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MARKET AND ENERGY DEMAND ANALYSIS OF A U.S. MAGLEV SYSTEM

by

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Market and Energy Demand Analysis of a U.S. Maglev System

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Abstract - **High-speed magnetically levitated (maglev) vehicles can provide an alternative mode of transportation for intercity travel, particularly for short- and medium-distance trips between 100 to 600 mi (160 and 960 km). The patterns of growth and the underlying factors affecting that growth in the year 2010 are evaluated to determine the magnitude of U.S. intercity travel that would become the basis for maglev demand. A methodology that is sensitive to the travelers' socioeconomic attributes was developed to forecast intercity travel. Travel between 78 major metropolitan areas by air and highway modes is projected, and 12 high-density travel corridors are identified and selected. The potential for a maglev system to substitute for part of that travel is calculated by using a model that estimates the extent of diversion from highway and air to maglev. Energy demand is estimated on the basis of energy usage during acceleration and cruise phases for each corridor and corridor connections.**

I. INTRODUCTION

Intercity travel, involving trips longer than 100 mi (160 km), in the United States by highway and air modes has shown consistent increases. Travel by urban and rural interstate highways increased at annual rates of 5.6% and 3.2%, respectively, during 1971-1989 [1,2]. Travel by commercial airlines, in terms of domestic enplanements, increased at an annual rate of 5.6% during the same period [3,4]. Intercity travel will continue to grow, requiring considerable enhancement of highway and air capacity. Travel by highways will increase by 1.3% per year during 1989-2010 [5] and air enplanements will increase by 3.8% per year through 2002 [4].

The projected 50% increase in air travel would worsen the air traffic congestion and spread delays to all major airports. Several ideas have been advanced to handle the projected increase in air travel, including approach procedure improvements, new terminal airspace procedures, new runways, and the development of new technologies to close the gap between visual flight rules and instrument flight rules. The Federal Aviation Administration (FAA) projects that new airports will be required beyond the year 2000 to maintain the quality of service available today [6]. Since new airport construction is an expensive, time-consuming, and politically sensitive option, other options need to be investigated. One viable option is to divert some of the intercity travel to an alternative mode.

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Short-haul aircraft operations represent an area where alternative travel modes could help alleviate air traffic congestion and allow airlines to concentrate on mid- and long-haul operations. Such alternative modes should provide service comparable with that of airlines at a similar price. Magnetically levitated (maglev) vehicles are expected to travel at speeds up to 300 mi/h (480 km/h) and have the potential to provide service comparable to airlines for trip lengths of 100-600 mi (160-960 km).

II. METHODOLOGY

The methodology employed for this research consisted of several sequential steps. A baseline scenario was developed, and future demographic, economic, energy price, and technological data were compiled. A set of 78 metropolitan statistical areas (MSA) from the 48 contiguous states was selected for analysis. This set contained all metropolitan areas with populations over one million, all airline hubs, areas that formed one end of the top 50 air traffic routes under 600 mi (960 km), and metropolitan areas identified as potential maglev cities by an earlier ANL study [7]. A trip generation methodology was developed to project highway and air travel. Both air and highway trips were distributed by using the Fratar model. The top 100 metropolitan area pairs involving distances of 600 mi (960 km) or less were analyzed, and 12 corridors of high density travel were identified. Highway and air travel times and cost estimates were developed by using data from a related project, while maglev time and cost estimates were generated specifically for this analysis. A diversion model was applied to assess the extent of diversion from highway and air to maglev. Energy consumption estimates were developed by using maglev vehicle characteristics from published and unpublished data. The resulting energy demands were computed and analyzed for each high-density travel corridor.

A. Travel Demand Projection

Intercity trips are generated by using a methodology that applies travel rates by demographic groups. The methodology assumes the propensity to travel is a function of the traveler's socioeconomic attributes. The travel rates have not reached saturation and would change as economic output, fuel prices, personal income, and household work force configuration change. Travel is also a function of mode maturity. As all travelers who could use a particular intercity travel mode use it and become familiar with it, that mode is assumed to have reached maturity. The methodology treats the highway mode as a mature mode, while the air mode has an opportunity to attract more travelers. Surveys by U.S. Travel Data Center (USTDC), along with data from the FAA, the Federal Highway Administration, and the Bureau of the Census were used to develop the travel rates.

Trip productions are dependent on three demographic attributes: household income, traveler age, and traveler employment status. Three trip production models, identical in structure, are applied, and a weighted sum of production is developed for each metropolitan area for each trip type,

$$P(i,t) = \Sigma_j W^j * T_p^j(i,t) \quad (1)$$

$$T_p^j(i,t) = \Sigma_k N^j_k(i) * R^j_k(t), \quad (2)$$

where P(i,t) represents productions from zone i for trip type t, W^j is the weight assigned to socioeconomic attribute j, and $T_p^j(i,t)$ is the productions for socioeconomic attribute j for the same zone and trip type combination from (2). $N^j_k(i)$ represents the number of units in subcategory k of attribute j for zone i, and $R^j_k(t)$ is the travel rate for the same combination.

Trip attractions are a function of four variables: households with income less than $20K, households with income greater than or equal to $20K, high-travel potential employment, and entertainment attractiveness. Professional, managerial, technical, and lower-level managerial employment are classified as having high travel potential. Each zone is assigned a code reflecting its entertainment attractiveness. Attractions, A(i,t) for zone i for trip type t, are the sum of trips attracted by each attribute times an entertainment factor plus a constant, with entertainment factor and the constant term dependent on the above mentioned code.

$$A(i,t) = \Sigma_j T_a^j(i,t) + F(k,t) \quad (3)$$

$$T_a^j(i,t) = N^j(i) * R^j(t) * EF(k,t), \quad (4)$$

where EF is the entertainment factor, F is a constant, and both are dependent on entertainment attractiveness code k. Values N and R represent zonal socioeconomic attributes and associated attraction rates as explained before.

Since the travel rates have not reached saturation, procedures to compute future travel rates were developed. The highway mode was considered mature, and all changes in trip rates were captured by tracking the changes in household income and number of workers per household. Past surveys by the U.S. Travel Data Center were used develop the following equation.

$$V_h = -15.454 + 0.193 * Y_h + 15.63 * W_h, \quad (5)$$

where V_h represents vehicle trips per household, Y_h is the average personal income per household in thousands of 1982 dollars, and W_h is the number of workers per household.

The changes in demographic composition of the nation's population are accounted for in the structure of the trip-generation model. The production component of the model allows for five classes of income (in 1988 dollars): <$20K, $20-25K, $25-35K, $35-50K, and >$50K; five classes of age: <18, 18-24, 25-44, 45-64, and >64; and four classes of employment status: high-travel potential employment, low-travel potential employment, retired, and not working. Future highway trips will be influenced by movement of population between the classes of these demographic attributes and also by changes in travel habits.

Changes in nationwide intercity travel were projected by applying the regression model to the U.S. Department of Commerce demographic projections [8]. The trip-generation model was also run using the state-level data for the years 2000, 2010, 2020, and 2030, while keeping the 1988 travel rates constant. This provided measures of changes caused by the movement of population among the demographic classes and geographical areas. The difference between the regression model and constant trip rate estimates provided a measure of the change in travel rates.

A different procedure was followed to estimate future year trip rates for the air mode. The air mode has the potential to attract more travelers as a greater and greater fraction of the population begins using it. A Gallup survey for the Air Transportation Association of America (ATA) [9] shows the incidence of flying (persons who used the air mode once) rising from 49% in 1971 to 74% in 1990. A model that projects enplanements per capita was developed as follows:

$$E_c = -1.7 + 0.154 * G_c - 0.0055 * C_e + 0.019 * IF, \quad (6)$$

where E_c represents enplanements per capita, G_c is gross national product per capita in thousands of 1982 dollars, C_e is airline revenue per enplanement in 1982 dollars, and IF is incidence of flying (as percent ever flown).

The above equation requires projection of revenue per enplanement and incidence of flying for future years for which procedures were developed. A logistic model was used to project incidence of flying. This variable, representing maturity of the air mode, is dependent on time. The following model was developed using the 1975-1988 data from ATA [9]:

$$IF = 1 - 0.42 * e^{-0.0343 * (t - 1975)}, \quad (7)$$

where t represents the forecast year.

A model for projecting airline revenue per enplanement, C_e, was developed using data published by Aerospace Industries

[3] and U.S. Department of Transportation [10]. This variable is dependent on fuel price and productivity improvements in air-carrier operations. The productivity variable is rather difficult to quantify, but it can be represented by time. The following relationship was established for any year beyond 1988:

$$C_e = 60.33 + 0.26 * J_p + (2030 - t)^2 / 101.2, \quad (8)$$

where J_p represents jet fuel price in 1982 dollars per 100 gallons and t is the year of interest.

The Fratar model was used to distribute both highway and air trips. The model adjusts an existing origin-destination trip matrix to match a set of growth factors for trip productions and attractions. Use of the model thus requires a base-year trip matrix. A base-year air-trip matrix was constructed using the 1988 10% ticket sample file from the U.S. Department of Transportation [11]. Next, the total trip matrix was subdivided into business and nonbusiness trip matrices by using the 1988 trip production and attraction shares provided by the trip-generation model. The Fratar model was then applied to produce a set of trip matrices for the year 2010. Production/attraction growth factors provided by the trip-generation model were used.

Since a comprehensive database for intercity highway travel between metropolitan areas does not exist, a step-wise procedure was employed to construct a base year highway-trip matrix. First, two MSA to MSA highway-trip matrices, one for business and the other for nonbusiness travel, were constructed by using distance based air trip to highway trip ratios. The ratios reflect an intercity mode preference pattern in which the highway mode carries several times the number of passengers as the air mode when the trip distance is short. Next, these matrices were revised to reflect the trip estimates from surveys conducted by states or other agencies. Data from Northeast corridor, New York state corridor, Pennsylvania corridor, Ohio High Speed Rail Study, Illinois-Michigan Study, Illinois-Wisconsin-Minnesota (Tristate) Study, Texas Triangle Study, and Florida High Speed Rail Study were incorporated. Finally, the Fratar model was applied to project year 2010 highway trip interchanges. Trip productions and attractions from the trip-generation methodology described above were used to compute these growth factors.

In our modeling effort, we found that intercity travel is strongly influenced by four major factors: population, number of households, employment, and income. The U.S. population is expected to continue to grow in absolute numbers, but the rate is expected to decline between 2000 and 2010. A likely strong influence on travel behavior is the percent of the population over 65, which increases significantly after 2010. Accompanying this trend is an increase in the number of households, which continues rapidly even out to 2030, but the current tendency towards smaller households is expected to continue -- helped along by the growing over-65 population. This has an important implication for highway travel (and, in turn, for the potential for maglev travel), because the vehicle occupancy for nonbusiness trips would be expected to decline as the household size shrinks. Thus the per-person cost of travel would increase, making travel by common carrier (air or maglev) more attractive.

Air travel is forecast to continue to increase, but at rates lower than historical rates. The number of air trips increased at an annual rate of 5.2% during 1970-90. The projected rate of growth for the next 20 years is 3.1% annually. The annual rate of growth during the last decade of this century is projected to be 3.3%. The demand for air travel will increase from 294.2 million trips in 1988 to 581.8 million trips in 2010. The air mode will be close to maturity in 2010, when a projected 87% of the population will have flown at least once as compared with 73% in 1988.

Since maglev is a common-carrier mode, a majority of its trips will be diverted from air, the existing high-speed common carrier mode. Also, as maglev technology develops, it will be tested first in select places before introducing it in a network of connected corridors. Air trip interchanges in the year 2010 were analyzed, and the top 100 MSA pairs involving distances of 600 mi (960 km) or less were tabulated. Twelve corridors were selected from the analysis of these trips and from the list of corridor studies conducted by states and federal agencies. Table 1 lists the selected corridors.

Thirty one metropolitan areas, out of 78, are part of the twelve selected corridors, representing 930 interchanges. Many of these are not feasible to traverse by maglev alone, given the selected maglev corridors. For example, Los Angeles to New York City or Dallas to Chicago trips cannot be made by maglev alone. When such infeasible interchanges were removed, and interchanges involving less than 500 annual trips were eliminated, a total of 400 interchanges remained for trip diversion and energy demand analysis.

TABLE 1 HIGH DENSITY TRAVEL CORRIDORS

1.	Northeast Corridor: Washington (DC), Baltimore, Philadelphia, New York City, Hartford, Boston
2.	New York State Corridor: New York City, Albany, Syracuse, Rochester, Buffalo
3.	California Corridor: San Francisco, Los Angeles, San Diego
4.	California-Las Vegas Corridor: Los Angeles, Las Vegas
5.	Florida Corridor: Miami, Orlando, Tampa
6.	Texas #1 Dallas-Houston Corridor: Dallas, Houston
7.	Texas #2 Dallas-San Antonio Corridor: Dallas, Austin, San Antonio
8.	Texas #3 Houston-San Antonio Corridor: Houston, Austin, San Antonio
9.	Illinois-Michigan Corridor: Chicago, Detroit
10.	Quad-State Corridor: St. Louis, Springfield (IL), Chicago, Milwaukee, Madison, Minneapolis-St. Paul
11.	Pennsylvania Corridor: Philadelphia, Harrisburg, Pittsburgh
12.	Michigan-Pennsylvania Corridor: Detroit, Toledo, Cleveland, Pittsburgh

B. Modal Characteristics Development

Travel time and cost characteristics were developed for air, highway, and maglev. Procedures to estimate travel time and cost components for air and highway modes were developed by using data from several sources while maglev components were derived based on published operating criteria, discussions among ANL staff, and technical judgement.

Air characteristics are subdivided as MSA level and MSA pair specific. The MSA level characteristics include access/egress time and cost, time spent in an airport before the aircraft doors are closed, time between aircraft door closing and being airborne, time between touching ground and aircraft doors opening, and time spent in an airport between aircraft door opening and boarding ground transportation.

The access and egress time values were computed using average distance from the most populated place in each county of the MSA and weighting them by county population. We obtained the county-level population forecasts from each state and used them to compute average distance. MSAs were classified by their population as extra-large (more than 5 million), large (3-5 million), medium (1-3 million), and small (less than 1 million) for the assignment of average speeds. The speeds represent average values for all approach modes, including coach and public transit where applicable.

Wait time and in-airport time were estimated using data from a ground-access study [12]. Base-year (1988) taxi, queue, and take-off times, as well as landing, taxi, and idle times, were estimated using an earlier study [13]. The values in the study were updated by using the percent of operations delayed by 15 minutes or more as published by the FAA [6]. The queue subcomponent will increase exponentially with the increase in aircraft operations if airport capacities are not expanded. We assume periodic capacity expansion by various means to cause a linear relationship between air travel demand and queuing time. The practice of not allowing an aircraft to take-off for a destination airport that is experiencing delays is assumed to continue in the future. Thus, average landing times are expected to increase very little.

Airport access costs are computed separately for business and nonbusiness purposes by using average distance and airport-specific access mode shares. Access modes include 1) drive and park or use of rental car, 2) taxi or limousine, 3) coach/airport bus, 4) mass transit, and 5) courtesy vehicle. A sixth mode, driven by friend/relative, was allowed for nonbusiness travel only. Cost components include fuel and nonfuel operating costs, parking fees, labor costs, tolls, and fares, which vary depending on the access mode.

Linehaul time and fare are two MSA pair specific components. Linehaul times were computed using a regression equation. Average fares were also computed using a regression equation that accounted for the effect of hubs, fuel prices, and productivity improvements. These fares do not account for increases in capital cost, which are likely to be substantial.

The highway mode characteristics were compiled for intercity passenger trips by assuming that all the trips were made by automobiles. A vehicle trip was subdivided into three parts: travel within the origin MSA, travel between MSAs, and travel in the destination MSA. Highway travel times and costs depend on such parameters as distance, intercity highway speed limits and miles driven per day, lodging cost per night, fuel economy and fuel prices, nonfuel automobile operating cost per mile, duration of stops for fuel and rest during highway travel, and time and distance traveled within origin and destination MSAs. A value of 700 mi (1120 km) was selected as the distance driven per day. A 50 mi (80 km) allowance is automatically made to allow a traveler to complete the trip without incurring lodging cost.

The automobile cost component consists of fuel and other operating costs. It does not contain depreciation, registration, and insurance. Both fuel and other operating costs are computed as dollars per mile using energy price and fuel economy data. Nonfuel auto operating costs include lubrication, tires, and maintenance [14].

Maglev time and cost information was developed using highway distance and some allowance for circuity. The resulting total distance for each origin-destination pair is subdivided by speed class, and the linehaul time is computed on the basis of the number of miles in each speed class, the number of stops, and the number of transfers. The speed classes are 165 mph (265 kmph), 200 mph (320 kmph), 250 mph (400 kmph), and 300 mph (480 kmph). All MSAs with populations over 3 million, and those in the Northeast corridor, are assumed to require travel at reduced speed for some distance within the metropolitan area (5 to 15 mi). All other distances for each speed regime were determined by technical judgment based on the individual corridor.

Direct travel is considered feasible between all large MSAs with stops at major intermediate points. For example, a trip from New York to Chicago does not require any transfers, but requires stops in Philadelphia, Pittsburgh, and Detroit. In addition, each major metropolitan area may have more than one stop (i.e., downtown, suburban, airport) and each stop is assumed to have a duration of 2.5 minutes. Travel to or from a smaller MSA can involve a transfer at a major hub (or half a transfer if some direct service is possible), with an average transfer delay of 30 minutes.

Maglev out-of-vehicle times (access/egress and waiting times) were obtained by multiplying the air out-of-vehicle times by a factor of 0.75. This factor accounts for the fact that metropolitan areas will probably have more than one maglev station, so that the average distance to a station will be less than the average distance to an airport. Maglev access costs were assumed to be 90% of those for air. The factor for access costs is higher than that for out-of-vehicle times because access cost is influenced less by distance than access time. Maglev fares were assumed to be 80% of the air fare to account for the lower linehaul travel speed.

C. Estimation of Diversion to Maglev

A diversion model was selected to estimate trip diversion from highway and air modes to the new mode. The model includes such logical parameters as waiting time, linehaul time, and cost [15]. Rail trips were added to the diversion estimates by using constant diversion rates. The model requires total travel cost, in-vehicle travel time, and out-of-vehicle travel time for highway, air, and the new mode. Business out-of-vehicle travel times were computed as 20 minutes less than nonbusiness out-of-vehicle travel time if the nonbusiness out-of-vehicle time for an origin-destination pair was greater than 100 minutes; as 15 minutes less if the nonbusiness out-of-vehicle time was in the range 80-100 minutes, and as 10 minutes less for all other values.

The trip diversion model multiplies the out-of-vehicle time by a factor less than 1. This reduction was not considered appropriate for the highway mode since it makes the common-carrier mode more attractive (by reducing the effect of access/egress time and waiting time). Also, the maglev mode has constant terms for each purpose and mode combination. Since the diversion model was developed for trips shorter than 500 mi (800 km), highway business diversion for longer distances may not be predicted properly. A value of −0.8 was added for distances of 600-900 mi (960-1440 km), and an additional −0.8 was added for longer distances. Even after these additions, the model tended to predict high shares (80-95% for longer trips). Thus, the diversion from business highway trips was restricted to 66% for distances of 500-750 mi (800-1200 km), assumed not to require any lodging cost, and restricted to 50% for longer distances.

Rail trip estimates were compiled from various origin-destination counts obtained from the Federal Railroad Administration. The rail trips were subdivided as business and nonbusiness equally. Fixed diversion rates of 85% for business and 70% for nonbusiness were applied for maglev.

D. Energy Calculations

Electric utilities are likely to view the loads generated by the maglev system as less than ideal because its demand is unsteady due to accelerations and because peak maglev demands tend to coincide with peak loads in the rest of the utility system (midmorning and late-afternoon). Maglev could operate either with long trains or in smaller units of one or two vehicles. When operating with one or two vehicles, the acceleration energy requirements of each individual unit would decrease, which would help smooth out the electrical demand oscillations of a maglev system.

Large-scale off-board energy storage facilities could be used to reduce the peak loads for maglev systems. These facilities could be distributed along the maglev corridor and charged from base-load power plants at night or from spinning reserve. Spinning reserve is the margin that utilities are required to maintain in order to handle unforeseen situations, such as a sudden shutdown of a power plant or a large unexpected load. The requirement is about 10% in excess of the current demand, and storage devices could be charged from this spinning reserve since the charging could be interrupted at any time.

Maglev vehicles travelling at cruising speeds require energy to overcome aerodynamic drag, which increases sharply with speed, and magnetic drag, which is highest at low speeds. In addition, hotel energy, which is independent of speed, is required for use on-board the vehicle (about 300 kW). During acceleration energy is also required to bring the vehicle up to speed. A 150-seat electrodynamic maglev vehicle was characterized by using data from various sources (most of which are unpublished).

The magnetic drag force (computed as 780 divided by speed in meters per second for speeds above 50, or 30.25 kN otherwise) and energy requirements to overcome magnetic and aerodynamic drag are given in Table 2 for various speeds.

The actual electric energy demand required from the power plant was computed by considering the efficiency of the linear synchronous motor mounted on the guideway (90%), the efficiency of the power conditioning unit at the wayside station (85%), and the electricity transmission efficiency (95%). These combine to give an overall efficiency of about 72.7% for maglev. The electric generation efficiency is not included.

TABLE 2 AERODYNAMIC AND MAGNETIC DRAG ENERGY

Speed (km/h)	Magnetic Drag Force (kN)	Drag Energy (kWh/km)		
		Magnetic	Aerodynamic	Total
200	13.96	3.88	1.56	5.44
266	10.58	2.94	2.72	5.66
322	8.73	2.42	4.00	6.42
402	6.98	1.94	6.24	8.18
483	5.82	1.62	8.99	10.61

III. RESULTS

Table 3 summarizes the most important ridership and energy results for each corridor. The table includes passenger demand, passenger miles traveled, energy intensity, and total energy demand. The individual corridor totals do not include trips that traverse that corridor but have either the origin or destination (or both) outside the corridor. However, those trips are accounted for in the "corridor connections" totals. The individual corridor totals for ridership and energy would increase if any corridor is connected to any other corridor, but since the values depend on the exact extent of the entire network, those projections cannot be made at this time. Travel demand will also increase if connections are provided at the airports involving high volumes of connecting trips. An air traveler could transfer to maglev for a part of the trip that either originates or terminates at a point outside the connected corridors. Estimates of such diversion will require more detailed analysis. We carried out a simple analysis of trips involving origin or destination in Albany, Syracuse, Rochester, and Buffalo with a maglev airport connection that showed potential increases in the range of 5-15%, depending upon airline cooperation.

The estimated total energy demand for the 12 corridors is 5.26 trillion watt-hours. Aside from energy demand, the power demand profile will influence utility planning and load management. A 150-seat maglev vehicle will require approximately 20 MW of power at startup (accelerating at 0.16 g or 1.57 m/s^2) and 5.4 MW while cruising at 300 mph (480 kmph).

TABLE 3 MAGLEV TRAVEL AND ENERGY DEMAND IN 2010

Corridor & Connections	Demand 10^3	PMT 10^6	EI Wh/PMT	Energy 10^6 kWh
Northeast Corridor	23,456	5,344	201	1,073
New York State Corridor	5,173	1,335	249	333
NE/NYS Connection	476	233	231	54
California Corridor	12,603	4,545	223	1,014
CA - Las Vegas Corridor	6,137	2,027	231	468
Florida Corridor	6,858	1,688	265	448
Dallas-Houston Corridor	3,069	773	255	197
DFW-Austin-S Antonio	2,487	560	255	143
HST-Austin-S Antonio	1,770	373	252	94
Chicago-Detroit Corridor	1,658	478	247	118
Quad-State (STL-MSP)	4,124	1,253	252	316
Midwest Connection	569	338	250	84
Pennsylvania Corridor	1,503	356	253	90
NE-Penn Connection	1,268	562	232	130
NYS-Penn Connection	30	18	246	4
Detroit - Pitt Corridor	419	89	256	23
Other Connections	3,596	2,720	245	665
System Total	75,197	22,691	232	5,255

A. Profile of Electricity Demand

The profile of potential electricity demand was analyzed by selecting two sections of the future maglev lines: 1) Boston to New York City and 2) Los Angeles to San Francisco. All trips that will use the selected sections were identified and summed. For example, the Boston to New York City section will be used by trips originating from or ending in Boston and having the other end in New York City or maglev cities beyond New York City, as well as trips originating from or ending in Hartford and having the other end in New York City and maglev cities beyond New York City.

In this analysis, we assumed the number of vehicles travelling daily between terminal cities to be distributed in the same way as the aircraft flights are. We computed the number of vehicles required to serve the demand by assuming a 60% load factor and uniformly distributed demand through the year. We also used the average energy intensity for the section. The number of vehicles en route at any specific time of day is computed from travel time and average headway. The power demand for maglev is computed by using 20 MW for accelerating vehicles and 5.4 MW for cruising vehicles. The actual power demand will be influenced by route geometry, location and number of stops, maximum speed, and demand charges.

TABLE 4 ELECTRICITY DEMAND PROFILE FOR THE BOSTON-NEW YORK CITY SECTION

Travel Distance (mi)	249			
Travel Time (min)	85			
Passengers per Year in each Direction (10^6)	4.86			
Average Passengers per Day in each Direction	13,310			
Vehicle Tips per Day in Both Directions	296			
Profile (both directions) by Time of Day				
	6-10 AM	10 AM-2 PM	2-6 PM	6-10 PM
Vehicle Trips	74	72	88	62
Avg. Headway	6.5	6.7	5.5	7.7
Vehicles en route	26-28	24-26	30-32	20-22
Potential Annual GWh Demand	124	121	149	104
Power MW[1]	265-285	244-265	306-326	204-224
Power MW[2]	329-354	304-329	380-405	253-278

[1] Assuming 33% of the vehicles accelerating at a time.
[2] Assuming 50% of the vehicles accelerating at a time.

TABLE 5 ELECTRICITY DEMAND PROFILE FOR THE LOS ANGELES-SAN FRANCISCO SECTION

Travel Distance (mi)	395			
Travel Time (min)	122			
Passengers per Year in each Direction (10^6)	5.31			
Average Passengers per Day in each Direction	14,560			
Vehicle Trips per Day in Both Directions	324			
Profile (both directions) by Time of Day				
	6-10 AM	10 AM-2 PM	2-6 PM	6-10 PM
Vehicle Trips	86	74	90	74
Avg. Headway	5.6	6.5	5.3	6.5
Vehicles en route	42-44	36-38	44-46	36-38
Potential Annual GWh Demand	254	220	268	220
Power MW[1]	428-448	367-387	448-469	367-387
Power MW[2]	531-557	455-481	557-582	455-481

[1] Assuming 33% of the vehicles accelerating at a time.
[2] Assuming 50% of the vehicles accelerating at a time.

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