Approach To Estimating Maglev Guideway Maintenance Costs

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Renewed interest in magnetically levitated (maglev) transportation systems in the United States has led to close examination of the costs associated with developing such systems. Of particular concern has been the largest cost item, guideway capital costs. Unfortunately, maintenance costs, the other costs associated with the guideway, have not been as thoroughly examined. In fact, very little information concerning estimation of maglev guideway maintenance costs is available. Whereas there are no operational maglev systems in the United States, a large number of conventional transit systems in this country have guideway characteristics similar to those of maglev systems. These systems offer a wealth of information about guideway maintenance. The feasibility of using such data, specifically data from the Morgantown People Mover system, to assist in estimating and understanding maglev guideway maintenance costs, is examined. The most common maglev guideway maintenance cost estimation approach, the capital cost percentage (rule-of-thumb) approach, is examined and found to be reasonable. However, it may not be appropriate to assume that maintenance costs are constant over time, as the capital cost percentage approach suggests. In addition, the general subject of guideway maintenance is discussed. A list of actual Morgantown guideway maintenance actions and their applicability to maglev systems is provided.

In 1990 Congress created the National Maglev Initiative (NMI), a comprehensive effort comprised of private, public, and government research projects aimed at determining the economic, technical, and operational safety aspects of a United States magnetically levitated (maglev) high-speed ground transportation system. The planned result of the initiative is an "all-American" maglev design.

The costs associated with construction of such a maglev system are high. For example, it is estimated that a proposed Los Angeles–to–Las Vegas system would cost over $5.6 million per kilometer to build (*1,2*). Most of the NMI projects dealing with costs focus on reducing the capital costs of maglev systems. The largest of these costs is the guideway. In some instances, the guideway makes up 80 percent of the capital costs of proposals (*3*), exclusive of land acquisition costs. While reducing the capital costs is viewed as the key to development, the costs of maintaining these systems must also be examined.

Currently, there are no operational maglev systems in the United States. Worldwide, there are only a handful of such systems. As a result, the maintenance costs of a maglev system are difficult to determine. In addition, since the existing systems are relatively new, there are no historical records available for study. Thus, estimating the future maintenance costs of a maglev system has been based strictly on "engineering judgment."

At present, there is no definitive approach to estimating the maintenance costs of maglev guideways. In fact, maintenance cost issues relative to all mass transit guideways, not only maglev, are an overlooked area. There is also a lack of basic information on maintenance in general, including procedures, labor requirements, and related items.

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PROBLEM STATEMENT

In order to assess the financial viability of specific U.S. maglev routes, it is imperative that accurate cost estimates be available. A few approaches have been developed to estimate the maintenance costs associated with maglev guideways. A popular approach, due to its simplicity, is the use of a rule-of-thumb—or capital cost—percentage. This approach estimates future maintenance costs based on a percentage of the original capital costs. However, to our knowledge, no scientific assessment of this approach has ever been conducted.

West Virginia University is the site of the first operational people mover, known as the Morgantown Personal Rapid Transit (PRT) system. Relatively low-speed, rubber-tired vehicles travel over a concrete-surface guideway between five stations. Since the PRT was built as a demonstration project, its operation has been studied extensively and a great deal of data has been collected relative to the system, including the guideway.

Although the PRT vehicles are electrically powered and rely on conventional rubber tires, the guideway, with a few modifications, appears suitable to accommodate maglev vehicles. Given that relatively detailed maintenance data are available for the Morgantown PRT, it seemed appropriate to consider the use of PRT data as an input in estimating maglev guideway maintenance costs. Information from conventional transit guideways such as the PRT can also be helpful in identifying key maintenance items or areas which should be addressed in any maglev feasibility studies. Consequently, the problem to be addressed here is to examine the feasibility and utility of using conventional transit system maintenance data, such as that from people movers, to estimate maglev guideway maintenance costs.

OBJECTIVES

One aspect of the NMI project conducted at West Virginia University addressed the problem described above. Specific project objectives were as follows:

1. To examine guideway maintenance data for the Morgantown PRT;
2. To sort the guideway maintenance data into appropriate categories for analysis;

3. To determine labor costs, material costs, and annual maintenance costs for the conventional guideway system;
4. To analyze these costs to determine any patterns or trends that may exist;
5. To use data from the conventional transit system to evaluate the rule-of-thumb percentage approach to estimating maglev maintenance costs; and
6. To identify significant conventional transit system maintenance elements that may apply to maglev.

DATA COLLECTION

System Characteristics

The West Virginia University Downtown People Mover system, known locally as the PRT, was the conventional transit system examined in this research. The PRT guideway is a limited-access structure consisting of both at-grade and elevated sections. Approximately 54 percent of the 14,000 linear meters of guideway is elevated. The elevated sections consist of both steel beams (Phase I) and precast, prestressed concrete beams (Phase II) with concrete column-supported structures. The running surface is concrete and contains piping for guideway heating and inductive communication loops.

The Morgantown PRT was selected as the "conventional transit" system for this research for several reasons: (*a*) its proximity to the university, (*b*) unrestricted access to available data, (*c*) the comprehensiveness of available data, (*d*) the availability of actual maintenance records for a 10-year period, and, (*e*) the structurally simple design of the Morgantown PRT guideway. A maglev system could use the same basic guideway design, with appropriate modifications for the maglev elements.

The Morgantown system does have characteristics that distinguish it from other mass transit systems. Because the system primarily serves West Virginia University, system operation is subject to the school calendar. As a result, during school breaks (when its passenger base is not present) the system shuts down. This affords the Morgantown system the luxury of performing maintenance actions without the time constraint of a 365-day-per-year schedule. Virtually all of the maintenance actions described in this report were performed while the system was out of service. Certainly, this would not apply in a maglev environment. The system operates 16 hours per day, Monday thru Friday, and on a limited schedule during the weekend.

Characteristics of the Morgantown system's maintenance staff also should be discussed. As of December 1992, 28 full-time employees were dedicated to system maintenance. While approximately one-third of the employees were electricians (or have electrical training), the remainder serve as jacks-of-all trades, performing maintenance on vehicles as well as the guideway. With a maglev system of significant length, this jack-of-all-trades arrangement may not be possible.

Data Collection Procedure

The organization of maintenance records for the Morgantown system (and in fact, most transit system records) is not conducive to examining a single maintenance element, especially a guideway element. As a result, it was necessary to manually examine a computer printout of the entire system maintenance records. Only those maintenance items judged by the researchers to be pertinent to the structural guideway system and the maglev guideway situation were selected. The process used is summarized in flow-chart form in Figure 1. Computer printouts were available for only the previous 10 years (1983–1992). The data obtained from this initial search included a generalized one– or two–word description of the maintenance action and the record number of the original maintenance work order.

Each individual original maintenance record (the PRT equipment status and maintenance record) then had to be located by record number and examined. For a typical year, almost 6,000 maintenance records were created.

From the original maintenance records, items of interest were reviewed to determine date, location, specific task, type of materials used and man-hours of labor involved. An item of major interest not on the original records was the quantity of material used for each repair or maintenance action. Therefore, the material costs and quantities had to be obtained from purchase orders. Although overall material costs and quantities per year were available, it was not possible to break down the amount of material used for each individual maintenance action. In addition, these material costs were only available for the previous 6 years (1987–1992). An approach was developed for estimating the other 4 years of material costs. A third source of information addressed the labor rates. All labor costs were provided by the PRT accounting office and were based on the 1992 labor rates. All costs presented in this paper are in 1992 dollars.

Categorization of Data

The guideway maintenance elements obtained from the maintenance records were categorized into five areas: surface, structural, debris, inspection, and heating. These categories were created to help in the analysis of the data by grouping similar maintenance

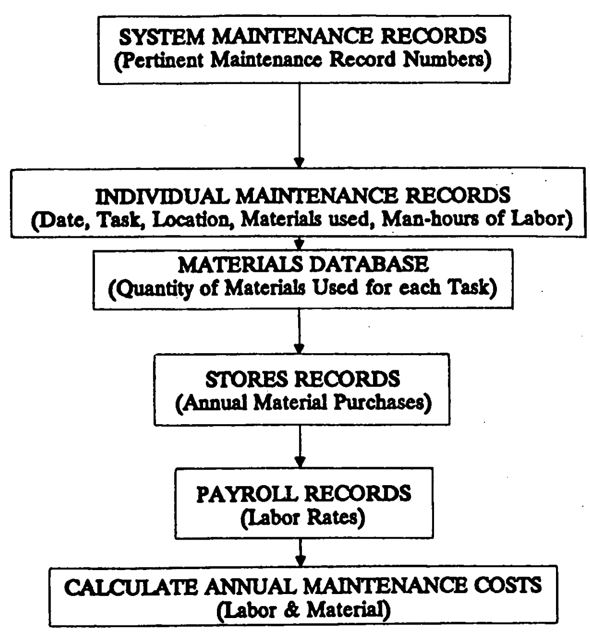

FIGURE 1 Steps involved in using Morgantown DPM system maintenance data.

actions together. The surface category included all maintenance to guideway surface elements, including repair of cracks and other surface irregularities. The structural category involved all elements relating to the specific structural system, such as the repair or replacement of pier pads and expansion joints. The third category covered the removal of debris on the guideway. The Morgantown system's vehicles, like proposed "attractive" maglev systems, are susceptible to damage from debris on the guideway. The fourth category was established to record the frequency of guideway inspections. The final category incorporated all maintenance actions concerning the guideway heating system for winter operations. Only maintenance actions concerning the guideway proper were included in the research. Repairs made to other portions of the heating system, such as the boiler plants, were not included. This category was created to permit an evaluation of guideway maintenance costs with and without the heating system. However, the two may not be mutually exclusive. For example, a crack in the guideway may be directly related to the inclusion of the heating pipes within the concrete running pad. In fact, there was evidence of this type of maintenance.

Limitations

It is important to recognize the inherent differences between acceptable tolerances with a maglev system and the Morgantown PRT conventional transit system. One major element of concern in certain maglev systems is the differential elevations of connecting spans at their joints (*3*). Due to the strict tolerances in some maglev systems, the alignment of this joint is critical. Maintenance costs of this joint will be higher for a maglev system than with the Morgantown system.

Another area of uncertainty involves the effect that the inclusion of heating elements within the running surface has on maintenance of that surface. The heating elements enter and leave each guideway span near the joint with the next span. Cracking of the surface on some of the spans has occurred where the heating pipes enter the guideway. The proximity of this location to the joint raises the question of whether the crack occurred due to the warming and cooling of the concrete by the heated pipe, because of pressure from the adjacent span during expansion of the entire slab, or a combination of both. The question of whether a maglev guideway will be heated in cold-weather climates has yet to be resolved.

DATA ANALYSIS

Statistical Analysis

The actual data were compiled into the five previously described categories (surface, debris, structural, inspection, and heating) in monthly and annual intervals. In addition, the number of maintenance actions or incidents was also noted. Of particular interest were the categories of surface maintenance and structural maintenance. Surface maintenance included such maintenance actions as sealing guideway cracks with epoxy and repairing damaged concrete with a concrete patch.

One trend identified was the high number of maintenance actions in May and August. The month of May is the first good-weather month in which the system shuts down for an extended period (2 weeks for the break between the end of the spring semester and summer school). The month of August is the last good-weather month in which the system has a 1-week shutdown period before resuming a normal schedule for the fall semester. This demonstrated an advantage of the Morgantown system: the ability to shut down for extended periods when its passenger base is low due to breaks in the academic calendar. It is unlikely that a maglev system would have that luxury.

The structural category included all maintenance involving the structural system, such as steel beams and pier pads. A pattern similar to that of the surface category was found. The categories of debris removal, inspections, and heating system displayed few noteworthy trends.

Total Maintenance Cost Model

Because material costs data were available for only 6 of the 10 years of data, costs for the first 4 years had to be estimated. A material cost function model was developed using surface and structural labor costs as the independent variables. Once the appropriateness of the model was determined using statistical techniques, the next step was to calculate the data for the missing years. Since the material costs could be determined for the entire 10-year study period, a generalized cost function for all guideway maintenance could be found. A cost function was developed to help eliminate the variability and provide for the development of a rule-of-thumb percentage.

The labor costs from the debris, surface, structural, and inspection categories were added to the yearly material costs to arrive at guideway maintenance costs for each year. The graph of years (or age of facility) versus total maintenance costs is displayed in Figure 2a. The graph displays considerable variability between 1986 and 1990. The next step was to smooth the data (*4*), as shown in Figure 2b, to remove the variability.

The resulting equation was $Y = 94.17X + 9{,}846.67$, where X is guideway age and Y is total guideway maintenance costs. A regression analysis of the modified data was performed. The comparison with existing data was very good. The high R value (.947) indicates a good correlation between years (age of facility) and guideway maintenance costs. A more detailed discussion of the statistical analysis is available for interested readers (*5*).

Capital Cost Percentage Examination

PRT Percentage

Since a total guideway maintenance cost function was developed, the final step was to determine if a rule-of-thumb percentage could be developed. Because the Morgantown PRT cost function was an increasing function, the percentage (of guideway maintenance costs to guideway capital costs) should also increase. The initial capital cost data were provided by the PRT staff. All costs were adjusted to 1992 dollars for a more valid comparison. In 1992 dollars, the initial guideway construction costs (Phases I and II) were $63.1 million.

As seen in Table 1, maintenance costs as a percentage of capital costs ranged from 0.0156 to 0.0186 percent for the period 1977 to 1997. These numbers are considerably less than the 0.12 percent used by CIGGT in its Los Angeles-to-Las Vegas study and the 0.08 percent used by Transrapid (*1,2*). The maintenance cost percentage using the actual values from 1987 to 1992 ranged from 0.0077 to 0.0306 percent (Table 2). The highest percentage was achieved in 1989. This was basically due to the high material costs in that year. The corresponding low year was 1977.

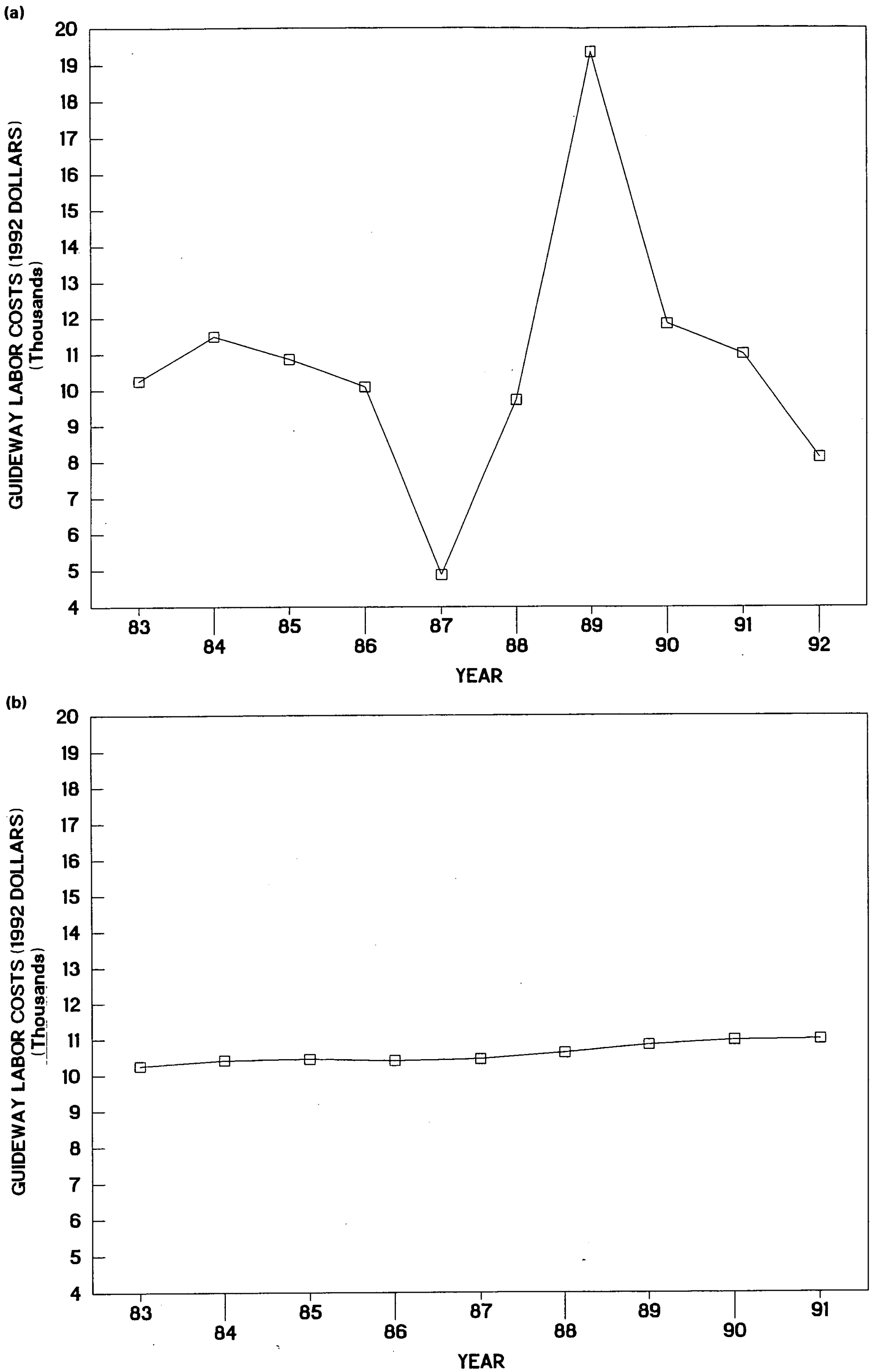

FIGURE 2 Total guideway maintenance costs per year, 1983–1992: (*a*) raw data, (*b*) smoothed data.

TABLE 1 Maintenance Costs and Capital Cost Percentage for Study Period Using Maintenance Cost Function

FACILITY AGE	YEAR	INIT. COST (MIL$)	MAINT. COST	CAP. COST PERCENT
0	1977	63.1	9850	0.0156
1	1978	63.1	9945	0.0157
2	1979	63.1	10040	0.0159
3	1980	63.1	10130	0.0160
4	1981	63.1	10225	0.0162
5	1982	63.1	10320	0.0163
6	1983	63.1	10415	0.0165
7	1984	63.1	10510	0.0166
8	1985	63.1	10605	0.0168
9	1986	63.1	10695	0.0169
10	1987	63.1	10790	0.0170
11	1988	63.1	10885	0.0172
12	1989	63.1	10980	0.0174
13	1990	63.1	11075	0.0175
14	1991	63.1	11170	0.0177
15	1992	63.1	11260	0.0178
16	1993	63.1	11355	0.0179
17	1994	63.1	11450	0.0181
18	1995	63.1	11545	0.0182
19	1996	63.1	11640	0.0184
20	1997	63.1	11735	0.0186

TABLE 2 Maintenance Costs and Capital Cost Percentage for Study Period Using Actual Maintenance Cost

FACILITY AGE	YEAR	INIT. COST (mil$)	MAINT. COST	CAP. COST PERCENT
10	1987	63.1	4885	0.0077
11	1988	63.1	9730	0.0154
12	1989	63.1	19360	0.0306
13	1990	63.1	11845	0.0187
14	1991	63.1	11000	0.0174
15	1992	63.1	8125	0.0128

Comparison with Maglev

The Canadian assessment (*1,2*) of the Las Vegas–Los Angeles maglev route provided estimated maintenance costs. The percentage used for those costs was a constant 0.12 percent. Unlike the PRT results, an increasing percentage was not used for the maglev guideway. However, the absolute percentage is much greater than even the highest value for the PRT analysis. Because literature on the original development of the capital cost percentage approach was not found, it is unknown if actual data were used in establishing the value. However, it is doubtful that an examination of actual guideway maintenance data was made.

Guideway Heating System

The maintenance of the heating system embedded in the Morgantown system guideway was considered separately for analysis purposes. This was done so that maintenance costs and a percentage that would apply to both a non-heated guideway and a glycol-heated guideway system could be developed.

Once the material costs were determined, a cost model for total maintenance costs could be developed. As was done in the earlier analysis, these data were smoothed to help develop a more linear relationship. The resulting equation was $Y = 1{,}059.03X + 3{,}419.18$, where X is guideway age and Y is total guideway maintenance costs.

Capital Cost Percentage Examination

The development of the capital cost percentage for the heating system total cost function was slightly more difficult than the previous development. The problem centered around the determination of the initial cost for the heating system. While construction cost data for both phases of the guideway were available, the cost of the Phase I heating system was not available. In addition, the cost breakdown of the Phase II heating costs did not separate boiler system costs from those of the guideway pipes. The problem of no Phase I costs was overcome by using a heating cost per linear-meter of guideway which had been developed by PRT personnel for Phase II. This cost figure was applied to the total system to arrive at a total initial cost (in 1992 dollars) of $11,653,000.

Because of the problems with the heating system material costs and the fact that no maglev proposals to date have included a heating system, only the 10-year period was examined. The range of percentages for Scenario 1 (using the total heating system cost with no separation of elements) was 0.0130 to 0.0258 percent and for Scenario 2 (the subjective cost of the heating system), 0.0148 to 0.0292 percent as shown in Table 3. As in the first analysis, the percentages are still significantly lower than those used in published maglev assessments.

GUIDEWAY COSTS AND ISSUES

Percentage Approach

Two significant characteristics of the percentage approach were observed from the data. First, the conventional transit system percentage was an increasing function (with time) as opposed to the constant values indicated by both CIGGT and Transrapid (*1,2*). Second, the percentage derived from the Morgantown PRT data was significantly less than the percentages mentioned in the literature.

Intuitively, one would expect maintenance costs to increase, albeit slowly, as a facility ages, especially after several years of operation. The use of a constant percentage, though, may not be entirely without merit. The corresponding dollar value of the percentage, which in the Los Angeles–Las Vegas assessment was $888,000, may serve as a budget mark. Actual maintenance expenditures may fall above or below the budgeted amount, depending on the circumstances.

The PRT data have, however, demonstrated that the maintenance costs for a guideway structure increase as the facility ages. An appropriate question, then, is at what rate maintenance cost estimation function for a maglev guideway should increase. The Morgantown PRT function increased at a rate of 0.08 percent per year, during the 10-year study period.

The other factor associated with the capital cost percentage is the significant difference between the percentage derived from Morgantown PRT data and those suggested by Transrapid and CIGGT. Even under a condition resulting in the highest PRT percentage (i.e., adding maintenance of guideway heating without the corresponding capital cost increase) it was found that the PRT percentage was only 40 percent as high as Transrapid's 0.08 percent. Eliminating the heating system from the percentage computation gave a PRT percentage of 0.018 percent for 1997, the high and last value from the function. The highest real value came in 1989, with 0.03 percent. The lowest real value was 0.008 percent in 1987.

TABLE 3 PRT Maintenance Cost and Capital Cost Percentage in 1992 Dollars: Scenarios 1 and 2

SCENARIO 1: Initial Guideway Cost - $63100000
Initial Heating - $11653000
Total Capital Cost - $74753000

FACILITY AGE	YEAR	MAINT. COST	CAP COST PERCENT	FUNCTION COST	CAP COST PERCENT
6	1983	11430	.0152	9775	.0130
7	1984	11690	.0156	10835	.0144
8	1985	11845	.0158	11895	.0159
9	1986	11910	.0159	12955	.0173
10	1987	12345	.0165	14010	.0187
11	1988	13455	.0179	15070	.0201
12	1989	15400	.0206	16130	.0215
13	1990	17540	.0234	17190	.0229
14	1991	19295	.0258	18250	.0244
15	1992	20480	.0273	19305	.0258

SCENARIO 2: Initial Guideway Cost - $63100000
Initial Heating - $ 2920000
Total Capital Cost - $66020000

FACILITY AGE	YEAR	MAINT. COST	CAP COST PERCENT	FUNCTION COST	CAP COST PERCENT
6	1983	11430	.0173	9775	.0148
7	1984	11690	.0177	10835	.0164
8	1985	11845	.0179	11895	.0180
9	1986	11910	.0180	12955	.0196
10	1987	12345	.0186	14010	.0212
11	1988	13455	.0203	15070	.0228
12	1989	15400	.0233	16130	.0244
13	1990	17540	.0265	17190	.0260
14	1991	19295	.0292	18250	.0276
15	1992	20480	.0310	19305	.0292

An important factor in explaining the difference between the percentages is the type of guideway maintenance being performed. The single greatest difference between the PRT guideway and a maglev guideway concerns the alignment of the guideway span joints. The PRT system has a high tolerance of differential joint settlement. For a maglev system, the tolerance is low, especially for designs that incorporate conventional magnets.

Concrete Surface Deterioration

Another maintenance issue is deterioration of the concrete surface. Unlike the rubber-tired PRT system, the maglev vehicle (Transrapid type) does not make contact with the guideway surface during normal operations. The Morgantown system's wheelpath has been the site of maintenance actions, typically the repair of a patch. While the area of joints may experience an increase in maintenance, the surface deterioration may likewise experience a decrease. As a low-speed facility, velocities on the Morgantown PRT do not cause a high degree of turbulence and speed which can easily move sand-sized particles and larger. Such particles can have a grinding wear effect on a maglev guideway and its electrical components.

Based on the findings from the Morgantown PRT system, it appears that the Transrapid 0.08 percent figure is conservative, especially for the early years of guideway life. The first year of operation may experience a higher than average maintenance cost as any joint problems become evident; however, no other guideway maintenance should be required. The actual percentages to be used in cost estimating are, at this point, purely subjective. However, there is no question that the estimation should include an increasing percentage as the facility ages.

PRT Maintenance Information

In addition to the examination and evaluation of the percentage approach, other information about maintenance in general was obtained from the Morgantown PRT system. The repair of deteriorated concrete was the single largest maintenance action undertaken by the PRT. The deterioration is relatively minor: small cracks or sections of loose material that need to be patched. The cracks are typically sealed with epoxy, while the area with loose material is patched or replaced. These types of actions are normally found in the wheelpath and at joints.

It is unlikely that "wheelpath" deterioration will exist with a maglev system. However, if large cracks develop in the guideway (at the joint), the load transfer may cause deterioration of the concrete around the crack, no matter where the crack is located on the guideway. Cracking of concrete is a natural phenomena and cannot be prevented. However, it is the larger cracks that pose a problem to the structural integrity of the slab.

Another type of concrete deterioration occurred at connections made to the concrete slab. For example, the PRT has experienced deterioration where steel beams (used to connect the guidance rail to the concrete slab) connect to the concrete slab. In this case, the connections were rebuilt. A similar problem was found with the Transrapid system. Replacement of the connection of a guidance rail (different type of guidance rail than that used by the Morgantown system) to the concrete trapezoidal box section was required at several locations. This example of similarity of maintenance actions between the Morgantown PRT and the Transrapid maglev system further demonstrates the utility of comparisons between the two types of systems and demonstrates the type of information that can be gained from examining conventional transit systems.

Relative to concrete, there are also differences in how loads are transferred to the guideway. In a maglev system, the vehicle's magnets are mounted on truck frames with their own suspension elements. The propulsion/braking magnet loads are transferred to the guideway by means of studs that attach the stator pack windings to the guideway. These mounts must carry the full thrust load to the guideway during acceleration (or reverse thrust during braking). Other systems may have magnet coils embedded in the sidewalls of the guideway; this may require special maintenance action that would be in addition to that described for a PRT guideway.

Other typical Morgantown PRT guideway maintenance actions included repair or replacement of expansion joints, cleaning of clogged guideway drains, removal of debris from the guideway surface, repair of metal grates, and repairs to the heating system. With the Morgantown system, expansion joint maintenance activities involved mainly the at-grade sections. These expansion joints consist of a rubbery material placed between the adjoining slabs. In the event the material becomes damaged or dislodged, it is replaced. For the elevated sections, a steel bracket attached to each slab is used to protect the concrete from damage in case expansion forces the two slabs together. No maintenance actions involving expansion joints on elevated sections were identified, although at one location, deterioration of the concrete around the bracket was visible.

Removal of debris from the PRT guideway was another frequent maintenance action. Depending upon the actual maglev system design, the issue of debris may be minor. If the system has a wide dedicated right-of-way that is cleared of trees and rock fall zones, this particular debris problem would be eliminated. On the other hand, a design such as the Los Angeles-to-Las Vegas system, which placed portions of the guideway at grade along an interstate highway, may experience more debris problems.

The heating system is another PRT maintenance action of concern. Typical maintenance actions are valve replacement and relocation of underground pipes. In some instances, the concrete surrounding a heating pipe had to be removed to replace the valve. Whether a maglev system would experience this type of maintenance depends on whether an embedded pipe heating system is used. This issue is still unresolved relative to maglev guideways.

The final area of PRT maintenance actions concerns periodic inspections. Inspection of the guideway is probably the most important maintenance element that can be performed to avoid major problems. Without a scheduled inspection program, deterioration of the guideway would go unnoticed until significant damage has occurred. This would especially be true on large systems that may travel through sparsely populated areas, such as the desert region of California on the Los Angeles-to-Las Vegas route.

The exact frequency and duration of an inspection schedule for a maglev guideway would depend on the type of system (e.g., size and location). However, there is no question that at least one inspection of the entire guideway would be needed each year; this was the frequency proposed for the Los Angeles-to-Las Vegas route. As the facility ages, it would be appropriate to increase the inspection frequency. For maglev, it is imperative that any problems be discovered at an early age. The fixed-schedule nature of the system would not be conducive to long delays resulting from problems with the guideway.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This assessment of using conventional transit system guideway costs to assist with maglev guideway cost estimation is believed to be unique. No other effort to date in the evaluation of guideway maintenance has examined the wealth of information available from operating conventional transit systems. It was concluded that it is feasible to use conventional transit system guideway maintenance costs as one input to the process of estimating maglev guideway maintenance costs. By examining the Morgantown PRT system, it was found that the rule-of-thumb capital cost percentage approach to estimating maintenance costs appears to be appropriate. However, modification of the constant percentage concept and the magnitude of the percentage is warranted. In addition, the typical maintenance actions on the PRT system give a good idea of what can be expected with maglev guideway maintenance. This is summarized in Table 4.

Recommendations

Guideway maintenance cost estimators are urged to use caution when applying published capital cost percentages. The research has shown that the existing published percentages (e.g., Transrapid) will provide conservative results. Improved results can be obtained by using an increasing percentage with a lower initial magnitude.

Additional research that examines other conventional transit system guideways is needed. A variety of geographical areas and operating concepts should be studied. A system with a trapezoidal box guideway would be an ideal candidate. The trapezoidal box guideway has been recommended by the Canadian Institute of Guided Ground Transport in its assessments of maglev systems (*1,2*).

TABLE 4 Morgantown PRT Guideway Maintenance Actions and Potential Applicability to Maglev Systems

Maintenance Action	Applicable to maglev?
Concrete Deterioration (patching required)	
Vehicle wheel path	No
Slab joints	Maybe
At connections	Yes
Other	Maybe
Concrete crack repair	Yes
Expansion joint replacement	Yes
Pier pad repair and replacement	Unlikely
Clogged drains	Yes
Debris	Yes
Metal grate repair	Unlikely
Heating System	Maybe
Pipe relocation	
Valve replacement	
Inspections	Yes

In addition, examination of other independent variables in the development of the PRT cost model would be worthwhile. Variables that affect guideway deterioration, such as freeze-thaw cycles, passenger volume, and guideway loads may provide improved results. The use of age as the independent variable served as a surrogate for such variables. Other maintenance prediction models, such as those used for highways, should be examined.

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