# COMPARISON OF MAGLEV PROJECTS PLANNED FOR U.S. AND GERMANY USING TRANSRAPID TECHNOLOGY

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## Abstract

Three high-speed Maglev projects in the U.S. and one in Germany have completed initial feasibility studies and have been completing the pre-construction planning necessary to secure financing and proceed to construction and revenue service. This paper presents and compares the performance characteristics and costs of these projects. Information on project capital costs is provided for major categories, and as both absolute levels and per route-km and track-km. These costs seem consistent and thus can be useful in planning efforts for other projects. Statistics derived for operations and maintenace costs, because they vary widely, appear to be less useful in providing an indication of their expected level for other projects.

## 1. INTRODUCTION

The U.S. Federal Railroad Administration (FRA) is currently funding pre-construction planning for four high-speed maglev projects in the United States. These projects are being planned by public/private partnerships consisting of a sponsoring state or local unit of government and a group of private sector engineers and/or industrial organizations. These projects have all selected German Transrapid technology and have been under intensive study by the sponsoring public/private partnerships since 1999. For three of the projects, preliminary engineering has been advanced to the point that credible detailed estimates of capital, operating, and maintenance costs have been prepared. Two of the projects are being planned for staged deployment, with the initial operating segment (IOS) planned as a stand-alone project. For those cases the characteristics of both the IOS and the full project are presented in the analysis.

In addition, since January 2001 the German Federal Ministry of Transport, Building and Housing has been providing financial support to the Federal State of Bavaria for the planning of a project deploying Transrapid technology in Munich. Detailed estimates of capital, operating and maintenance costs have also been prepared for this project.

This paper describes the alignment and station location, engineering and operational features, travel market served, and the estimated costs and financing of construction and operation of each of the four proposed projects. Specifically the paper describes:

- Type of travel and markets to be served
- Service to be provided (e.g., capacity, frequency of service, etc)

- Layout of alignment and structures and engineering features of design
- Design features and numbers of vehicles required to provide service
- Location and design of stations and maintenance facilities
- A breakdown of estimated capital and operating costs

The information provided for the various projects is compared to identify significant differences in concept, design and costs. Unit costs for the major common elements of the projects are presented along with an analysis and explanation of the observed differences among the unit costs.

# 2. DESCRIPTION OF PROJECTS

Following is a short description of each project, a summary of project physical and operating characteristics, and estimated project costs. Finally, unit costs (e.g., U.S.$ per kilometer, U.S.$ per vehicle-kilometer, etc.) are computed for each project and compared. Unit cost differences are discussed and partially explained by the differing physical and operating characteristics of the projects, and assumptions incorporated into the estimating methodology.

Preliminary engineering for a fourth project in the U.S. in Los Angeles, has been initiated, but the detailed cost estimates needed for this analysis are not yet available.

All of the estimates and data presented in this paper were developed by the various public/private partnerships planning each of the projects, as provided to FRA. Each project planning team has retained reputable engineers and planners. However, by reporting this information, it should not be implied that FRA accepts or endorses the information presented. Because the information was developed by different groups using differing methods for design and estimating, there may be some inconsistency in comparing the various projects. Still, it is the best information available at this time, and it is hoped that it may provide some meaningful parameters and insights for the design of maglev projects.

## 2.1 Baltimore-Washington Maglev Project

This is a 63 kilometer project linking center city Baltimore's Camden Yard (a sports complex and convention center) and Amtrak's Union Station in Washington, DC with an intermediate stop at Baltimore-Washington International (BWI) Airport. This project has been under study by the Maryland Transit Administration and its private partner since 1994. Forecasting models indicate the project would attract 9.2 million passengers in 2010. It would provide residents and visitors to Washington, DC with convenient access to a second airport only 12 minutes from the primary railroad station (Union Station) in Washington, and take some of the pressure off Reagan National Airport which serves as the primary Washington airport for short and medium distance flights and is currently operating at capacity. At an average speed of 203 km/h the full trip from Baltimore to Washington, with a stop at BWI, would take 18 minutes. It would also serve business travelers, tourists, and commuters in the corridor. The project is visualized as the initial stage of a high-speed maglev system that would serve the entire Northeast Corridor between Boston, MA and Charlotte, NC.

The Baltimore-Washington Maglev Project is estimated to cost $3.74 billion in year 2002 dollars. This cost estimate includes the construction of 62.9 km. of double tracked guideway (16% in tunnel and 33% elevated), three underground stations, a maintenance facility, substations, transformers, and other electrical distribution facilities, 12 highway bridges and fly-overs, and 3,200 parking spaces. Only 22% of the total cost is attributable to the maglev vehicles, propulsion, control, and communication systems. The total capital unit cost is $59.5 million/km. Based upon the level of design information, as well as relative risk potential, a contingency allowance between 10 percent and 30 percent was added to each line item in the estimate.

The estimated annual cost of operation and maintenance (O&M) for the project is estimated at $53 million, with 21 percent attributable to energy costs. The annual operating and maintenance estimates reflect the staffing plan, fringe benefits, material costs for maintaining the vehicles and guideway, utility costs for vehicle propulsion and station light and air conditioning, insurance, and administrative costs. To reflect uncertainties and the level of detail in the study of operations and maintenance, a contingency factor of 30 percent was applied to the total O&M cost.

A statistical summary of the physical design, operating features and estimated costs of the proposed project is included in the Appendix.

## 2.2 Pittsburgh Maglev Project

This is a 88 kilometer project linking Pittsburgh Airport to center city Pittsburgh and its eastern suburbs. The project has been under study since 1990. Pre-construction planning for the project is being carried out by the Port Authority of Allegheny County (the provider most of the transit service in the Pittsburgh area) and its private sector partner, Maglev Inc. The rugged physical terrain, a full four-season climate, and stops at an airport, downtown and in the suburbs would demonstrate the full potential of maglev technology to provide service in a variety of U.S. urban environments. The project has a top speed of 400 km/hr and an average speed of 140 km/hr. The project is projected to be the first segment of an extensive maglev network that would eventually provide high-speed intercity service between Cleveland to the west and Philadelphia to the east.

The project has been designed for staged construction. The 28 km initial operating segment (IOS) between the airport and downtown Pittsburgh was designed as an independent project, and the Full Pittsbugh project would then follow.

### 2.2.1 Full Pittsburgh Project

The Full Pittsburgh Project is estimated to cost $3.82 billion in year 2003 constant dollars. This estimate includes the construction of five stations, with 54 km of dual steel guideway linking four of the stations, and 33 km of single steel guideway linking the system to the less-used fifth station. The project includes a major river crossing, a maintenance/operations control and visitors facility, and significant highway improvements to accommodate increased traffic generated by the project, primarily in the vicinity of the stations. For safety and aesthetic reasons, the guideway is designed to be supported on elevated structure for the full length of the project (the minimum column design height through cut sections is 3 meters). The estimate includes contingencies of between 10 and 30% percent. The project design team estimates that only 12 percent of the project costs are attributable to the cost of maglev vehicles, propulsion, control and communication systems. The total capital unit cost is estimated at $43.7 million/ km.

The estimated annual cost of operation and maintenance is $37.9 million, with the cost of energy accounting for 23 percent of the total. Included in the costs are all labor, materials and administrative costs, and 12 percent for contingencies.

### 2.2.2 Pittsburgh Initial Operating Segment (IOS)

The total capital cost of the Pittsburgh IOS is estimated at $1.6 billion in year 2003 constant dollars ($56 million/km). The IOS will require the construction of three stations, 28 km of dual guideway, a maintenance facility, a major river crossing, a maintenance/operations control and visitors facility, and significant highway improvements to accommodate increased traffic generated by the project, primarily in the vicinity of the stations. Because of security and parking considerations, the station at the airport was divided into two stations. The Airport Terminal Station is located adjacent to the airport terminal, and provides convenient access for air travelers arriving and departing flights. The second station, is located 3 km away. It includes a substantial parking area, and will primarily serve commuters bound for downtown Pittsburgh. The division of the station effectively separates commuters to downtown jobs from air travelers and airport workers. The trip from the airport to downtown is scheduled for 11 minutes, including a stop at the airport commuter station. The annual cost of operation and maintenance is estimated to be $16.7 million.

A statistical summary of the physical design, operating features and estimated costs of both the full 88 km project, and the 28 km IOS are included in the Appendix.

## 2.3 Las Vegas–Anaheim Maglev Project

Intensive pre-construction planning for this project was initiated in 1999 by a public/private partnership formed for the purpose of building a 433 km maglev system between Las Vegas, Nevada (NV) and Anaheim, California (CA). The six station project, when fully completed, would provide service to intermediate stations at Primm, NV, and Barstow, Victorville, and Ontario, CA. The termini at Las Vegas and Anaheim represent two of the most attractive tourist destinations in the United States (gaming casinos and entertainment attractions in Las Vegas, and Disneyland in Anaheim), and would generate significant ridership between the two points. The intermediate stops would link the system to a major airport and the planned high-speed rail system at Ontario, a regional airport at Victorville, a growing recreational area and new airport being planned to serve Las Vegas near Primm. The full system would also serve growing long distance commuter demand throughout the corridor.

The public partner, the California-Nevada Super Speed Train Commission, and its private partner, the American Magline Group, are planning to implement the project in stages, and have designated the 56 km eastern-most segment of the project, between Las Vegas and Primm, NV, as the first portion to be constructed. It is proposed to implement the 51 km western-most end of the project as the second segment. Detailed studies of these two segments of the alignment as stand-alone projects have been completed.

A statistical summary of the physical design, operating features and estimated costs of the Las Vegas-Primm Segment, and the Anaheim-Ontario Segment of the Las Vegas to Anaheim Maglev Project are included in the Appendix.

### 2.3.1 Las Vegas-Primm Segment

The 56 km eastern-most segment of the project, between Las Vegas and Primm, NV, runs through a sparsely developed desert area along an existing highway right-of-way (I-15). It is mostly a single-track guideway, constructed largely at grade, and would be the least expensive and likely the easiest project to build among the documented projects.

The total capital cost is estimated at $1.3 billion in year 2000 constant dollars ($23 million/km). The initial segment is designed to operate three eight-section trains between two stations at 20-minute headways. The design includes construction of 37.5 km of steel single guideway and 18.5 km of dual guideway, a maintenance facility and a maintenance/operations control and visitors facility. Only 34 percent of the guideway would be elevated, with the remainder constructed at grade. Over 35 percent of the capital cost is attributable to acquisition of maglev vehicles, propulsion, control and communication systems. The service would be operated at an average speed of 280 km/hr, with a top speed of 500 km/hr.

The annual cost of operation and maintenance in 2020 is estimated to be $36.7 million, with more than 30 percent attributable to energy costs. Initially the primary market served by the project would be as a tourist attraction. However, with the completion of a proposed new airport near Primm, the market would shift to serving as an airport connector.

### 2.3.2 Anaheim-Ontario Segment

The 51 km Anaheim-Ontario western-most segment of the project would traverse a densely developed urban area with the Ontario station located at Ontario airport, a major facility serving Los Angeles and surrounding communities. The project would serve a large commuter market, as well as providing convenient airport access for Anaheim.

The project is estimated to cost $2.8 billion in year 2000 constant dollars ($54 million/km). This estimate includes the construction two stations, 51 km of dual steel guideway, and a maintenance facility. Over 80 percent of guideway is designed to be supported on elevated structure. The estimate includes contingencies of between 10 and 20 percent. The project design team estimates about 20 percent of the project costs are attributable to the cost of maglev vehicles, propulsion, control and communication systems.

The estimated annual cost of operation and maintenance for the project is estimated at $45 million, with about 30 percent attributable to energy costs. The annual operating and maintenance estimates reflect the staffing plan, fringe benefits, material costs for maintaining the vehicles and guideway, utility costs for vehicle propulsion and station light and air conditioning, insurance, and administrative costs.

### 2.4 Munich, Bavaria Maglev Project

In connection with the decision of the German government in February 2000 not to pursue the Maglev line between Berlin and Hamburg, a feasibility study was initiated to identify another location in Germany to showcase Transrapid technology. After considering several candidates a 37 km route in Bavaria between Munich's main railway station and the new international airport was selected, with direct service between the Munich Central Rail Station and Munich Airport. Its plans call for departures every 10 minutes in peak times, and a travel time of 10 minutes, reducing the trip to the airport by 30 minutes. Bayrische Magnetbahnvorberietungsgesellschaft mbH (BMG) has been charged with the complete planning, design, and analysis of the project.

The service is proposed to operate at a maximum speed of 350 km/hr and an average speed of 220 km/h. Because over 20 percent of the dual-track guideway runs underground through twin single-track tunnels, and nearly the entire alignment runs alongside motorways, societal impacts are minimized. Only about 35 percent of the alignment is elevated and 45 percent is constructed at grade. The project is estimated to cost €1.6 billion (about $1.9 billion, at a rate of 0.823 euros per dollar). The unit cost of the project is estimated to be about €41.1 million/km ($53.7 million/km). About 28 percent of the total cost is attributable to vehicles, and propulsion, control and communications systems.

The annual cost of operation and maintenance is estimated to be €32.5 million ($ 42.2 million), with 28 percent of the amount for energy.

A statistical summary of the physical design, operating features and estimated costs of the proposed project is included in the Appendix.

## 3. SUMMARY OF PROJECT DIFFERENCES

The above descriptions point out the great diversity of the projects currently being planned in the U.S. and Germany. They vary greatly in the type of trips to be served; the length of project; the terrain features, land use and extent of development adjacent to the right-of-way; the grades and curvature of the proposed alignments; the type of guideway structure and the extent to which the guideway will be elevated, at grade, or in tunnel; the extent to which the guideway is single or double track; the number, locations, and types of stations planned; the planned average and maximum operating speeds; the planned headways during peak and off-peak periods; the number of vehicles needed to provide the planned service and the quantity of service provided, as measured in vehicle-km per year. Each of these factors can have a significant impact on the capital costs of the project and the annual costs of operation and maintenance. Table 1 compares selected statistics of the various projects to illustrate their range of diversity.

### 3.1 Type of Trips Served

All of the projects described above would provide service for travelers to an existing or planned airport. Most of the projects also provide service for a large market of non-airport related commuter and business trips. A major portion of the expected market for use of the Las Vegas-Primm Project would be attributable to a tourist-recreational market.

## 3.2 Length of Projects

The projects analyzed range from short airport to downtown connectors of 28 and 38 km to a longer multi-purpose project of 88 km.

## 3.3 Terrain Features, Land Use and Extent of Development

With the exception of the Las Vegas-Primm Project, all of the alignments traverse relatively well developed and growing urban and suburban corridors. To minimize the disruption of adjacent communities, all of the projects are located within, or adjacent to, existing transportation corridors to the extent that they are available and suitable. With the exception of the Pittsburgh Project, the terrain traversed is relatively flat and encounters no major river crossings.

In contrast to the others, the Las Vegas-Primm Project would be built in a sparsely developed, flat, dessert area adjacent to an existing Interstate highway (I-15). The Pittsburgh Project traverses a hilly topography dissected by numerous rivers and streams and includes a major river crossing.

## 3.4 Grades and Curvature of Alignments

Because of the hilly nature of the terrain, the Pittsburgh Project includes steep grades of up to 8.1 percent. However, the grades used for the remainder of the projects are relatively flat, with maximum grades of about 3 percent.

To maximize speed and reduce operating costs, the ideal horizontal alignment for a maglev system is a straight line between two points. However, in practice the alignments must curve to avoid various natural obstacles and man-made development. Route Circuity, the ratio between the actual distance along the alignment, and the ideal straight-line distance between termini, provides an indication of the curvature incorporated into the alignment. The Baltimore-Washington Project with a ratio of 113%, is relatively direct, requiring few curves, while the Pittsburgh project with a ratio of 130% is circuitous and incorporates more curvature in the alignment. The remainder of the projects fall between these two limits.

## 3.5 Guideway Structure

The estimates prepared for the U.S. projects all assume that the guideway will be constructed of precision manufactured steel beams. Dual guideway is designed for the Baltimore-Washington, Pittsburgh IOS, Anaheim-Ontario, and Munich projects. However, the last two stations of the Full Pittsburgh Project are connected by single guideway (33 km, or 38% of the route). The Las Vegas to Primm Project is designed as a single-track guideway project, with dual track sections providing access to the stations ( 37.5 km, or 67% of the route is single guideway).

The Pittsburgh Project is designed to be on elevated structure for the entire route. For safety and aesthetic reasons, the guideway is designed to be supported on elevated structure, even through cut sections (the minimum column design height through cut sections is 3 meters). In contrast, the Anaheim-Ontario Project is designed for 82% of the route to be elevated, and for the remainder of the projects, the percentage varies between 33% and 35%.

To minimize disruption of adjacent communities, and provide access to stations, both the Baltimore-Washington and Munich Projects are designed with significant portions of the guideway to be located in tunnel. For the Baltimore-Washington Project, 9 km of the guideway (16% of the route) are located in tunnel. The Munich Project is designed with 8 km of tunnel (22% of the route)

### 3.6 Number, Locations, and Types of Stations

With the exception of the Baltimore-Washington and the Pittsburgh Projects, all of the projects analyzed are designed for only two stations. The full 433 km Las Vegas-Anaheim Project is planned for six stations, however, the two segments of that project included in this analysis are two-station projects. The Full Pittsburgh Project is designed with 5 stations (airport, center city, and 3 suburban locations). The Pittsburgh IOS and the Baltimore-Washington Projects are each designed with 3 stations (both have airport stations and center city stations; in Pittsburgh the third station is suburban and in Baltimore it is in a second center city). The Anaheim-Ontario Project and the Munich project have located one station in or near a center city and the other at an airport. The Las Vegas-Primm Project has located stations close to an airport and in a growing resort area.

The design of the stations for each project varies greatly from the three elaborate underground stations and additional parking designed for the Baltimore-Washington Project, to the much simpler stations planned in connection with the Las Vegas-Primm Project. Because of their location, the estimated cost of the Pittsburgh Project's suburban stations includes the costs of substantial improvements to the highway network needed to accommodate the increased traffic generated by the stations. The cost estimate for the Munich Project does not separately present the costs of station modification at the Central Rail Station or the airport.

### 3.7 Operating Speeds

Depending upon the horizontal and vertical alignments and spacing of stations, the maximum speed of the various projects varies from 320 km/hr for the Anaheim-Ontario Project to 500 km/hr for the Las Vegas-Primm Project. However, because of the radius of curves in the alignment, acceleration rates limited by passenger comfort, and dwell time at intermediate stations stops, average speeds end-to-end are significantly less than the top speeds. They vary from 142 km/hr for the Pittsburgh IOS Project (about 35% of the maximum speed) to 280 km/hr for the Las Vegas-Primm Project (56% of the maximum speed).

### 3.8 Headways

With the exception of the Full Pittsburgh Project and the Las Vegas-Primm Project, all of the projects provide 10 minute headways during peak hours. The Full Pittsburgh Project and the Las Vegas-Primm Project provide 8.5 minute and 20 minute peak period frequencies, respectively. During the off-peak period the planned frequency of service varies from 10 minutes to 30 minutes.

### 3.9 Number of Vehicles

The number of trains to be operated (including spares) varies from 3 eight-car trains for the Las Vegas-Primm Project to 8 three-car trains planned for the Full Pittsburgh Project. However, the number of cars required varies from 12 for the Pittsburgh IOS to 24 for the Full Pittsburgh, the Anaheim-Ontario and the Las Vegas-Primm projects.

### 3.10 Annual Service Provided

The quantity of service provided each year, as measured by million vehicle-km per year, varies significantly among the projects. The Full Pittsburgh Project and the two Las Vegas projects are planning to provide more than 16 million vehicle-km of annual service, while the Baltimore-Washington and Munich projects are planning less than 60% of these levels. The Pittsburgh IOS will provide less than one-third the service provided by the higher intensity projects.

## 4. COMPARISON OF COSTS

Following is a comparison of the capital, and operating and maintenance costs of the various projects.

## 4.1 Capital Costs

The detailed capital cost estimates prepared by each project and submitted to FRA were summarized into the following broad categories of cost:

- Rights-of-way
- Guideway
- Propulsion, Control and Communication Systems
- Maintenance Facilities
- Power Distribution
- Stations and Parking
- Vehicle Acquisition
- Financial and Other
- Total Capital Cost

Table 2 presents a summary of the capital costs of each project by category and the percentage of total cost attributable to each category. It also compares the percentages of each project cost attributable to basic infrastructure elements (i.e., Guideway, Propulsion, Control and Communication Systems, and Power Distribution), and the percentages attributable to equipment that would probably be supplied by Transrapid (i.e., maglev Vehicles, Propulsion, Control and Communication Systems).

Despite the diverse characteristics and designs of the projects being analyzed, and the various methods used by different engineers to estimate costs, the percentage of total project costs allocated to guideway cost is extremely consistent across projects. With the exception of the Anaheim-Ontario Project, between 45 and 48 percent of Total Capital Cost is attributable to the guideway. However there does not appear to be much consistency regarding the percentage of cost allocated to other elements of each project The greatest variation appears to be in the percentage of cost allocated to propulsion, control and communications systems, which varies from 6 to 19 percent of project cost. Largely because of the great variability in the estimated cost of propulsion, control and communication systems, the basic project infrastructure consisting of guideway, propulsion, control and communication systems and power distribution, varies between 55 and 74 percent of the total cost and the percentage of each project cost attributable to elements that would probably be acquired from Transrapid varies from 12 to 36 percent.

## 4.2 Comparison of Unit Capital Costs

Several categories of capital cost (i.e., Guideway; Propulsion, Control and Communication Systems; Power Distribution; and Total Capital Cost) are clearly related to the length of the route. For comparison purposes, unit costs for these elements of the various projects were computed on the basis of million dollars per route-kilometer ($M/km). The costs of vehicle acquisition and the maintenance facility constructed to maintain the vehicles will depend upon the number of vehicles acquired, and unit costs for these elements are expressed as million dollars per vehicle ($M/vehicle). Each project has adopted a unique philosophy regarding the function, location, and design of stations. They range from the three elaborate underground stations and additional parking designed for the Baltimore-Washington Project that account for 11 percent of project cost, to the much simpler stations planned in connection with the Las Vegas-Primm Project that accounts for less than 2 percent of project cost. Although related, to some degree to the length of trains, most of the station cost is attributable to the architectural treatment, the designed function of the station as an intermodal transfer facility, and the extent to which included in the cost are the parking, and substantial improvements to the adjacent highway network that are needed to accommodate the increased traffic generated by the stations. To give some indication of the range of station costs, the unit cost of stations has been presented as million dollars per station ($M/station).

Table 3 presents the estimated unit capital costs of each project.

#### 4.2.1 Total Capital Unit Cost

Considering the diversity of the projects being compared, the total capital cost per route-km of project are remarkably similar, ranging from $54 to $60 million per route-kilometer for the three projects planned for full dual guideway to $25 million per route km for the Las Vegas-Primm project that is planned for single guideway operation. The Las Vegas-Primm project is also to be constructed 66 percent at grade, and this contributes to its lower unit cost. When the variation in the percentage of the route that is dual or single tracked is accounted for by using track-km to estimate unit costs, the variation between Las Vegas-Primm and the others narrows. Total unit costs vary between $30 and $25 million per track-km for the other projects, and the Las Vegas-Primm project costs are closer at about $19 million per track-km.

#### 4.2.2 Guideway Unit Cost

On average, 50 percent of total project cost of a project is attributable to construction of the elevated, at grade or (in two cases) tunneled guideway. Again, with the exception of the Las Vegas-Primm project, unit costs vary between $21 and $31 million per route-km. Taking into account the mix of dual and single guideway, the costs vary between $13 and $15 million per track-mile.

#### 4.2.3 Propulsion, Control and Communications Unit Cost

On average propulsion, control and communication systems account for only about 13 percent of project costs. However, the computed unit costs appear to vary widely from about $3 million to almost $10 million per route-km. The extent of dual and single guideway does not explain this great variation. The variation may seem surprising, considering that presumably these costs were developed from price quotes or other estimates provided to the various projects by Transrapid, though because various contingency percentages were added to the estimated costs and some costs vary with project length while others are of a relatively fixed nature, some variation among projects is to be expected in both absolute and unit costs.

#### 4.2.4 Basic Infrastructure (Guideway, Propulsion, Control and Communications, and Power Distribution)

The basic infrastructure needed to operate a maglev system is comprised of the concrete and steel guideway needed to support the vehicles and provide a path to travel, the stator packs, motor windings and electronic equipment installed primarily in the guideway to provide a means of propulsion, control and communications with the vehicles, and the power distribution system needed to power the vehicles. When adjusted to take account of the mix of duel and single guideway, the unit costs are remarkably similar, ranging from $13 to $18.5 million per-track-km.

#### 4.2.5 Vehicle, Propulsion, Control and Communications Systems

It is presumed that maglev vehicle, propulsion, control and communications equipment and systems for the projects would be acquired from Transrapid. The remainder of the structures and equipment will be provided by local contractors. The vehicles, propulsion, control and communications equipment and systems constitute an average of about 20 percent of the project with a range from about 12% to 36%. The wide range occurs in part because some of the costs do not vary with project length, though other differences in the cost estimates are also likely part of the explanation.

### 4.2.6 Stations and Parking

As pointed out in 3.6 above, the cost of stations vary greatly from project to project depending upon the location, the architectural treatment, and the need to provide parking and or modifications to the adjacent highway system to accommodate highway traffic generated by the maglev service. Costs vary from $10 million to $132 million per station.

## 4.3 Operating and Maintenance Costs

Each of the project has developed detailed estimates of the annual costs of operation and maintenance (O&M) that reflect staffing plans, fringe benefits, material costs for maintaining the vehicles and guideway; utility costs for vehicle propulsion, and station light and air-conditioning; insurance and administrative costs. Table 4 presents a comparison of the total estimated O&M costs prepared for each of the projects, and the portion allocated to energy consumption

Table 4 also presents a comparison of the unit costs of total O&M costs on the basis of annual vehicle-km of service, and the energy component of O&M on the basis of dollars per megawatt-hour and vehicle-km of service.

### 4.3.1 Energy Consumption Costs

On the average energy costs account for about 28 percent of the total annual O&M cost, ranging from 21 to 31 percent. However the unit cost for energy varies widely among the projects, from $56 per MWh to $100 per MWh. Reflecting the variation in energy unit cost, the reported cost also varies widely on the basis of vehicle-km, from $ 0.6 per vehicle-km to $1.3 per vehicle-km.

### 4.3.2 Total Annual O&M Costs

Total O&M costs should be closely related to the amount of service provided, expressed as vehicle-km. However, reported costs vary from about $2 per vehicle-km, to about $6 per vehicle-km. Some, but not all of this variation, can be explained by the large variation in the cost of energy.

# 5. CONCLUSION

Based upon the above analysis of six diverse projects currently being planned in the U.S. and Germany, preliminary estimates of the capital cost of proposed short maglev projects of less than 100 km can be prepared with some confidence. The cost of guideway infrastructure (guideway, propulsion, control, and communication and power distribution) ranges between $19 and $13 million per track-km, depending the extent to which the project is elevated, at grade, or in tunnel. The cost of vehicles appear to range between $9 and $13 million each. Stations can range from $132 million each to about $10 million, depending upon location, and complexity of design. On average these items will account for 79 percent of total capital cost of a project. Statistics derived for O&M costs, because they vary widely, appear to be less useful in providing an indication of their expected level for other projects.