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John Harding

THE ROLE OF HIGH SPEED MAGLEV IN THE FUTURE U.S. TRANSPORTATION SYSTEM

RICHARD A. UHER
HIGH SPEED GROUND TRANSPORTATION CENTER
CARNEGIE MELLON UNIVERSITY
4400 FIFTH AVENUE
PITTSBURGH, PA 15213

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INTRODUCTION

MAGLEV refers to guided ground transportation which depends on magnetic forces for vehicle suspension and guidance and vehicle propulsion using linear electric motors. There is minimal physical contact between the vehicle and guideway while the vehicle is in motion. High speed MAGLEV (150-300 mph) is regarded by some as a new mode of guided ground transportation which fits between air and rail modes -- a flying train or -- a guided aircraft. The speed range of MAGLEV overlaps the rail mode on the lower end and the air mode on the upper end. For trips of 100-600 miles, MAGLEV may be more efficient than either highway or air.

There is a forecast of a national transportation crisis around the year 2000. Many say that gridlock will be a common occurrence on our highways and in our airways. It is evident from present data trends that America is losing its mobility. Although more of the population will have access to the highway and air modes, both intercity and intracity trips will take longer because of congestion.

The purpose of this paper is to examine the nature of the forthcoming transportation crisis and to suggest that high speed guided ground transportation using high speed MAGLEV technology can be used along with improvements in the highway and air modes to soften the crisis. A proper integration of highway, air and MAGLEV modes could result in a maximum increase of mobility for each transportation dollar spent.

This paper is divided into four parts. The first part is an historical reference to earlier developments in high speed ground transportation in the world, with special emphasis on the U.S. program. The second part examines the imminent transportation crisis in more detail. Projections of highway and air system congestion are highlighted. Since highway and air are the principal modes of passenger transportation in the U.S., worsening congestion is an extremely serious problem in terms of national mobility.

The third part of the paper summarizes the present state of the art of MAGLEV technology. The technology is reviewed from the point of view of its maturity as a transportation system. Finally, in the fourth part of the paper, a concept is put forward on how this new technology might help meet the approaching crisis.

BACKGROUND OF MAGLEV AND HIGH SPEED GROUND TRANSPORTATION

"There is a growing and painful awareness that we in the United States have permitted the growth of a serious transportation gap. I refer to the lack of suitable transportation in (average) speed ranges very roughly from 100 to 200 mph and over distances, equally roughly delineated of about 100 to 500 miles. The automobile is too slow and laborious for this spectrum, and the airplane leads to a false sense of speed since, when we consider point-of-departure to point-of-destination trip times, the average speed is often less than 100 mph and the trip is accompanied by frustrating ground connections, unpleasant mode mixes in the airport and the threat of delays or trip cancellations as a result of inclement weather."

This quotation appears at the beginning of a preface to the proceedings[1] of a high speed ground transportation (HSGT) conference held in Pittsburgh in 1969, three years after passage of the High Speed Ground Transportation Act, Public Law 89-220, by the 89th Congress. This law, which established the Office of High Speed Ground Transportation (OHSGT) under the Department of Commerce, authorized the R&D for HSGT. The objectives[2] were to advance rail technology as rapidly as possible and to explore other technologies which might be useful for new modes of intercity ground transportation.

When the 1966 surveys of technologies for HSGT were completed, magnetic levitation was not chosen for inclusion into the R&D program. It was thought that installing magnets aboard the vehicle would cause the vehicles to weigh too much and imbedding them in part of the guideway would cost too much. Because of these findings, early research on non-contact levitation concentrated on air cushion vehicles.

MAGLEV research in Germany and Japan began in the late sixties. Research in Germany, sponsored by the Federal Ministry of Research and Development, has proceeded in the direction of the electromagnetic system (EMS), which depends on attractive magnetic forces to balance gravity, thus levitating the vehicle. Air gaps of 0.6 inches between the levitation device on the vehicle and guideway device are typical in this system which must be actively stabilized.

The early Japanese work included university and industrial research as well as that by the Japanese National Railway research staff. This work was directed toward the concept of the Electrodynamic System (EDS) which used superconducting coils aboard the vehicle to react with coils in the guideway. In this system, the vehicle must be moving to levitate, but an air gap of several inches can be maintained between the vehicle and guideway devices.

The years during which the HSGT law was in effect slipped by quickly. The final report on the law was written in May, 1977. That report summarized the completed research and the philosophy developed in the U.S. during those years. Most of the hardware efforts in the advanced technology were directed toward the development of a linear induction motor-driven rail research vehicle, a tracked air cushion research vehicle, a prototype tracked air cushion vehicle (intended for airport access) and rail related research, much of which was directed toward the Northeast Corridor Demonstration Project.

A breakdown in the expenditures for the HSGT program is shown in Table 1. MAGLEV R&D was a very small part of this program and consisted of paper studies and small model development. Total expenditures in this area were less than $3M. The early work was carried out at Brookhaven National Laboratory, Massachusetts Institute of Technology, Ford Motor Company, Stanford Research Institute, Mitre Corporation, and TRW Systems Inc.

Table 1

Allocation of Funds
For
US HSGT Program (1966-75)

Research & Development	10 Year Total ($M)
Systems Engineering	11.4
Test Center	28.7
High Speed Rail Research	41.8
Advanced Systems	39.5*
Supporting Technology	23.0
Subtotal	144.6
Demonstration (All Rail Related)	51.8
Administration	12.9
Total	209.3

*MAGLEV R&D < $3M out of $39.5M

All work on HSGT MAGLEV development in the United States stopped in 1975, with the expiration of the HSGT Act of 1965. International information exchanges with the Germans, Japanese and Canadians had proven fruitful, and the final report of the Act pointed out that for the U.S. "to continue to benefit from the foreign research, the United States will need to have information to exchange". It is interesting to note that in the same report two reasons were given for dropping the advanced technology effort.

1. The need for large amounts of government money to maintain existing rail service in the Northeast and Midwest, principally to rehabilitate roadbed.

2. The growth of demand for transportation had slowed over the predictions made in the mid-1960's. "Advent of larger aircraft has reduced airport congestion - at least temporarily. Therefore, the pressures to relieve congestion, which seemed so urgent in the 1960's, diminished - at least for a decade."

In Canada[3], work on MAGLEV was concentrated at Queen's University, where a large rotating wheel facility was constructed. Detailed transportation system design studies, as well as analysis of EDS systems, were also carried out at the University.

Thus, during the intervening years, since 1975, North American efforts in advanced technology were minimal while Germany and Japan continued MAGLEV developments.

Perhaps the most advanced high speed railroad operation is in France on the line between Paris and Lyons. The portion of the line between the outskirts of Paris and the outskirts of Lyons is totally dedicated to high speed service. Construction of the line began in 1976 and the entire line was in revenue service by September, 1983. The system has a maximum speed of 168 mph and covers the 273 miles between Paris and Lyons in 2 hours.

There are other high speed rail developments in both Europe, the Soviet Union and Japan which are also directed at decreasing travel time from city center to city center. Most of the plans call for raising rail speeds even higher: 150 mph in Japan, 186 mph in France and 160-180 mph in Germany.

In all of the high speed rail developments in Europe, Japan and even the U.S. Northeast Corridor, the philosophy has been to consider city centers as the starting and ending points of journeys. In Europe and Japan, where public transportation is used as part of an intercity trip, the new high speed services have been and are projected to utilize upgraded versions of traditional rail routes. The infrastructure to support rail operation still exists in those countries.

But let us look at the typical intercity trip in the U.S. First, with the exception of the Northeast Corridor, it is not accomplished by using the rail mode and it generally involves use of the private automobile for some portion or all of the trip. If the private automobile is not used for all of the trip, it is, at least, driven to an airport and parked while the traveller(s) uses the air mode to his destination airport. At this point, the traveller(s) uses public transportation, taxi or limousine, rents a car or is picked up by someone in a car to continue his trip to the final destination. The return trip is the reverse of this procedure. Due to urban sprawl and the difficulty in getting to center city by private automobile, the center-city to center-city trip is becoming more and more outdated.

NATURE OF THE TRANSPORTATION CRISIS

The nature of the transportation crisis is one of increasing congestion in the highway and air modes, the principal modes of travel in America.

Highway System Congestion

Highway congestion in urban areas continues to worsen. More and more Americans have access to an automobile. A study[4], which is now being conducted by the Federal Highway Administration, forecasts that the vehicle-miles travelled on the highways will increase from 1.6 trillion in 1985 to 2.6 trillion in 2005. There are several reasons given for this increase; namely, increases in licensed drivers, increases in households because of changing lifestyles, longer trip lengths because of continued suburban sprawl and the change in the nature of the economy from manufacturing to service based (requiring more travel).

Although more people will have access to automobiles, the average speed during trips will decrease because of increasing congestion. The Federal Highway Administration has also forecasted the congestion expected on the nation's highways through the year 2005[5]. This was done using the Highway Capacity Model[6]. Table 2 summarizes these results. Vehicle delay will increase from 2.7 billion vehicle-hours in 1985 to over 11.9 billion vehicle-hours in the year 2005, if both major urban freeways and signalized arterials are included. Just the increase of 9.2 billion vehicle-hours is over three times the present delay.

There have been attempts to quantify this delay in terms of cost to the user. Table 3 summarizes these costs. The 1985 cost of $12.2 billion/year will increase to $46.5 billion/year in the year 2005. This represents an increase of $34.3 billion/year in lost time and fuel costs. A report by the American Public Transit Association[7] quotes this cost increase at $41 billion/year.

The data[8] on vehicle congestion in peak hours shows that in the year 1983, about 54% of peak-hour travel was congested. In 1987, this increased to 65%. If the trend continues, by the year 2005, nearly all peak hour travel would be under congested conditions.

Table 2
Vehicle Congestion on U.S. Highways

	Delay (Billion Vehicle-Hours)		
	1985	2005	Increase
Urban Freeways	1.6	8.1	+6.5
Signalized Arterials*	1.1	3.8	+2.7
TOTAL	2.7	11.9	+9.2

* Estimated from data sample given in Reference 2.

Table 3
Cost of Vehicle Congestion to the Highway User

	1985	2005	Increase
Billion Person-Hours*	3.2	14.3	+11.1
Billion Gallons Fuel**	0.8 (1.3%)	3.6 (4.4%)	+2.8
Billions of Dollars***	12.2	46.5	+34.3

* 1.2 persons per vehicle

** .3 gallons of fuel per vehicle-hour

( ) indicates percent of total fuel

*** $3.00/person-hour +$1.00/gal.

Calculations of total fuel:

1985: 27 MPG
1.6T VMT/27MPG=59.3B gal

2005: 32MPG
2.6T VMT/32MPG=81.3B gal

Air quality is also a growing problem for the nation. The culprit is the use of the private auto. Sixty eight[7] of our cities fail to meet ozone standards, fifty-nine cities fail to meet carbon monoxide limits, and over one hundred suburban areas exceed present pollution standards.

Air System Congestion

Air traffic is also congested, with very little hope of relief in the future. The nation faces a rising crisis in aviation[9]. Eleven major airports experience severe delay of over 8 minutes per air operation*, as shown in Figure 1. The number of airports experiencing severe delay will increase to twenty-nine by 1996 and is expected to be as high as 47 by 2005. Since the 100 busiest airports handle 95% of the total traffic, the effect of chronic delay on half of the busiest airports will be immense.

Table 4 presents some of the forecasts which indicate the severity of the air congestion problem. Expressions of demand, either in enplanements or passenger miles, will more than double by the year 2005. The cost of delay is expected to increase from $5B in 1986 to $13B in 2005.[10]

At the present time, 63% of all air operations are flights whose origin-destination are within 600 miles, the range at which high speed ground modes may be more efficient than the air mode.

STATUS OF MAGLEV TECHNOLOGIES

MAGLEV technologies, which are presently recognized worldwide, are described with the help of Figure 2. In moving from left to right in the figure, the first division of the technologies is by method of levitation, either ATTRACTION or REPULSION.

The REPULSION systems are based on superconducting magnet technology. Although there are many such systems in the conceptual and even small model development stage, the only system demonstrated in large scale is the one developed by the Japanese Railway (JR) with its associated 4 mile test track at Miyazaki.

Several ATTRACTION MAGLEV systems are in various stages of development. These are usually divided by their means of propulsion: SHORT or LONG STATOR, referring to the linear motor which drives the vehicles, whether the active elements are located on board (SHORT) or off board (LONG) as part of the guideway, as illustrated in Figure 3. For SHORT STATOR systems, some method of propulsion and auxiliary power pickup is required. For LONG STATOR systems, only auxiliary power pickup is required. Auxiliary power is the hotel load used aboard the vehicles.

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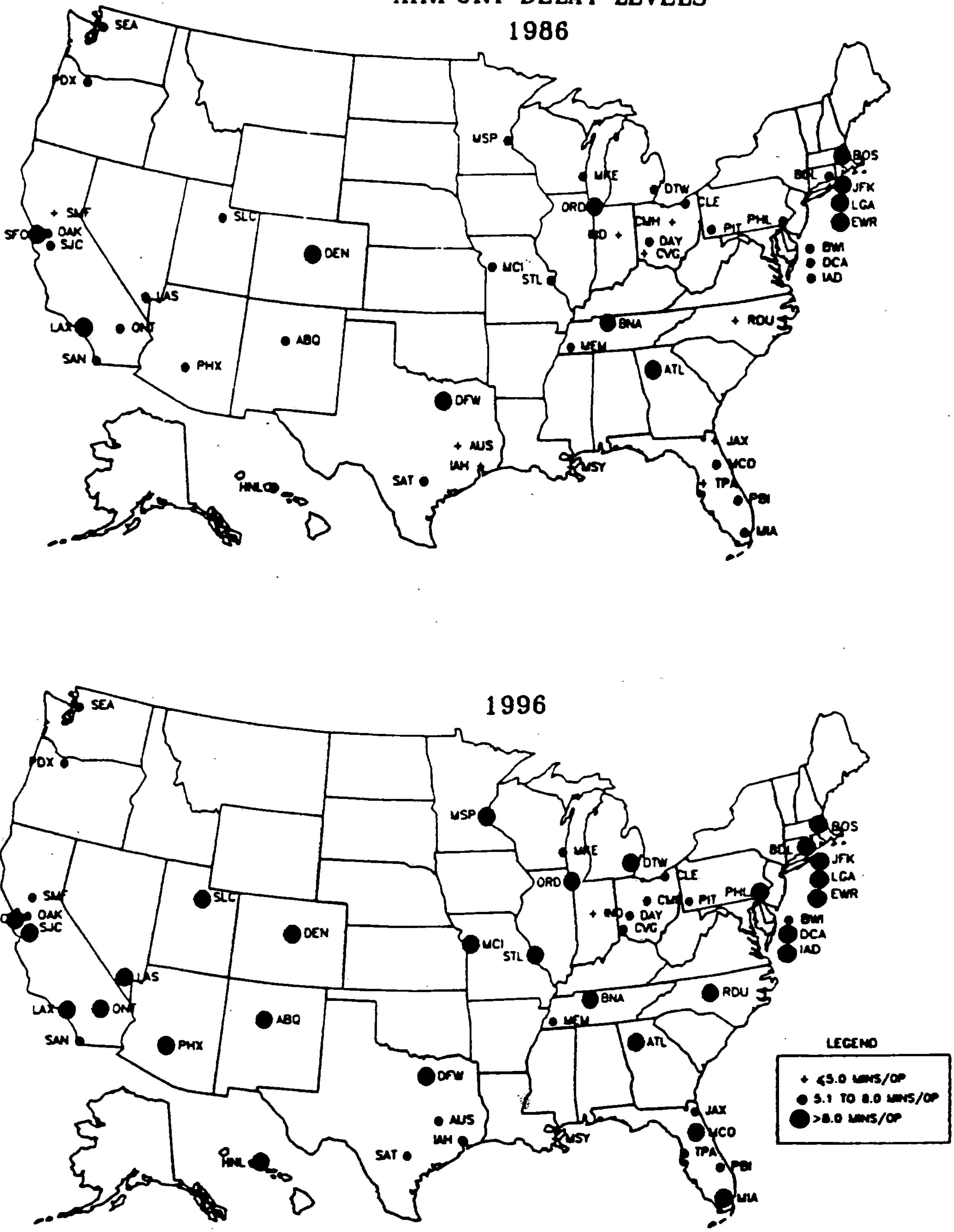
* An air operation is one takeoff (every plane that takes off also lands).

AIRPORT DELAY LEVELS



Source: Federal Aviation Administration

Figure 1

Table 4

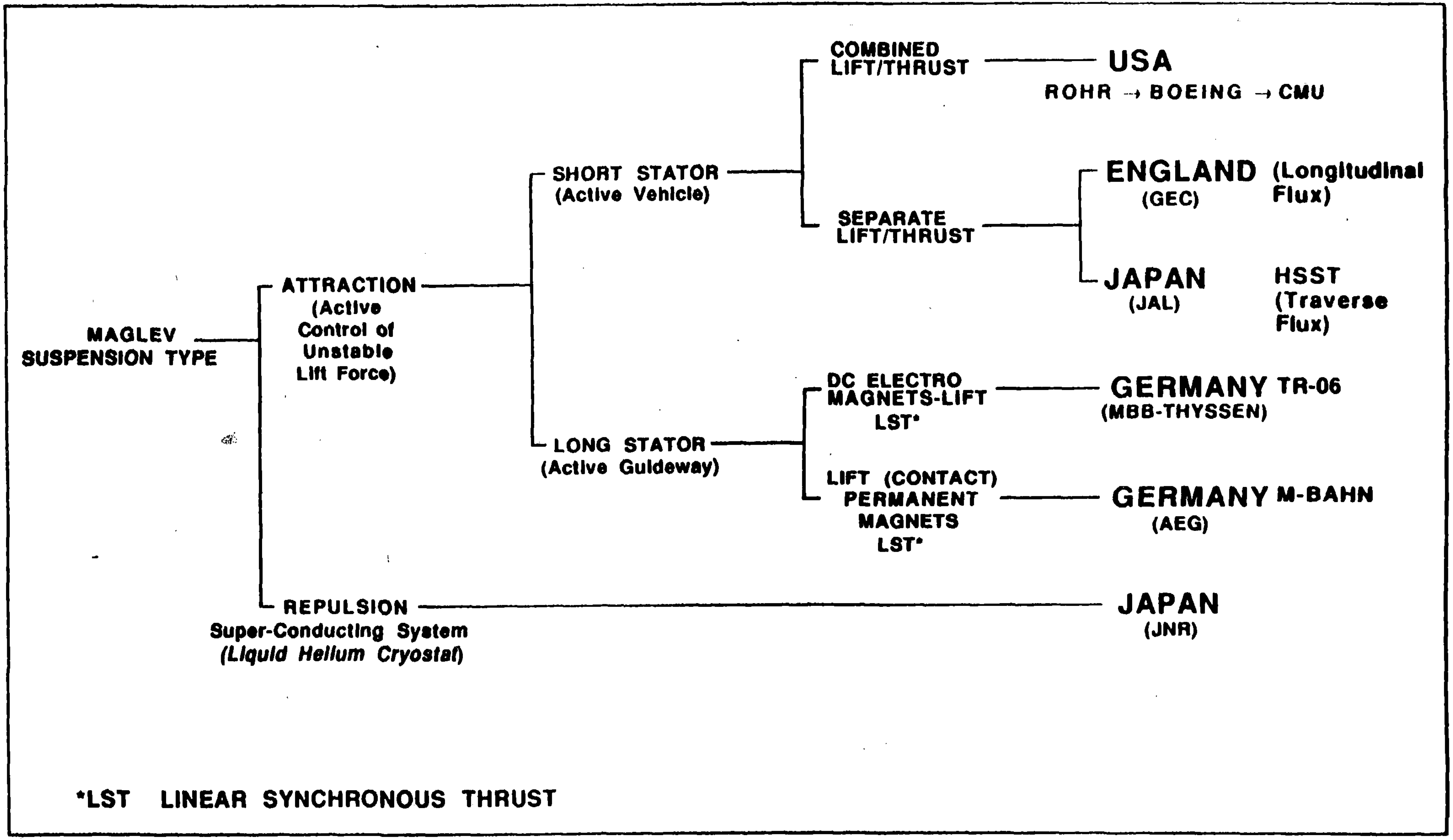
Air Congestion

DEMAND:	1986	2005
Enplanements	414M	887M
Passenger Miles	359B	935B
Air Operations	29M	46M
Airports with Chronic Delay*	11	47
Cost of Delay**	$5.0B	$13.3B

* Delay exceeds 8 min/operation

** Projection to 1996 taken from reference 10. Projection to 2005 at the same annual rate as in 1996.

MAGNETIC LEVITATION TECHNOLOGY — WORLDWIDE



*LST LINEAR SYNCHRONOUS THRUST

Figure 2

Comparison between conventional "rotating" motors and short-stator or long-stator linear motors

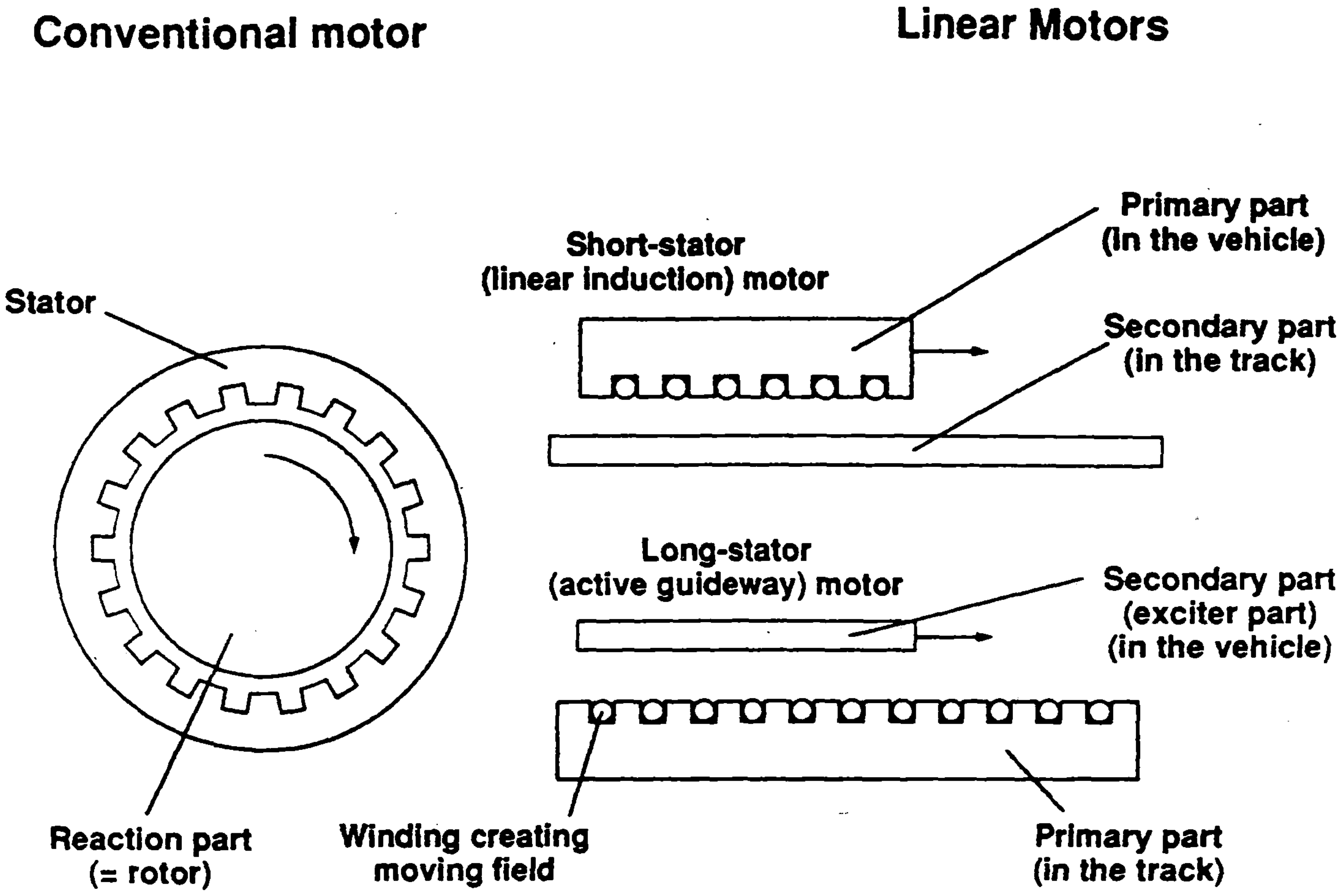


Figure 3

Technologies can further be divided into how levitation, guidance and thrust are accomplished in single units or separate units aboard the vehicle, and the nature of the magnetic forces, whether achieved through combined permanent and electromagnets or pure electromagnets.

Only three of the developments illustrated in Figure 2 are capable of high speed operation (above 150 MPH): the Japanese JR, the Japanese HSST and the German MBB - Thyssen (Transrapid). Table 5 provides a summary of the present state of the art of these high speed technologies.

Of the three developments, the German Transrapid system is the furthest along in its development cycle. It is estimated that they will furnish development late in the year 1990, at which time the total cost will be $1B. The Germans have announced a commitment to build a MAGLEV system in Germany, either from Hamburg to Hanover or Essen to Bonn, with construction to begin in the early nineties and with operation in the middle to late nineties.

APPLICATION OF MAGLEV TECHNOLOGY

High Speed Ground Transportation (HSGT) using high speed MAGLEV technology, is expected to play a large role in the evolution of the U.S. transportation system in the 21st century. This technology, together with capacity as well as innovative improvements in both the highway and air modes, will be used to meet a national transportation crisis, which is imminent in the next decade. Air and highway congestion, as demand for both modes roughly doubles over the next 15-20 years, will severely worsen. The role for MAGLEV is not one of mere substitution for railroad passenger service, but rather to meet a need in the rough range of 100-600 miles, where both the highway and air passenger modes are less efficient.

Regional MAGLEV systems, with top speeds exceeding 300 mph, and with the airport of a major metropolitan area as the hub, and with service extending to smaller cities (airports) in the surrounding region, make a great deal of sense. The hubbing concept, now practiced at many of these airports, can in many cases be more efficiently handled by MAGLEV, freeing valuable air and airport space to long distance flights. As our economy becomes strongly linked with those of other nations, demand for long distance flights is expected to continue to increase rapidly.

Since such regional MAGLEV systems will run through suburban areas surrounding the major metropolitan airport, it is highly likely that these same systems would be used for suburban commuter and airport access as well. Since the lines for the regional system would have to be built, the suburban commuter and airport access would be obtained at a marginal capital cost increase over the regional system cost. The suburban commuter system would be built first, since the lines are shorter, generating early revenue, while the regional system is being built. The regional system is simply an extension of the suburban initiative. The method of building, small to large, is not new. Historically, this method was used in the development of every new mode of transportation, including railroads, trolleys, highway and air.

Table 5

High Speed MAGLEV Systems

	JAPANESE		GERMAN
	JR	HSST	TRANSRAPID
Top Speed Range (MPH)*	250-300	60-180	250-300
Type of System	EDS Long Stator	EMS Short Stator	EMS Long Stator
Development Started	1967	1975	1969**
Development Cost Thru 1988	$416M	$40M	$812M
Length of Test Track	4 mi	<1 mi	19 mi
Commercial Cost***	$36M/mi	?	$20M/mi
Revenue Operation Readiness	1996	1994+	1990

* Jr - Maximum speed reached unmanned 323 MPH
Transrapid - Maximum speed reached with passengers 256 MPH

** Began development with EDS. Started EMS development in 1975

*** Per double track mile exclusive of right of way and stations

\+ Estimated. Will require larger test track for high speed operation

The nodes (stops) of these systems are prime candidates for controlled economic development. Because the automobile, taxi or feeder bus would be the primary mode of transportation to the MAGLEV node, the MAGLEV system would function as the engine of economic development of activity centers surrounding the node. All nodes would function as entry points to the hub airport, thus substantially reducing ground access time to the air mode.

Top speeds of the suburban commuter and airport access system would be 150-200 MPH. Even the regional MAGLEV trains would operate at these lower speeds while moving through the suburban areas. When outside of the urban areas, top speeds would lie in the 200-300 MPH range.

The regional and suburban MAGLEV systems are further explained, conceptually, with the help of Figures 4 and 5.

At the center of the regional MAGLEV system lies the airport and downtown of a major metropolitan area. The MAGLEV lines run outward connecting to smaller cities (either at airports or major highway junctions) and to adjacent major metropolitan airports and downtowns. The circled area shown in Figure 4 is the extent of the suburban MAGLEV system, which is detailed further in Figure 5. This system, which operates on the same regional high speed lines as shown in Figure 4, provides a MAGLEV commuter service for the urban sprawl of the major metropolitan area; including the downtown, as well as an airport access system which is far superior to a congested urban highway system. The key to the success of such a system will lie in the connectivity of the MAGLEV systems and the ability to provide an easy interface with the highway and air modes. All nodes, with the possible exception of the major airport and downtown, must have provision for auto, bus, rail and taxi access, with major parking facilities.

Many of the nodes could handle baggage for the air carriers, so that check-in could occur at the access node. Likewise, the system could also carry high priority freight and mail similar to that now carried by airlines.

Let us suppose, for example, that such MAGLEV systems existed around Pittsburgh, PA and Washington-Baltimore and were connected via regional high speed lines via Cumberland, MD. The average trip time (door-door) would be reduced from 4-5 hours to 2-2 1/2 hours. This is a substantial improvement in travel time.

The building of such a system would proceed from the suburban to the regional system so that early revenue may be obtained while other lines are being built.

Step 1: Major Airport to Major Urban Sprawl Access
Top Speed: 150-200MPH
Internodal Distances: 7-20 miles

CONCEPTUAL HIGH SPEED REGIONAL MAGLEV SYSTEM

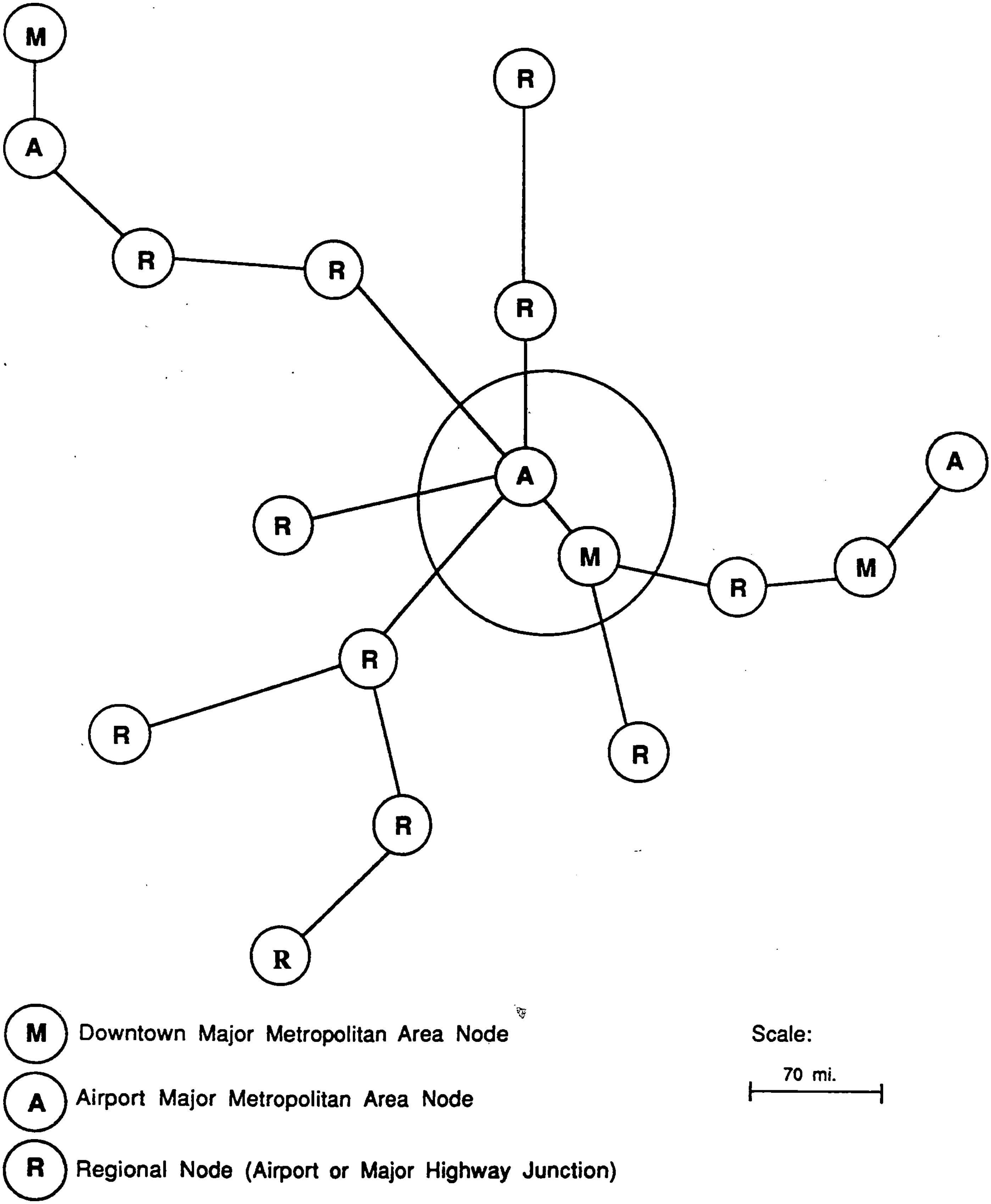


Figure 4

CONCEPTUAL HIGH SPEED SUBURBAN MAGLEV SYSTEM

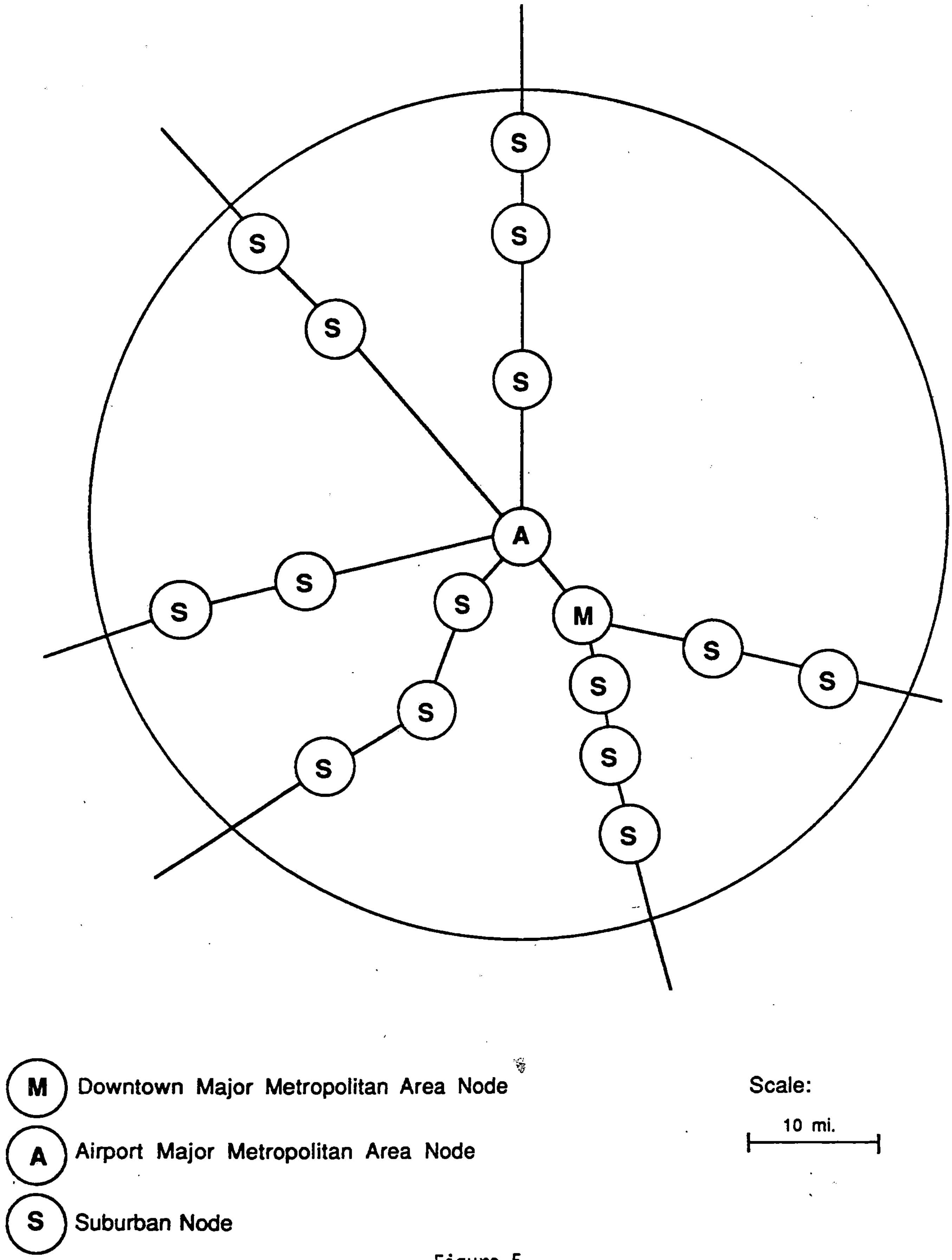


Figure 5

Step 2: Extension of Major Airport Service to
Surrounding Region
Top Speed: 200-300MPH
Internodal Distance: 20-100 miles

Step 3: Linking of Major Airports (Step 1 & 2) Over Two
or More Major Metropolitan Areas

There are certain requirements that such MAGLEV technologies must have in order to meet the emerging transportation need which was just discussed. These requirements are:

1. High speed and high maneuverability
2. Potential for low cost (Capital & Operating)
3. Environmental acceptability
4. High level of ride comfort
5. Fully developed before application
6. High level of safety

The high speed and high maneuverability aspects of a MAGLEV technology refer to low trip times. Maneuverability refers to the capability to bank and take smaller curves without much speed reduction and negotiate large grades at high speeds. It also refers to the ability to have off-line stations so that local and express service can be intermixed. Climbing of grades of 10% and banking of curves at 12^o allow these MAGLEV systems to go around communities better than conventional rail and still maintain speed. Therefore, there would be less intrusion on existing communities. The suburban service requires systems which have a top speed of 150-200 MPH, while regional high speed service requires speeds of 200-300 MPH.

The only MAGLEV technologies, illustrated in Figure 2, which are capable of these speed ranges are the German MBB-Thyssen (Transrapid International), and the Japanese JNR developments.

The second requirement for the HSGT system is low cost. Improvements in automated guideway manufacture and installation would naturally contribute to low guideway initial cost. Using automated airline manufacturing techniques, which are more appropriate in these systems than rail car techniques, could contribute to lower vehicle costs. Because these systems do not contact their guideway, maintenance costs are reduced on the guideway as well as the vehicle. Maintenance of superconducting coils aboard the vehicle is still an open question. Without right-of-way acquisition or station costs, the average cost of the German Transrapid is $20M/mile[11] and the Japanese JR is $36M/mile[12].

The guideways of most MAGLEV systems can be made to blend in with the countryside. The only noise created is that of the vehicle moving through air at a high speed--a wshhh. There are no emissions along the guideway, because the systems are all electric. Emissions are relegated to the power plant where they can be better handled.

In the case of MAGLEV, a high level of ride comfort is assured by having a secondary suspension in the attraction-based system, and including damping (and possibly a secondary suspension) in the repulsion-based system. Ride qualities similar to airliners flying in non-turbulent air could be expected.

It is important that these MAGLEV technologies be fully developed before revenue deployment. The fear of lack of complete development haunts us in North America, because of previous experience with new technology introduction into guided ground based systems. Therefore, there must be a conviction that the MAGLEV technology used is fully developed from the point of view of good transportation practice and it is imperative that a demonstration be incorporated into any revenue system building plan.

Because of the high speed nature of the system, both the perceived and actual safety of the MAGLEV technology must be at least as great as either airline or rail passenger safety. Since this is a new mode of ground transportation, safety will be highly scrutinized.

In addition to high speed MAGLEV technologies providing a partial easing of the transportation crisis, improvements in the highway and air modes will also play a substantial role. These will be somewhat restricted because most of the facilities have already been built.

Highway projects are costly undertakings. Just to maintain the highway and bridge system until the year 2005 will be $550B-$630B. There still will be a shortfall of 11,000-15,000 lane miles. The rate of increase in demand for highway space is seven times greater than the ability to build them, whether caused by shortfalls in dollars or institutional related problems.

There are several air mode solutions to easing the transportation crisis. In addition to optimizing the present airport system, adding new airports in congested areas and adding remote transfer airports are among proposed solutions.

To build more airports means to build them further from the cities and other areas to be served. Thus, an access problem will develop and naturally result in longer, rather than shorter, door-to-door travel times, especially if the private auto is to continue as the access mode. If other than the private auto access mode is to be used, then MAGLEV again becomes the answer.

SUMMARY

The need is imminent for improved mobility in North America. Airport and highway congestion are presently decreasing the mobility of the population. High speed ground transportation systems, which can interface the airports with urban and regional sprawl, can meet the improved mobility need by providing alternatives and complements to the highway and air modes of travel.

Recent developments in MAGLEV technologies are demonstrating that these technologies can meet this need for 21st Century North America. It is expected that these MAGLEV systems will be deployed here as well as abroad in the middle to late nineties.

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MAGLEV Presentation

RICHARD UHER
CARNEGIE MELLON UNIVERSITY

Name/Title	Organization	Phone
PAT SUTTON	US DOE	586-8058
Ron Kangas	UMTA	366-0212
GEORGE PRYTULA	GRUMMAN	875-8412
BOB KRICK	FRA	366-9601
TOM SCHULTZ	FRA	366-0466
Bill MEEKER	NTSB	382-6676
ARNE BANG	FRA	366-0457
LARRY SCHULMAN	UMTA	366-4052
STEVE BARSONY	UMTA	366-0090
BRIAN CLYMER	—"—	366-4040
JEFF MORA	—"—	366-4035
RON KANGAS	—"—	366-2896