generated by an armature winding) which travels at the synchronous speed of the static field. The static field can be produced by either superconducting magnets, electromagnets, or permanent magnets.

Long stator - A type of linear propulsion motor having an extended propulsion winding length. Long stator-type linear motors are incorporated into the maglev guideway.

Low temperature superconductors - Materials which exhibit superconductivity below a critical temperature, T_c, of approximately 10°K (-441.7°F).

Magnet driver - The controlled power source used to feed power to the magnet load.

Magnetic keel - A magnetic circuit used by Magneplane to stabilize vehicle motion against roll.

Magnet pole pitch - The distance corresponding to a 180 degrees change in phase of the motor excitation winding.

Normal repulsive levitation - Repulsive-type vehicle levitation derived from interaction of static magnetic field on vehicle with conducting coils (or sheets) positioned in a horizontal plane on the guideway.

Null-flux - An electromagnetic circuit formed of figure-eight coils such that exposure to a uniform magnetic field produces no net flux coupling to the electromagnetic circuit. See Figure V-16.

Melt quench - A metallurgical process used to improve the magnetization properties of selected superconductors by cooling the molten superconductor in the presence of a magnetic field.

Miyazaki Test Facility - Japan's primary experimental test facility for high speed tests of the superconducting train. The 7 km test track facility in the Miyazaki prefecture was commissioned in 1979.

Permanent magnet suspension (PMS) - Type of levitation derived from the attractive force generated by a permanent magnet interacting with a secondary ferromagnet.

Power demand - Electrical power needed to meet operational requirements, usually the peak power requirement.

Power factor - The ratio of the (real) mechanical power to the total (apparent) power given by the product of ac input voltage and current.

Power distribution system - Power equipment including utility substations, converters, feeder lines, used to feed power to the maglev system.

Power rails - Conducting rails extending along the guideway used to transfer (dc or ac) electrical power from a source supply to a moving maglev vehicle through mechanical contact with the rail.

Propulsion efficiency - The ratio of the power equal to the product of thrust and speed to the active real power supplied by the source utility.

PWM Inverter - A power conditioner using a variable width of modulation pulse to control the output variable voltage/frequency power of the conditioner.

Quench - Condition describing the sudden change from superconducting to normal conducting state.

Ride quality (standard) - A measure of the ride performance based on acceptable levels of random acceleration in the longitudinal (thrust), vertical, and lateral directions.

Radius of curvature - A measure of the severity of a curve in a guideway structure based on the length of the radius of a circle that would be formed if the curve were continued.

Ram wing -

Shinkansen - Japanese high speed train. Tokaido Shinkansen is the steel-wheel high speed train operating between Tokyo and Osaka. Chuo Shinkansen (Chuo Linear Express) is the high speed superconducting train (maglev) scheduled for operation between Tokyo and Osaka early next century.

Short stator - A type of linear propulsion motor having a relatively short propulsion winding length. Short stator-type linear motors are housed on-board the maglev vehicle.

Specific energy consumption - Maglev energy consumed for specified distance travelled or per specified distance travelled per passenger.

STARLIM - A maglev system being jointly developed by France & Germany using Transrapid suspension/guidance technology and a (U-shaped) linear induction motor for propulsion.

Stopping point - Designated point on guideway at which decelerating maglev comes to a stop.

Superconductivity - The property of materials characterized by an effective zero electrical resistance below a specified critical temperature.

Terrestrial topographics - Ground surface features which can affect the siting of maglev guideways.

Tesla - Unit of magnetic flux density equal to 10,000 gauss.

Vacuum switches - Vacuum-type contactors used to control feeding of sections of propulsion winding.

VV/VF inverter - A power conditioner which converts dc power to variable voltage/variable frequency output power.

Yamanashi Test Facility - A 43 km maglev test facility to be constructed in the Yamanashi prefecture (west of Kofu) to be used for operational tests of Japan's future revenue service superconducting train.

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