Baltimore–Washington Corridor Magnetic Levitation Feasibility Study

JACK KINSTLINGER AND STEVE CARLTON

The Magnetic Levitation Feasibility Study evaluates the ability of the 64-km (40-mi)-long and 16-km (10-mi)-wide Baltimore–Washington Corridor to accommodate a system of Maglev guideways and stations. Particular attention is given to locating guideway alignments within four existing transportation rights-of-way: Interstate 95, the Baltimore–Washington Parkway, the CSX Railroad, and the Amtrak Railroad. Alignments are assessed relative to the criteria established in the Intermodal Surface Transportation Efficiency Act of 1991 for siting the Maglev prototype demonstration project. Operation of Maglev between Baltimore and Washington was found to significantly increase the passenger-carrying capacity of the corridor while making maximum use of existing rights-of-way. Additionally, travel time between Baltimore and Washington, D.C., will be significantly reduced. Revenue projections were found to be favorable in comparison with operating and capital costs. The initiation of Maglev service at this location has potential for extension of Maglev service along the entire Northeast Corridor.

The Magnetic Levitation Feasibility Study evaluates the ability of the 64-km (40-mi)-long and 16-km (10-mi)-wide Baltimore–Washington Corridor to accommodate a system of Maglev guideways and stations proposed under the Maglev prototype development program. The study evaluates several potential routes between Baltimore and Washington, D.C., within a corridor generally defined by Interstate 95 on the west and the Amtrak Railroad on the east. The corridor traverses four Maryland counties (Baltimore, Anne Arundel, Howard, and Prince Georges) and portions of Baltimore City and the District of Columbia.

In the present study, potential high-speed Maglev guideway alignments and station locations between Baltimore, Maryland, and Washington, D.C., are examined (Figure 1). Particular attention is given to establishing the feasibility of locating guideway alignments within four existing transportation rights-of-way: Interstate 95, the Baltimore–Washington Parkway, the CSX Railroad, and the Amtrak Railroad. Alignments are assessed relative to the criteria established in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 for siting the Maglev prototype demonstration project as well as regional criteria, such as economic stimulation and the need to avoid undesirable impacts to the community. This investigation focuses on the following:

- Use of existing rights-of-way (availability and compatibility);
- Ability to attain high speed;
- Access to city centers, to Baltimore–Washington International (BWI) Airport, and to other intermediate stations;
- Intermodal connections;
- Environmental impacts;
- Ridership and revenues;
- Costs and cost-effectiveness; and
- Potential for future integration into an intercity Maglev network along the Northeast Corridor.

The study described here represents a broad feasibility analysis for determining whether there exists sufficient potential to justify proceeding into the subsequent and more detailed analyses (e.g., environmental assessments and preliminary engineering) required to select specific route and station locations and to estimate costs, cost-effectiveness, and impacts in greater detail.

MAGLEV TECHNOLOGIES

This investigation is not intended to select a preferred Maglev technology or a preferred alignment. Rather, it is to determine the extent to which alternative corridors are compatible with the requirements, geometric and otherwise, of potential candidate technologies. To that end six Maglev technologies that exist as prototypes or as design concepts are examined to develop an understanding of the interactions among technical design features, performance levels, required alignments, attributes, and operational considerations. The six technologies considered are the German Transrapid TR07, the Japanese MLU-002, and four system concept definition designs prepared for the National Maglev Initiative by Grumman, Foster-Miller, Bechtel, and Magneplane. The first two technologies have been termed *conservative,* the next three have been termed *moderate,* and the last one has been termed *aggressive* with respect to passenger comfort criteria and consequent geometric design standards. These three combined technology groups provide lower and upper bounds for critical parameter values that influence route alignment, including those that affect passenger comfort such as acceleration, maximum roll rate, total bank angle, and maximum speed. A summary of the critical parameters is provided in Table 1. Alignment studies and cost estimates are based on the construction of an elevated double guideway on a single pier, as shown in Figure 2.

DEVELOPMENT OF ALIGNMENTS AND STATION LOCATIONS

Station locations were set, and then the alignments between them were developed. Station locations were considered at four locations: downtown Baltimore (Penn Station or Camden Yards), BWI Airport, a location along the Capital Beltway, and Union Station in Washington, D.C. Ridership and urban accessibility analyses revealed that a station location at Camden Yards appears preferable to one at Penn Station.

J. Kinstlinger, KCI Technologies, Inc., 10 North Park Drive, Hunt Valley, Md. 21030. S. Carlton, Martin Marietta Air Traffic Systems, 400 Virginia Avenue, SW, Suite 300, Washington, D.C. 20024.

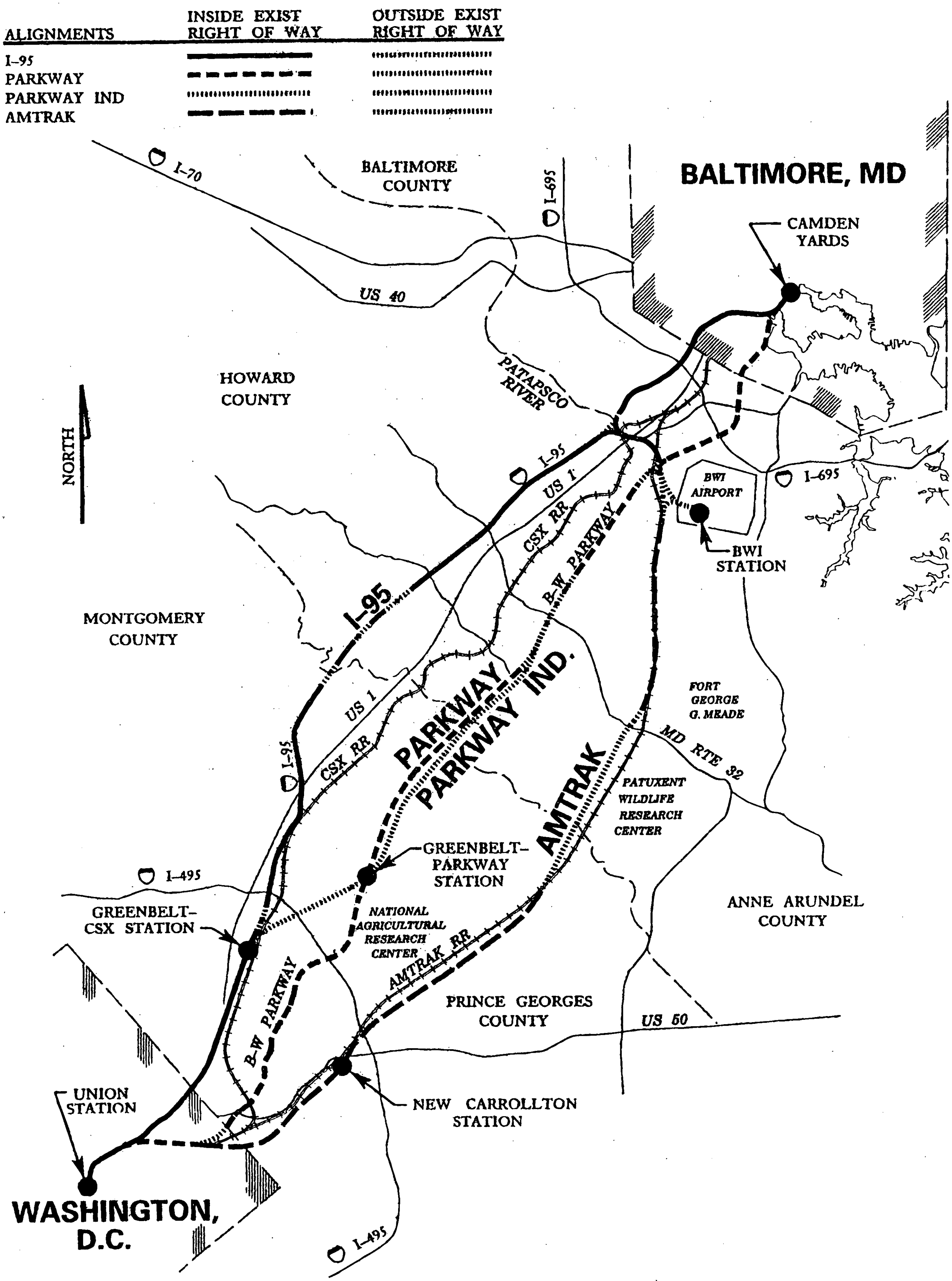

FIGURE 1 Final alignments and stations.

TABLE 1 Critical Engineering and Operations Parameters

Engineering and Operations Parameters	Technology Groups		
	Conservative Group	Moderate Group	Aggressive Group
Maximum Speed (kph)	483	483	483
Maximum Bank Angle (deg)	12	30	45
Minimum 300 mph Curve Radius (m)	5,825	2,653	1,433
Lateral Acceleration Limit (g)	0.10	0.10	0.20
Maximum Roll Rate (deg/s)	5	5	10
300 mph Spiral Transition (m)	750	1,653	1,296
Longitudinal Acceleration (g)	0.1	0.16	0.60
Minimum Curve Radius (m)	402	402	402
Dual Guideway ROW Width (m)	18	18	18

Initially, two sets of baseline alignments were selected for each of the four corridors. Center line alignments follow centerlines of existing rights-of-way and represent the most constrained alignments. The centerline alignments have long travel times with minimal community impacts and no requirements for new rights-of-way. High-speed alignments use existing rights-of-way where possible but are permitted to depart from existing rights-of-way when necessary to achieve an operating speed of 483 km/hr (300 mph). Significant deviation from rights-of-way was necessary because existing radii of curvature for railroads and highways are insufficient to accommodate high-speed operation while maintaining acceptable levels of passenger comfort. For each baseline alignment Maglev operation was evaluated in terms of travel times and average vehicle speeds as well as distance operated within rights-of-way and distance operated at more than 483 km/hr (300 mph). The potential Maglev performance for the four interim alignments was assessed for each of the three technology groups: conservative, moderate, and aggressive. As a result of this analysis the middle section of the CSX Railroad corridor between Beltsville, Maryland, and the Baltimore Beltway was deleted from further consideration because its narrow right-of-way and severe curvature would not permit high-speed operation.

Interim alignments were then developed for the three remaining corridors, Interstate 95, the Baltimore–Washington Parkway, and the Amtrak rail road using the high-speed alignment as the starting point. Adjustments were made to avoid or mitigate the most severe community impacts subject to the requirement that each adjusted alignment continue to be compatible with a 483-km/hr (300-mph) operating standard over at least some portion of its length. Following a review of these alignments, a new fourth alignment, designated the *Parkway Independent,* was established. This alignment is identical to the Baltimore–Washington Parkway alignment north of MD Route 175, where the Parkway is under state ownership, but is located outside the park boundaries of the Baltimore–Washington Parkway south of MD Route 175. The Parkway Independent alignment then extends southwesterly across the Beltsville Agricultural Research Center to join up with the CSX Railroad leading to Union Station. This fourth alignment incorporates favorable aspects of the Baltimore–Washington Parkway corridor in terms of the short length of the spur to BWI Airport, a relatively shorter distance between city centers, and few adverse community impacts, while it avoids intrusion into the Parkway, which has been designated a federally protected parkland and historic place under the jurisdiction of the National Park Service.

Further adjustments were made to the final alignments and station locations following meetings with some of the agencies having jurisdiction over rights-of-way and the property affected by interim alignments and station locations. The final analysis was limited to a consideration of the moderate technology group, since it was found that operating parameters and environmental impacts did not differ significantly among the three technology groups and that the aggressive technology group provides questionable ridership comfort and yields alignments that would be unable to accommodate future technological advances. In the final phase of the study, final alignments were further revised to reduce community and institutional impacts. Final alignment performance characteristics are given in Table 2. For the Amtrak alignment about one-third lies outside existing transportation rights-of-way; for the other three alignments, about one-half lies outside existing rights-of-way. This amount of guideway location beyond existing rights-of-way was found to be necessary to achieve a maximum speed of 483 km/hr at one point on each alignment.

The Interstate 95 alignment has the longest route distance (66.3 km) because of the length of the spur to BWI Airport. Travel times are longer because of consecutive reverse curves on the alignment between the Baltimore and Washington beltways. Travel times are substantially increased on the Airport service because of relatively long, slow-speed spur alignment between Interstate 95 and BWI Airport.

The Parkway alignment is the shortest from Camden Yards to the Capital Beltway; however, the alignment for the Parkway inside the Capital Beltway has many tight consecutive reverse curves, which necessitate slower speeds and extra guideway length. The alignment allows fast travel and the longest period of 483-km/hr operation. The Parkway Independent alignment has the shortest route length, permits achieving a travel time that is comparable to those with

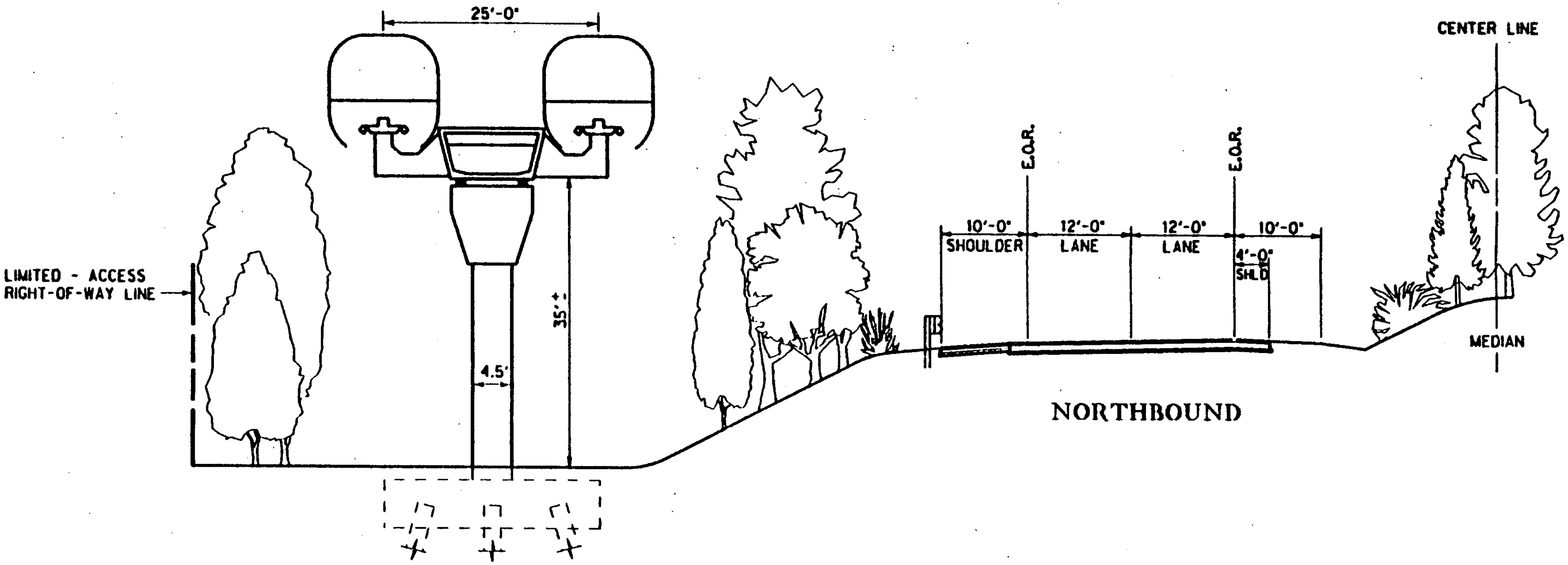

FIGURE 2 Schematic section, Baltimore–Washington Parkway.

TABLE 2 Final Alignment Performance

Measures	I-95	Pkwy	Pkwy Ind.	Amtrak
Total Route Guideway Length (km)	66.3	63.6	62.3	64.9
Length of Guideway Outside Existing Right-of-Way (km)	32.2	31.8	32.5	22.2
Camden to Union Express Service Travel Length (km)	58.1	57.9	56.8	60.2
Union to BWI Airport Express Service Travel Length (km)	52.9	49.4	48.3	50.4
Travel Time (min)/Average Speed (kph):				
Camden to Union Express Service	17/211	17/207	15/220	17/215
Union to BWI Airport Express Service	17/185	13/227	14/211	12/244
Route Length (km)/Travel Time (min) at 483 kph or more	1.6/0.2	7.7/1.0	7.4/0.9	4.2/0.5

the Parkway and Amtrak alignments, and has a long period of 483-km/hr operation. Although 32.5 km of the alignment is outside of the existing right-of-way, most of these right-of-way departures are located on public land within the corridor.

The Amtrak alignment achieves the best travel time and highest average speed from BWI Airport to Union Station among the four alternatives. The short length of the spur from this alignment to BWI Airport compensates for the longer distance between Camden Yards and Union Station. This alignment has the shortest length (22.2 km) outside the existing right-of-way.

The final station locations recommended are Camden Yards in downtown Baltimore, BWI Airport, Union Station in Washington, D.C., and a future station to be located along the Capital Beltway. This future station would be needed to accommodate expected ridership increases in the event that the Baltimore–Washington Maglev becomes part of a larger Northeast Corridor operation, and therefore, land for this station should be acquired initially during development of the prototype stage for later development. Analyses have shown that constructing a spur alignment at Penn Station in downtown Baltimore would be impractical.

An extension of the Maglev route to the Northeast, beyond Baltimore through Philadelphia, New York, and Boston, would run parallel to Interstate 95 and the Fort McHenry Tunnel via a new tunnel or bridge and would join the Amtrak Northeast Corridor line at Eastpoint, just east of Baltimore City.

The ancillary facilities required to support the Baltimore–Washington Maglev prototype include a yard and shop for heavy maintenance, servicing, inspection, and storage purposes. The yard and shop would be located approximately midway between the Baltimore and the Washington, D.C., terminals. In addition, a control and communication center and high-, medium-, and slow-speed switches would be required. This facility could be housed at the yard, at one of the stations, at the maintenance facility, or as a standalone facility. Figure 3 presents a schematic of the entire Maglev system between Baltimore and Washington, D.C.

ENVIRONMENTAL IMPACTS

The environmental evaluation is concerned with identifying principal environmental issues that would have a major influence on corridor and station feasibility and location. These issues focus on potential impacts to historic properties, hazardous waste sites, wetlands, parks and wildlife sanctuaries, floodplains, forests, residential and commercial areas, noise, and electromagnetic fields. Environmental impacts are described in Table 3. Except for the protected status of the Baltimore–Washington Parkway, no environmental features were identified to be unusual or extraordinary given the scale and magnitude of the project. The Interstate 95 alignment would affect the most commercial areas and one potential hazardous waste site. The Amtrak alignment would have the most impact on historic properties and potential wetlands, and the Parkway Independent and Amtrak alignments would have the greatest impacts on parks and wildlife sanctuaries. The 100-year floodplain would be affected the most by the Interstate 95 alignment and the least by the Parkway alignment. Some noise impacts would be generated in residential areas and on some institutional buildings in all four alignments, but these could be abated through the construction of sound-absorbing noise barriers mounted on the elevated guideway structure or by soundproofing the receptors. More detailed environmental impact statement analyses and preliminary engineering studies subsequent to this feasibility study would focus on mitigating or avoiding unacceptable impacts.

Some of the Maglev technologies under consideration incorporate electromagnetic (EMS) propulsion; others incorporate electrodynamic (EDS) propulsion. When compared with generally accepted guidelines, the available data on the magnetic fields generated by Maglev vehicles indicate that EMS Maglev operation produces fields consistent with earths ambient levels and well below levels that would cause interference problems. Unshielded EDS Maglev operations could interfere with nearby communications signals. The use of shielding material as passive barriers or current coil

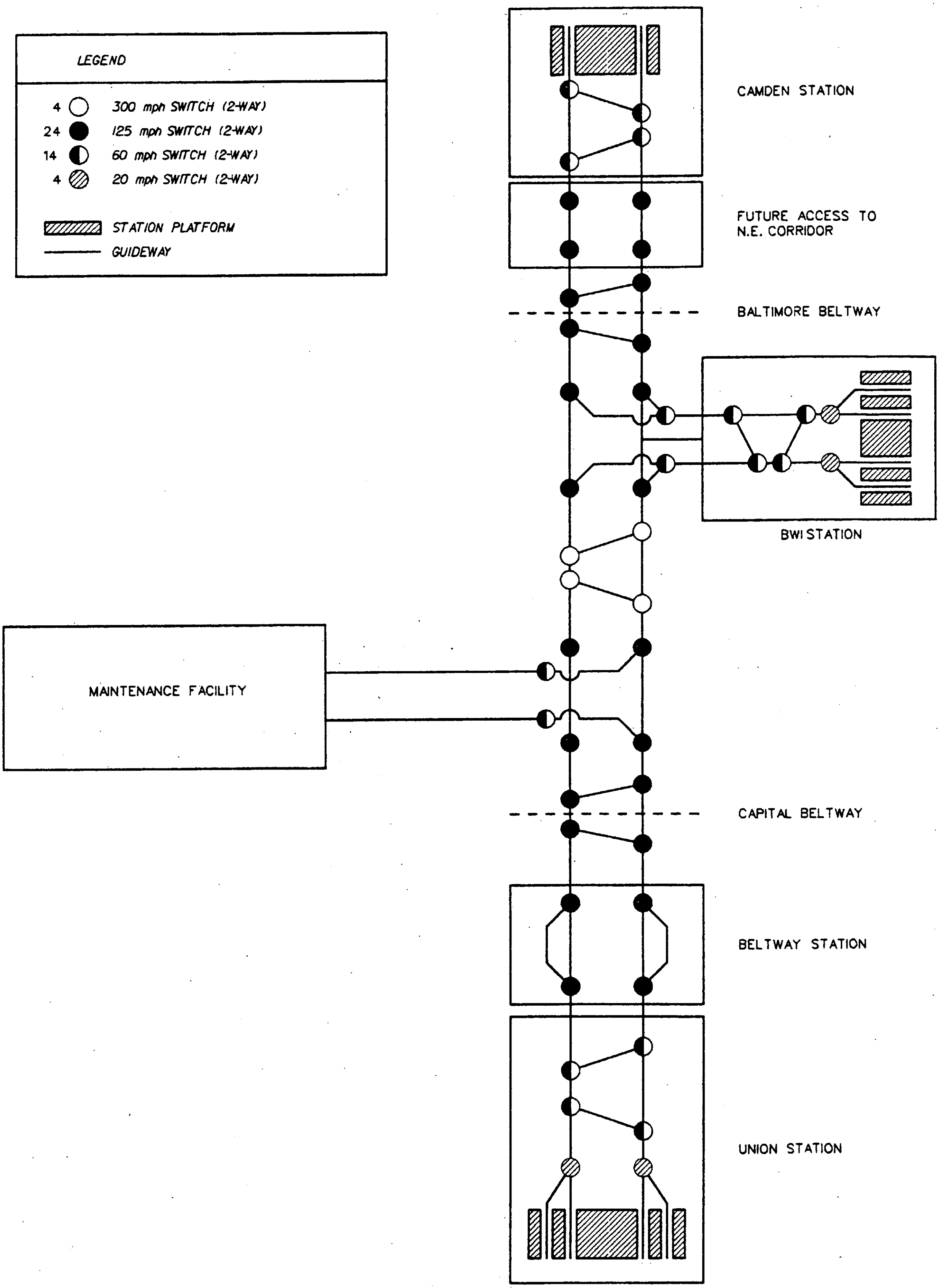

FIGURE 3 Alignment schematic.

TABLE 3 Environmental Impacts (Using Technology Group 2, Moderate Parameters)

Impacts	Alignments			
	Interstate 95	Baltimore Washington Parkway	Baltimore Washington Parkway Independent	Amtrak Railroad
Historic Properties (No.) 600' Buffer	10	5	6	14
Waste Sites (No.)	1	0	0	0
Potential Wetlands (ha.)	2	4	6	8
Parks & Wildlife Sanctuaries (ha.)	4	10	11	11
Floodplains (ha.) (100 Year)	10	6	10	8
Forest (ha.)	44	42	50	47
Residential (ha.)	28	13	27	29
Commercial (ha.)	24	20	16	12

windings to cancel out stray magnetic fields can reduce EDS magnetic fields perhaps to acceptable levels. Additional research and investigation are required to develop EMS field standards and technologies that will fall within those standards. Where practicable Maglev alignments and station locations should be selected to minimize magnetic field exposure.

RIDERSHIP, REVENUES, AND OPERATION

Ridership estimates were made on the basis of two fare assumptions, a base fare and a high fare, and assumed different fare levels considering multitrip discounts (weekly and monthly discounts) by using proportions from a 1993 ridership survey of the Maryland Commuter Rail System (MARC). The base fare range is from $6.00 to $10.00 per one-way trip (twice the MARC fare), and the high fare range is from $19.00 to $21.00 per one-way trip (Metroliner fare) between Baltimore and Washington. The study investigated several different market segments: home-based work and nonwork trips; BWI Airport employment trips; BWI Airport passenger trips; and entertainment trips, as might be made by visitors, tourists, and conventioneers.

The method used for estimating the number of work and nonwork trips by mode, BWI Airport work trips by mode, and BWI Airport passenger trips by mode is a logitbased statistical model in which mode choice is related to the interrelationships among travel cost, travel time, frequency of service, and access time for all competing travel modes (i.e., Maglev, MARC, and automobile).

A multinominal mode choice model was used in which the percentage of riders on each mode, automobile, MARC, and Maglev, is related to the actual and perceived utilities of each mode.

The mode preference values and coefficients used for the evaluation of ridership from the different market segments were determined from the results of previous market research surveys, existing travel by mode in the corridor, the results of a passenger survey of MARC riders that was part of the present study, and the validation of the model against observed travel in the corridor.

Maglev ridership in the year 2005 is projected to range from 20,900 to 39,400 trips per day under the base-fare assumption and 16,400 to 32,700 trips under the high-fare assumption (Table 4). The study assumed that the existing MARC commuter rail system, which provides more frequent stops, would continue to operate after the initiation of the Maglev system. Amtrak service was assumed to continue along the Northeast Corridor, although few passengers use Amtrak to travel between Baltimore and Washington.

Primary Maglev travel will be between BWI Airport and Washington, D.C. (Airport Express Service), and between Baltimore and Washington, D.C. (Express Service). A relatively limited volume of riders would use the local service from Baltimore to BWI Airport to Union Station (Local Service). As such, Local Service is not recommended in the initial operating phase, but could be added when ridership warrants it.

Low hourly ridership in the year 2005 would total about 1,500 passengers per peak hour for Airport Express Service and 600 passengers per peak hour for Express Service. Ridership forecasts could be accommodated by a minimum of 11 operating vehicles; including spares and maintenance requirements, a total fleet of 16 vehicles with a capacity of 150 passengers per vehicle operating as a single vehicle consist would provide effective service. Service would require a staff of 251, including vehicle operators, controllers, and maintenance and management personnel. A 22-vehicle fleet would be required if low ridership estimates for the year 2005 were exceeded by up to 25 percent.

Maglev ridership is drawn from automobile drivers and passengers and air passengers diverted to BWI Airport from other regional airports. Entertainment, tourist, and visitor ridership under the low scenario was based only on current tourist travel between Baltimore and Washington. For high estimates this ridership category includes induced riders who could be attracted to the Maglev service, especially if a tour package program involving tour agents, airlines,

TABLE 4 Baltimore–Washington Corridor Estimated Average Daily Maglev Ridership (Base Fares)

Market Segment	2005		2020		2040	
	Low	High	Low	High	Low	High
Home-Based Work and Non-work	15,800	21,800	19,400	26,600	27,800	37,400
BWI Employment	100	100	100	100	200	200
BWI Passengers	1,900	1,900	2,700	2,800	3,700	4,000
Entertainment	2,500	12,400	3,500	17,500	14,900	27,600
Washington National & Dulles Diversions	600	3,200	900	4,500	6,400	6,400
Total	20,900	39,400	26,600	51,500	53,000	75,600

hotels, and rental car agencies were mobilized. Ridership growth to the years 2020 and 2040 is due to increases in population, employment, and commercial interaction between the two regions, in part due to the Maglev service.

Maglev revenues, including fare revenues, other operating revenues (mail, freight, advertising, and concessions), and nontransportation revenues (station rental and parking fees), for the year 2005 range from $60 million to $157 million per year under the base-fare scenario and $108 million to $229 million per year under the high-fare scenario (Table 5).

Maglev passengers would primarily use automobiles to gain access to the system at BWI Airport, with automobiles accounting for 62 percent of passenger access at Camden Station and 20 percent of passenger access at Union Station, with the balance of passengers using primarily transit, bus, or rail. Parking requirements in the year 2005 by using low ridership assumptions would total 500 spaces at Camden Station, 4,700 spaces at BWI Airport, and 400 spaces at Union Station.

COST AND COST-EFFECTIVENESS

The total cost for the Maglev system in 1993 dollars, including fleet and program management, ranges from a base cost without contingencies and a 16-vehicle fleet of $1.5 billion to $1.7 billion to a high cost with full contingencies and a 22-vehicle fleet of $2.0 billion to $2.2 billion (Table 6). By using these figures costs per kilometer range from a base cost of $24 million to $25 million/km to a high cost of $31 million/km. Principal cost elements are the guideway and substructure, which represent 45.5 percent of the total cost estimate; program management (cost of design, construction management, and start-up), which represents 16.9 percent; station, parking, and maintenance facilities, which represent 14.4 percent; and the fleet, which represents 9.4 percent. Given the uncertainty of the technology, contingency factors vary from 20 to 50 percent. Ridership and revenue projections and construction cost estimates were found to be about equal for all four alignments. Annual operating costs are estimated to be about $40 million in the year 2005, increasing to $53 million in the year 2020.

The capital cost estimates for guideway beam structure, magnetics, wayside control and communications, guideway power, and power distribution, exclusive of the cost of substations, are based on a blend of U.S. Maglev technologies as developed by the U.S. Corps of Engineers and other NMI specialists.

In the first year of service, year 2005, fare box recovery, considering only operating and maintenance costs with full contingencies, would be 142 percent, increasing to 267 percent by the year 2020 (Table 5). Although these fare box recovery rates are unprecedented

TABLE 5 Baltimore–Washington Corridor Estimated Annual Maglev Revenues (in Millions of Dollars)

Year	Base Fares (2 x MARC Fares)		High Fares (7 x MARC Fares/$21.00 Maximum)	
	Low	High	Low	High
2005	$ 60	$157	$109	$229
2020	79	213	140	304
2040	200	323	302	450

FAREBOX RECOVERY

Year	Without Contingencies	Full Contingencies
2005	155%	142%
2020	292%	267%

TABLE 6 Maglev Summary Capital Costs (1993 Price Levels in Millions of Dollars)

	I-95	BWP	BWPI	Amtrak
Total Capital Cost (without contingencies)	1,667	1,518	1,540	1,599
Contingency Cost	491	461	468	478
Total Capital Cost (full contingencies)	2,158	1,979	2,008	2,077
Guideway related costs per km	15	14	14	14
Total cost per km (without contingencies)	24	23	24	24
Contingency allowance per km	7	7	7	7
Total cost per km (full contingencies)	31	30	31	31

in urban transit operations, they are in line with those of current Metroliner service in the Northeast.

Once the 64-km-long Baltimore–Washington Maglev system became part of a longer system extending to New York and Boston, cost-effectiveness is expected to increase dramatically, with greater time savings over highway travel and the system's ability to attract commuters currently using commuter air service.

EVALUATION OF ALIGNMENTS

Each of the four corridor alignments is evaluated in light of the requirements of ISTEA, including the availability of public rights-of-way, attainment of high speeds, intermodal connections, safety, environmental impacts, cost-effectiveness, ridership, and several other key criteria. Additionally, the advantages and disadvantages of each corridor alignment are identified and discussed.

The evaluation revealed that all four alignments and proposed station locations meet the basic ISTEA criteria and could successfully host the Maglev prototype program, more specifically, that the ISTEA speed objective of 483 km/hr (300 mph) can be attained, cost-effectiveness measures are encouraging, projected environmental impacts from the Maglev project are comparable to those found elsewhere for projects of similar size and scope, existing rights-of-way can be used over substantial portions of each alignment, and structural safety concerns can be addressed satisfactorily. However, the institutional issues may be of critical importance in deciding the viabilities of these alignments. These issues include the positions of federal agencies on the use of their lands, especially the position of the National Park Service on the use of the Baltimore–Washington Parkway, and the position of the railroad owners on the terms and conditions for collocation.

As project development proceeds and environmental assessments and more detailed alignment analyses are performed, differences between the alignments in terms of institutional positions, costs, and environmental impacts will emerge and will facilitate the process of selecting one specific guideway alignment and precise locations for stations and other support facilities.

ACKNOWLEDGMENTS

Funding for the study was furnished by the U.S. Department of Transportation, through FRA; the State of Maryland, through the Maryland Department of Transportation and the Maryland Department of Employment and Economic Development; the City of Baltimore, through the Baltimore Development Corporation; and a number of Maryland industries and organizations, through the Maryland Economic Growth Associates affiliated with the Maryland Business Council. All of these agencies made up an executive committee, which provided oversight and guidance during the study.

The project was managed by the Mass Transit Administration of the Maryland Department of Transportation (MTA). The project team under contract to MTA was headed by KCI Technologies, Inc., of Baltimore, Maryland, supported by a number of subcontractors: Martin Marietta Corporation; Gannett Fleming, Inc.; Daniel Consultants, Inc.; Canadian Institute of Guided Ground Transport; R. L. Banks & Associates, Inc.; Louis Berger International, Inc.; and Dunn and Associates, Inc.

Publication of this paper sponsored by Committee on Guided Intercity Passenger Transportation and Committee on Intercity Rail Passenger Systems.