Table 44. Comparison of SSTSIM results with MPS results for TR07 using identical LSM and vehicle characteristics.

Location	*Position MPS (m)*	*Position SSTSIM (m)*	*Deviation (%)*	*Time MPS (s)*	*Time SSTSIM (s)*	*Deviation (%)*	*Energy MPS (kWh)*	*Energy SSTSIM (kWh)*	*Deviation (%)*
Terminal 0 (Gate 1)	0	0		0	0		0	0	
Gate 10	39,900	40,004	0.3	637	641	0.6	1,270	1,268	–0.2
Gate 20	94,731	95,007	0.3	1305	1305	0.0	2,583	2,584	0.0
Gate 30	141,179	142,002	0.6	1955	1963	0.4	3,862	3,880	0.5
Gate 40	186,082	187,003	0.5	2534	2538	0.2	4,966	4,989	0.5
Gate 50	220,088	221,005	0.4	3070	3066	–0.1	5,994	6,011	0.3
Gate 60	260,702	262,005	0.5	3595	3596	0.0	6,949	6,982	0.5
Gate 70	306,076	307,002	0.3	4208	4206	0.0	8,207	8,234	0.3
Gate 80	348,547	350,005	0.4	4735	4734	0.0	9,180	9,227	0.5
Gate 90	386,337	388,005	0.4	5274	5253	–0.4	10,290	10,296	0.1
Terminal 2 (Gate 93)	398,334	400,000	0.4	5473	5447	–0.5	10,530	10,547	0.2
Gate 100	441,295	443,008	0.4	5925	5905	–0.3	11,680	11,705	0.2
Terminal 3 (Gate 104)	468,294	470,000	0.4	6169	6144	–0.4	12,130	12,146	0.1
Terminal 4 SST Total	**798,294**	**800,000**	**0.2**	**8779**	**8758**	**–0.2**	**19,000**	**19,019**	**0.1**
Segment 1	398,334	400,000	0.4	5473	5447	–0.5	10,530	10,547	0.2
Segment 2	69,960	70,000	0.1	696	697	0.1	1,600	1,599	–0.1
Segment 3	330,000	330,000	0.0	2610	2614	0.2	6,870	6,873	0.0

straight and flat route and along the SST route. Table 45 summarizes the trip times and LSM energy consumption for these cases.

Figure 112 shows the speed profiles for each system along the 40-km straight and flat route. The SCDs all have much higher thrust/weight ratios than TR07, resulting in shorter distances (and times) to reach cruise speed (see also Table 45).

Figure 113 shows the speed profiles for the TR07 and Bechtel vehicles along the SST route. Results for the other SCDs are similar to the Bechtel results. The SCDs have the largest performance advantage along segment 1 (closely spaced curves) where their higher speed gates and greater acceleration capabilities result in much higher average speeds (see also Table 45). Figure 114 shows in more detail the speed profiles for

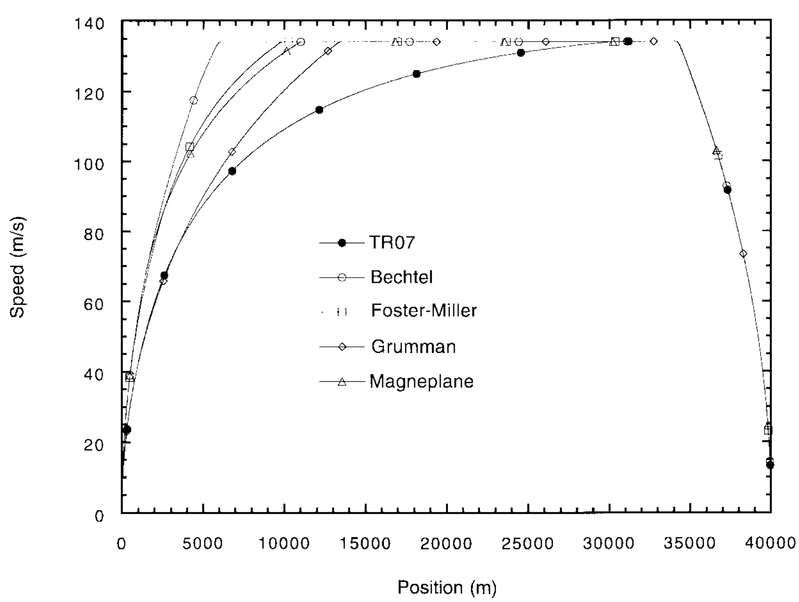
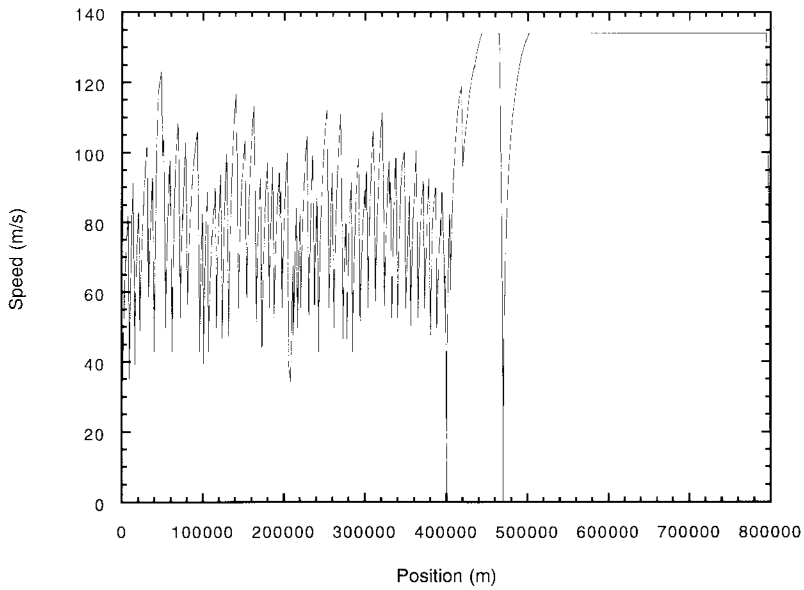


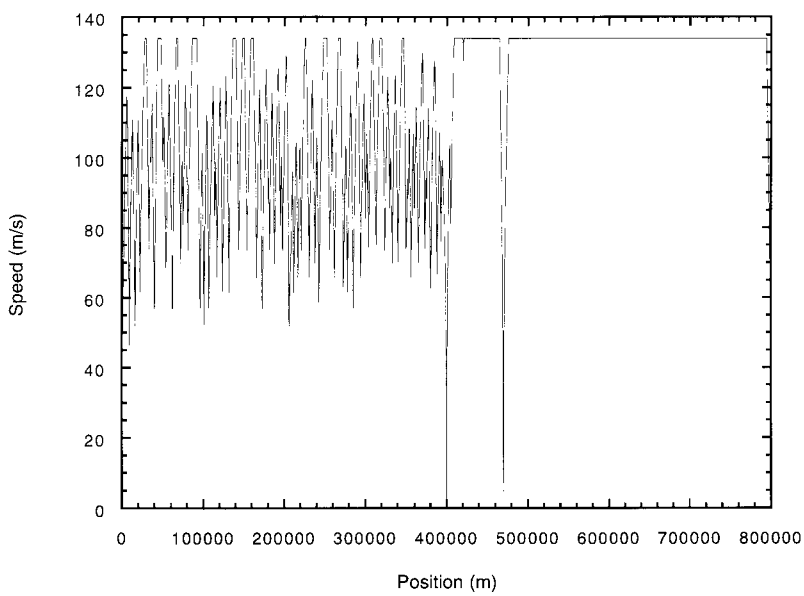
Figure 112. Speed profiles for TR07 and the four SCDs along a 40-km straight and flat route.

TR07 and Bechtel for the first 100 km of the SST. TR07's lower speed gates and lower maximum speeds between curves show more clearly (note that the speed gates for the two systems are equal only for vertical curves). As shown in Figure 115, TR07's longer acceleration periods at peak thrust cause its energy consumption to be higher for the same distance covered, even though its peak power is much lower than Bechtel's.

Table 46 compares the performance of the SCDs against that of TR07 for travel along the 40-km straight and flat and SST routes. Energy intensity (EI) is the electrical energy consumed by a system (i.e., the energy supplied by an electrical utility) to move a standard passenger 1 m along the given route section. Normalization by standard passengers (SP = 0.80 m^2 of vehicle floor area) corrects for differences in vehicle interior space allocated



a. TR07.



b. Bechtel vehicle.

Figure 113. Speed profiles along SST route.

Table 45. SSTSIM results for TR07 and SCDs along 40-km straight and flat and SST routes. TR07-24° is TR07 with 24° total bank angle (other characteristics unchanged). SST segment 1 is between terminals 1 and 2 (rugged terrain), SST segment 2 is between terminals 2 and 3 (rolling hills), and SST segment 3 is between terminals 3 and 4 (straight and nearly flat).

Item	*TR07*	*Bechtel*	*Foster-Miller*	*Grumman*	*Magneplane*	*TR07-24°*
Time (s)						
0–134 m/s straight and flat	318	89	123	182	133	318
40 km straight and flat	436	386	392	424	393	436
SST segment 1	5,318	4,244	4,359	4,669	4,399	4,762
SST segment 2	755	626	634	654	631	671
SST segment 3	2,607	2,555	2,558	2,596	2,563	2,607
SST total	8,680	7,425	7,551	7,919	7,593	8,040
LSM energy (kWh)						
0–134 m/s straight and flat	852	314	293	397	426	852
40 km straight and flat	930	736	629	614	698	930
SST segment 1	10,159	8,938	7,221	7,304	7908	9,492
SST segment 2	1,546	1,207	1,060	942	1,067	1,527
SST segment 3	6,606	5,095	4,649	3,679	4,138	6,607
SST total	18,311	15,240	12,930	11,925	13,113	17,626

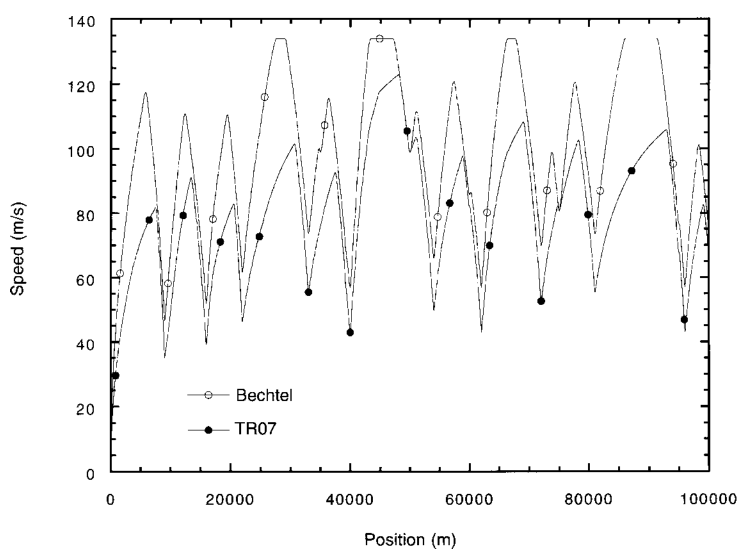


Figure 114. Speed profiles for TR07 and Bechtel vehicle along first 100 km of SST route. Symbols are spaced at 100-s intervals.

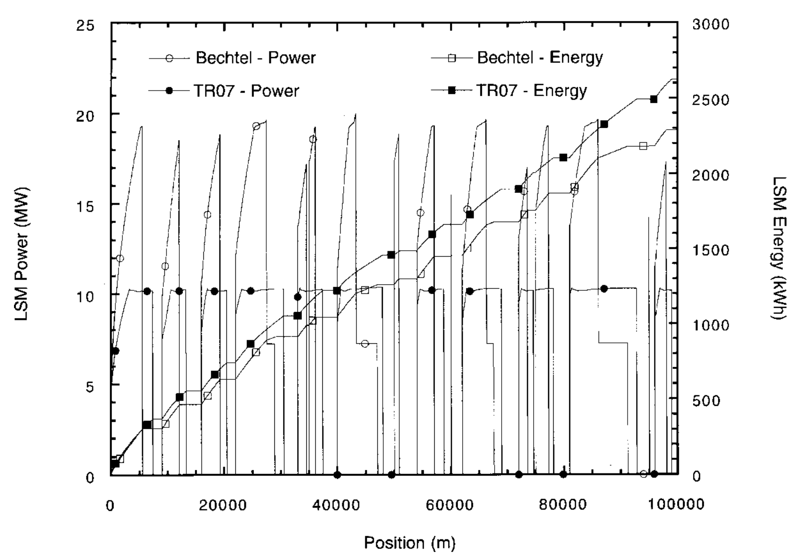


Figure 115. LSM power and energy consumption for TR07 and Bechtel vehicle along first 100 km of SST route. Symbols are spaced at 100-s intervals.

Table 46. Trip times and energy intensities, normalized by results for TR07. Energy intensities include losses through the converter stations.

Item	*TR07*	*Bechtel*	*Foster-Miller*	*Grumman*	*Magneplane*	*TR07-24°*
Standard passengers (SP)	162	106	137	116	108	162
Converter efficiency	0.95	0.90	0.94	0.95	0.95	0.95
Energy intensity (J/SP-m)						
40 km straight and flat	544	694	440	502	612	544
SST segment 1	594	843	505	597	694	555
SST segment 2	517	651	423	440	535	510
SST segment 3	468	583	394	364	440	468
SST total	535	719	452	487	575	515
Time SCD/TR07						
40 km straight and flat	—	0.89	0.90	0.97	0.90	1.00
SST segment 1	—	0.80	0.82	0.88	0.83	0.90
SST segment 2	—	0.83	0.84	0.87	0.84	0.89
SST segment 3	—	0.98	0.98	1.00	0.98	1.00
SST total	—	0.86	0.87	0.91	0.87	0.93
Energy intensity SCD/TR07						
40 km straight and flat	—	1.28	0.81	0.92	1.13	1.00
SST segment 1	—	1.42	0.85	1.00	1.17	0.93
SST segment 2	—	1.26	0.82	0.85	1.04	0.99
SST segment 3	—	1.24	0.84	0.78	0.94	1.00
SST total	—	1.34	0.84	0.91	1.07	0.96

to each passenger. The estimated converter station efficiencies are consistent with those shown in section 3.3.2 and are independent of vehicle speed. They transform the LSM energy consumption calculated by SSTSIM into the energy supplied to the system by an electrical utility.

The SCDs develop the largest trip-time advantages over TR07 along segments 1 and 2 where, as mentioned, they maintain much higher average speeds. To investigate the relative importance of bank angle vs. acceleration capability, we simulated TR07 with an increase in its allowable bank angle to 24°, designated TR07-24°, while keeping its original LSM and vehicle-resistance characteristics. This change brings TR07 close to the performance of the Grumman concept (see Table 46), the SCD with the lowest baseline acceleration capability. For the twisty segment 1, higher bank angles and greater acceleration capabilities of the SCDs contribute roughly equally to their trip time advantages over TR07. Bank angle exerts proportionately more influence on trip time along the gently curved segment 2, while acceleration capability accounts for all of the modest advantage of the SCDs on the straight segment 3. Note that, except for Grumman, the DG ride comfort criterion of 24° used in these simulations limits the maximum bank angles (and hence the gate speeds) of the SCDs. Thus, three of the four concepts would achieve even greater trip-time advantages over TR07 under less conservative ride comfort criteria (e.g., MR, see Table 106). Bechtel and, to a lesser extent, Magneplane would further increase their trip-time advantages with a less restrictive longitudinal acceleration criterion.

The effects of higher average speeds (i.e., reduced trip time) on system energy intensity are more complicated. The major sources of energy loss are aerodynamic drag and LSM inefficiency at maximum thrust. Aerodynamic losses increase by the square of vehicle speed, so they increase with increasing average speed. Conversely, maximum-thrust LSM losses decrease with shorter acceleration times, because of either higher thrust:resistance ratios (see eq 21) or higher gate speeds. The 40-km straight and flat route, because it has no turns, reveals the benefit possible with higher thrust:resistance ratios—two of the SCDs (Foster-Miller and Grumman) have lower energy intensities than TR07 despite having higher average speeds. The SST results for TR07-24° demonstrate the energy benefit of higher gate speeds. Even with the same LSM, reduced acceleration losses from higher gate speeds can more than compensate for increased aerodynamic losses from higher average speed

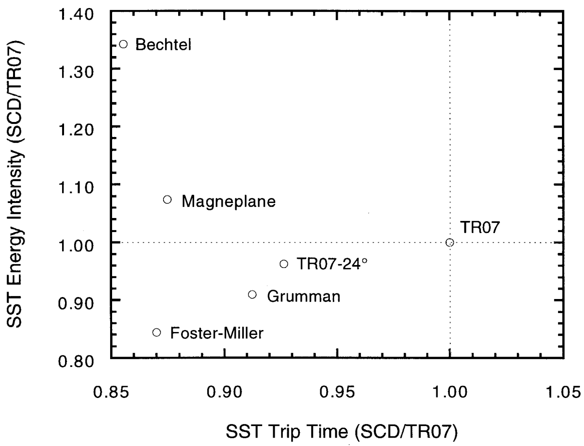


Figure 116. SST total trip time vs. energy intensity for each SCD and TR07-24°, normalized by the corresponding value for TR07.

(see Table 113a). Eventually, however, increasing average speed will lead to increased energy intensity (e.g., Bechtel) because of higher aerodynamic losses. The exact break-even point depends on the vehicle and LSM design, and the characteristics of a particular route.

Figure 116 summarizes the potential real-world performance advantages of the SCDs compared with TR07. Normalized by the values for TR07, the figure shows SST energy intensity vs. trip time for each SCD. Notice that all SCD systems traverse the SST route much faster than TR07. In addition, two of the SCD's (Foster-Miller and Grumman) achieve shorter SST trip times *and* lower energy intensities than TR07. Increasing the total bank angle of TR07 to 24° (which would require a major redesign of the TR07 vehicle and guideway) reduces but does not eliminate the performance advantages of the SCDs. That is, larger bank angles and higher thrust:resistance ratios both contribute to the superior performance of the SCDs, and this combination represents an important design advantage of a U.S. maglev system optimized for typical U.S. routes.

Guideway offset requirements

As noted earlier, SSTSIM does not include features needed to design guideway spiral transitions for horizontal curves. However, MPS has this feature, and we used it to determine the offset of an actual guideway path (with a transition spiral) to that of a circular curve radius without a transition section.

Recall that a segment of circular arc at the specified minimum radius is required for each SST curve. Transition spirals allow for smooth changes between tangent sections (infinite radius) and the required curve radius, and can be designed to satisfy the secondary ride comfort criteria. However, transition spirals offset the guideway towards the center of curvature and away from the PI (Point of Intersection), and these offsets alter ROW geometries. Figure 117 shows a 400-m-radius curve with change in azimuth of 40°. The PI is 9000 m from the last PI. The extent of the 400-m-radius circular arc is indicated by the two radial lines from the center to the points of tangency of the straight tangent sections. The spiral transition displaces the circular arc about 5 m toward the center of curvature; the transition begins 102 m before the circular arc.

Similarly, Figure 118 shows curves of different radii, each with a change in azimuth of 20°. By including spiral transitions, each curve's required circular arc moves inward a distance that depends on the curve's radius. Thus, the guideway offset for a 500-m-radius, 20° curve is approximately 2 m. If the radius were increased to 700 m, the off-

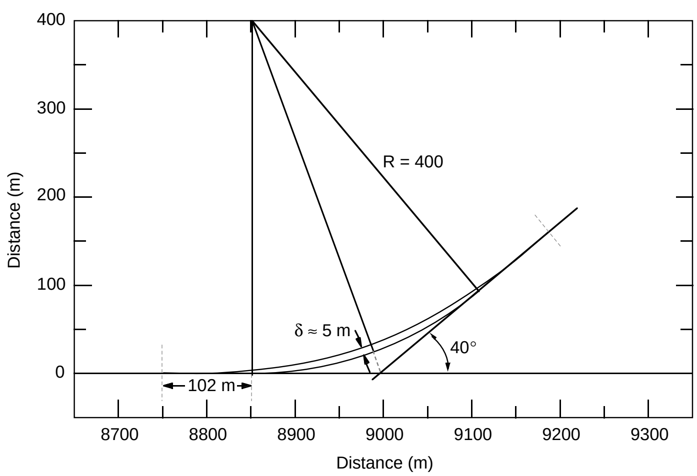


Figure 117. Offset difference between 400-m radius curve and spiral.

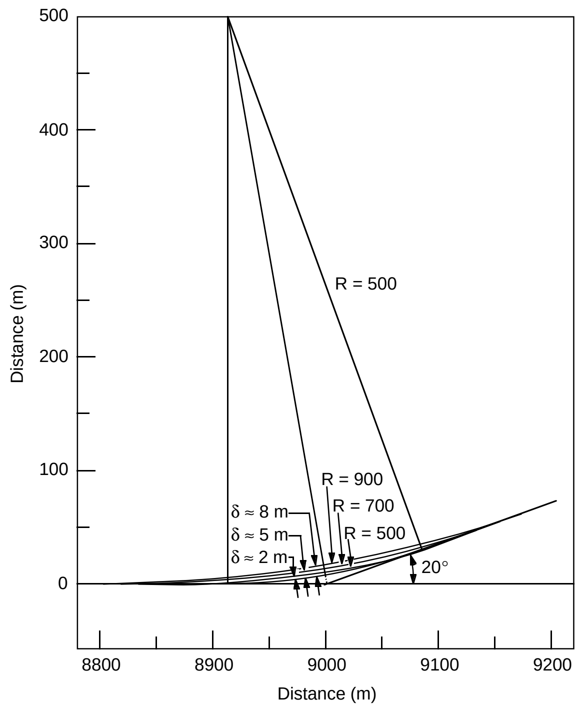


Figure 118. Offset difference for spiral curves, 500–900 m.

set would be 5 m. If it were further increased to 900 m, the offset would increase to 8 m. The associated speed through the curve, assuming 24° of total bank angle, is shown in Table 47. The difference in speed in percent from the 500-m case is shown as the percent difference from cruise speed (134 m/s). Reasonably large speed increases are possible for modest offsets (i.e., modest ROW deviations).

Typically, Interstate Highway ROWs are about 100 m wide and have 11–17 m on either side of the roadway. Although details of route alignment are site specific, there should be sufficient latitude to accommodate the small offsets resulting from spiral transitions. Furthermore, there may be instances where the radius of curvature can be increased, with an associated increase in speed. On the other hand, there may also be instances where planners are so constrained as to require the acquisition of some additional land. These results indicate that land acquisition, if needed, is likely to be on a small scale.

Table 47. Guideway offset and SCD vehicle speed for a 20° turn using spiral transitions. Offset is measured relative to simple circular curve.

R (*m*)	*Offset* (*m*)	V (*m/s*)	*Δ*V/V$_{500m}$ (*%*)	V/*134 m/s* (*%*)
500	2	52.1	—	39
700	5	61.7	18	46
900	8	69.9	34	52

Conclusions

We developed software, SSTSIM, to simulate the motion of maglev vehicles along prescribed routes to examine how technological characteristics translate into system characteristics that affect ridership and costs. Inputs to SSTSIM include route specifications, ride comfort criteria, and the system-dependent vehicle and LSM performance data. For the SST route traversed under DG conditions, the primary ride comfort criteria governing vehicle motion are lateral acceleration in horizontal or combined curves, vertical acceleration in vertical curves, and longitudinal acceleration–braking and longitudinal jerk during speed changes. Comparison of the results of SSTSIM with the previous GMSA model, MPS, confirmed the validity of this approach.

We used SSTSIM to compare the performance of TR07 and the four SCDs along a 40-km straight and flat route and along the SST route. These simulations revealed that, compared with TR07, the larger bank angles of the SCDs combined with higher LSM thrust-to-vehicle resistance ratios can yield shorter trip times *and* lower energy intensities. This remarkable result occurs because higher gate speeds (larger bank angle) and more efficient acceleration (higher thrust:resistance ratios) produce energy savings that more than compensate for the increased aerodynamic losses associated with shorter trip times. This combination of shorter trip time and lower energy intensity constitutes an important performance advantage that could result by designing the technological characteristics of a U.S. maglev system to satisfy the requirements of typical U.S. routes.

3.3.2 Guideway cost estimates*

Background

The guideway, with its critical support, propulsion, and control functions, will be the most expensive part of a maglev system. For this reason, the GMSA team developed its own guideway cost estimates for TR07 and the four SCD con-

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* Written by Richard Suever and Dr. John Potter, U.S. Army Engineer Division, Huntsville

cepts. We drew heavily on the Corps of Engineers' experience with costing of civil structures and advanced military technologies to develop these estimates.

The guideway cost estimates prepared by the SCD contractors did not allow for easy comparison among them. The estimating approach varied widely by contractor. Variances resulted from different guideway heights, different unit prices for similar commodities, nonuniform allocation of components into subsystems, missing items, and differences in the application of contingencies, overhead, and profit factors.

The inconsistencies in the estimates, particularly in the allocation of design components into subsystems, had a significant effect on the cost model developed by the Volpe National Transportation Systems Center (VNTSC). To obtain the capital cost of a maglev system for a particular corridor, the model takes the length along the alignment and multiplies it by the unit cost for each subsystem. The results obtained from the model are useful in comparing the different concepts in terms of total costs.

A problem arose when the contractors did not uniformly allocate design components to subsystems. For example, the guideway beam subsystem may only consist of the structural elements in one contractor's estimate; it may include magnetic components that are attached to the guideway in another's; and it may include power distribution in a third. Clearly, each subsystem must consist of the same components to compare costs across concepts.

An effort was undertaken by the Government to rework the guideway cost estimates so that the different technologies could be equivalently compared. The specific objectives of the effort were to:

- Compare estimates based on a common set of parameters, such as guideway height.
- Provide an independent assessment of the SCD estimates.
- Develop a standard method of allocating components into subsystems.
- Develop unit costs for each subsystem in each concept for use in VNTSC's cost model.

Note that the total construction cost of a maglev system includes many items that are not dependent on the technology chosen. Such technology-independent items include ROW, site preparation, fencing, stations, central control facility, maintenance facilities, etc. The cost of these items may be estimated reliably using standard practices. Here, we focused on the technology-dependent costs of each guideway concept. The resulting estimates are only about one-third of the total construction cost of each system. Also, we did not estimate vehicle costs for each concept. We did not have the necessary expertise in aerospace construction, and vehicles do not represent a cost related to the length of the guideway. VNTSC's cost model is specifically designed to estimate total maglev system costs, including total construction cost. For its technology-dependent guideway costs, it uses the subsystem unit costs developed here.

Procedure

The guideway cost estimates prepared by the Government were based on the following:

- It is an 11-m-high, dual guideway.
- Consistent unit costs were applied.
- No site work or fencing was included in the costs.
- No high voltage power distribution was included.
- No markups, contingencies, or profits were included.

The unit costs used for each component are an all-inclusive number that takes into account manufacturing, transportation, and installation, unless otherwise noted. The unit costs for the guideway structure and the electrical systems are from standard cost estimating manuals (Walter 1991). These unit costs were adjusted on the basis of Corps of Engineers experience to reflect unusual construction techniques or materials.

The components were allocated to subsystems as follows:

- *Guideway structure*—This subsystem consists only of the structure itself, i.e., the footings, columns, and girders. For Magneplane, the aluminum levitation sheets are included in this item because they are also structural members. In the case of the TR07, the guideway structure includes the steel sliding surface used for emergency braking.
- *Magnetic components*—This subsystem includes the motor windings, coils, stator packs, and guidance rails. In the case of Grumman, we included both the thick and thin laminated rails in this subsystem, even though the thick rail also serves as a structural component.
- *Guideway power distribution*—This subsystem includes the power components between the rectifier, inverter, or converter station, and

the magnetic components on the guideway. This includes primarily the distribution cable and the grounding system. For the Foster-Miller concept, the LCLSM switches are included in this item because they are located on the guideway.

- *Wayside control and communication*—This item is taken directly from the VNTSC model. It includes wayside installations and connections to the central control facility. Although the uniform application of this unit cost to all concepts makes it a technology-independent item, it does represent a significant cost directly related to the guideway.
- *Power stations*—This subsystem includes all of the components in the rectifier, inverter, or converter stations, depending upon the technology. The estimate includes the transformer at the end of the high voltage distribution line. The high voltage distribution line is not included.

The cost estimates reflect the baseline designs as described in the SCD reports. No attempt was made to optimize the designs provided by the SCD contractors. The quantities of materials in the guideway structure have been adjusted for the 11-m height, depending upon the baseline guideway height.

Results

The cost estimates prepared by the Government for each concept are shown in the following tables. Tables 48–51 show the detailed cost breakdown by component for Magneplane, Grumman, Foster-Miller, and Bechtel. Table 52 shows the cost breakdown for TR07. The cost information for the TR07 was taken primarily from the information in the Cal-Nev proposal (City of Las Vegas 1987). The quantities shown in the tables are for a 1-km length of guideway. This information has been summarized at the subsystem level in Table 53a.

In addition, the estimated cost of each concept for an at- or on-grade guideway was prepared so that the SCD concepts and TR07 could be compared to the TGV in the VNTSC model. The Grumman and TR07 concepts require a near- or at-grade guideway because of the wraparound configuration of the vehicle. The guideway for the other concepts can be placed directly on a soil or crushed stone subgrade. The summary of the at- or on-grade guideway cost by subsystem is shown in Table 53b.

The difference in cost between the elevated and at- or on-grade systems is in the guideway structure itself. We assumed that the other subsystem costs were independent of height. The footings, columns, and cross beams were eliminated for the Magneplane, Foster-Miller, and Bechtel designs. Minimum height columns of 0.92 m (3 ft) were used in the Grumman and TR07 concepts. In addition, we decreased the size of the guideway beams and the quantity of reinforcing because an on-grade beam will be uniformly supported by a soil or stone subgrade, providing much of the required stiffness. In the case of Grumman, the spacing of the columns was decreased to 4.6 m (15 ft) as described in the final SCD report.

The TR07 at-grade guideway cost is based on the at-grade section shown in the Cal-Nev proposal. The span length for this section was reduced to 12.34 m (40.50 ft). The higher cost of this at-grade guideway compared with the U.S. concepts reflects the tighter construction tolerances required for the TR07.

U.S. maglev cost estimate

We attempted to estimate the technology-related costs of a U.S. maglev system that might result from further development, despite the difficulty that such an estimate poses. This is useful to efforts by the NMI and others to forecast the market performance of maglev in the U.S.

Clearly, significant concept-related differences exist in the technologies that could be used in a U.S. maglev system. Despite this, relatively little variation exists among subsystem-level costs for the SCD concepts. With a couple of important exceptions (discussed below), it appears that the broadly defined functions of these subsystems generally govern their costs. Thus, by excluding exceptional cases, we may estimate the cost of a U.S. maglev system by averaging the subsystem costs of the SCD concepts. The resulting estimated cost of a “U.S. maglev” is shown in Table 53.

The two exceptional cases are the Foster-Miller and Magneplane concepts. For both elevated and at-grade U.S. maglev systems, we did not average in the cost of the Foster-Miller guideway magnetics, power distribution, and power substation costs. The innovative Foster-Miller LCLSM requires use of components that are very expensive at present (i.e., the inverters). Foster-Miller could use a more conventional approach and bring the cost of these subsystems closer to those of the other concepts; alternatively, the cost reductions Foster-Miller anticipates for mass production of

Table 48. Magneplane system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
FOOTING/COLUMN/COLUMN CAP					
Concrete (27.58MPa (4000psi))					Adjusted to 11 m height.
Footing	cu. yds.	4,603	$152.00	$699,656	
Column	cu. yds.	1,458	$477.00	$695,466	
Column Cap	cu. yds.	3,239	$530.00	$1,716,670	
Reinforcement (Assumed 60 ksi rebar)	lbs.	1,286,000	$0.75	$964,500	
TROUGH (Span length 9.23m (30 ft.))					
Aluminum Rail (6061 Aluminum)	tons	834	$8,520.00	$7,105,680	Inc. material, fabrication, delivery & erect.
Alignment (Dual Guideway)	km	2	$4,900.00	$9,800	Based on $1.50 per ft. (Magneplane Est.)
SUBTOTAL GUIDEWAY STRUCTURE	km			$11,191,772	
GUIDEWAY MAGNETICS					
LSM WINDING					
Propulson Coil (1000 MCM,15kV, Copper).	ft.	205,920	$10.00	$2,059,200	
Coil Installation (Materials)	lot	1	$205,920	$205,920	10% of Materials Cost (FRP).
Coil Installation (Labor)	ft.	205,920	$2.86	$588,931	
SUBTOTAL GUIDEWAY MAGNETICS	km			$2,265,120	
GUIDEWAY POWER DISTRIBUTION					
LIGHTNING PROTECTION (Inc. Grounding)	lot	1	$15,000.00	$15,000	
GUIDEWAY POWER					
Guideway Cable (1000 MCM,15kV, Aluminum, Shielded, Tri-plex)	ft.	14,000	$27.00	$378,000	
Cable Tray (4" by 18", Aluminum, Covered)	ft.	1,650	$15.76	$26,004	Inc. Installation and Supports.
TOTAL FOR GUIDEWAY POWER	km			$419,004	

Table 48 (cont'). Magneplane system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
WAYSIDE CONTROL & COMMUNICATION					
SUBTOTAL FOR WAYSIDE CONTROL & COMMO	m			$870	PARSONS BRINKERHOFF MODEL
SUBTOTAL PER KM	km			$869,565	
POWER SUBSTATION AND CONVERTER COST					
34.5 kV SERVICE					
Gang Operated Switch	ea	2	$10,300.00	$20,600	
Conduit (4 in. Galvanized)	lf	200	$30.50	$6,100	
Cable (500 MCM, 34.5 kV, EPR)	lf	600	$10.10	$6,060	
Capacitors - Equipment	mvar	9.6	$3,340.00	$32,064	
Capacitors - Installation	mvar	9.6	$400.00	$3,840	
34.5 kV Switchgear - Equipment	ckt	9	$50,000.00	$450,000	
34.5 kV Switchgear - Installation	ckt	9	$520.00	$4,680	
CONVERTER CIRCUITS					
6 MVA Transformer - Equipment	ea	4	$59,000.00	$236,000	
6 MVA Transformer - Installation	ea	4	$1,040.00	$4,160	
6 MW Converter - Equip. (inc. input transformer)	ea	4	$578,000.00	$2,312,000	
6 MW Converter - Install. (inc. input transformer)	ea	4	$3,000.00	$12,000	
15kV Switchgear - Equipment	ckt	4	$25,000.00	$100,000	
15kV Switchgear - Installation	ckt	4	$520.00	$2,080	
Conduit (4 in. Galvanized)	lf	400	$30.50	$12,200	
Cable (#1/0 AWG, 34.5 kV, EPR)	lf	1500	$5.55	$8,325	
Bus Duct (1200 amp, 5 kV)	lf	100	$2,000.00	$200,000	
Guideway Winding Switch - Equipment	ea	4	$15,000.00	$60,000	
Guideway Winding Switch - Installation	ea	4	$800.00	$3,200	
Cable (3 - 1/0, 500 MCM, 15 kV, Tri-plex)	ft.	30000	$28.00	$840,000	
Cable Tray (24 in. Aluminum Ladder)	ft.	15000	$15.80	$237,000	
Capacitors, Switched - Equipment	mvar	172.8	$3,500.00	$604,800	
Capacitors, Unswitched - Equipment	mvar	172.8	$4,000.00	$691,200	
Capacitors - Installation	mvar	345.6	$400.00	$138,240	
SUBSTATION (480V)	ea	1	$65,000.00	$65,000	Equipment and Installation
MATCHING TRANSFORMER (Special 2500 V, 6 MVA)	each	4	$73,000.00	$292,000	Concept Specific

Table 48 (cont'd).

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
BYPASS BREAKERS	each	4	$31,000.00	$124,000	Concept Specific
BUILDING					Rectifiers and Inverters Inside
Structure (Concrete Block)	sf	5500	$55.00	$302,500	
Equipment Cooling	lot	1	$274,000.00	$274,000	
UPS System (5 KVA)	ea	1	$17,000.00	$17,000	
SECURITY LIGHTING	lot	1	$10,000.00	$10,000	
GROUNDING	lot	1	$10,000.00	$10,000	
SUBTOTAL FOR CONVERTER STATION				$7,079,049	
SUBTOTAL PER KM (SUBTOTAL/8km)	km			$884,881	
COST SUMMARY					**PERCENT**
SUBTOTAL GUIDEWAY STRUCTURE				$11,191,772	71.60
SUBTOTAL GUIDEWAY MAGNETICS				$2,265,120	14.49
SUBTOTAL FOR GUIDEWAY POWER				$419,004	2.68
SUBTOTAL FOR WAYSIDE CONTROL & COMMAND				$869,565	5.56
SUBTOTAL FOR CONVERTER STATION				$884,881	5.66
TOTAL GUIDEWAY (PER KM)				$15,630,342	100.00
TOTAL GUIDEWAY (PER MILE)				$25,169,633	

Table 49. Grumman system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
GUIDEWAY STRUCTURE					
FOOTING (Cast in Place)					
Concrete (41.37 MPa (6000psi))	cu. yd.	1189	$152.00	$180,728	Adjusted to 11 m. height.
Reinforcement, Conventional (Assumed 60 ksi)	lbs	314635	$0.75	$235,976	
H-Piles, HP-14 (14 X 117)	ft.	10920	$32.04	$349,877	
COLUMN (Cast in Place)					
Concrete (41.37 MPa (6000psi))	cu. yd.	1190	$477.00	$567,630	
Reinforcement, Conventional (Assumed 60 ksi))	lbs	236428	$0.75	$177,321	
BEAM BEARING PAD (4 per span)	ea	148	$750.00	$111,000	
GIRDER SYSTEM (Precast)					
Box Girder (27.5m (90 ft) span)					
Concrete (55.16 MPa (8000 psi))	cu. yd.	4138	$530.00	$2,193,140	
Reinforcement (Assumed 60 ksi steel)					
Conventional	lbs	596895	$0.75	$447,671	
Prestressed	lbs	230447	$2.91	$670,601	
SUBTOTAL GUIDEWAY STRUCTURE	km			$4,933,944	
GUIDEWAY MAGNETICS					
LAMINATED RAIL (2.3m (7.5 ft) span)					
Thick laminations	lbs	1541696	$0.90	$1,387,526	
Thin laminations	lbs	1194540	$0.90	$1,075,086	
BRAKE RAIL	lbs	99672	$0.80	$79,738	
STATOR CABLE (600 MCM, 5 kV, Alumnium)	ft	138000	$6.00	$828,000	
Stator Cable Installation (Material)	lot	1	$41,400.00	$41,400	5% of Material Cost.
Stator Cable Installation (Labor)	ft	138000	$1.60	$220,800	
SUBTOTAL FOR GUIDEWAY MAGNETICS	km			$3,632,550	

Table 49 (cont'd). Grumman system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
GUIDEWAY POWER					
POWER DISTRIBUTION					
Feeder Cable (1500 MCM, 5 kV, Aluminum, Single Phase)	ft	19600	$10.40	$203,840	
Feeder Cable Installation (Materials)	lot	1	$6,115.20	$6,115	3% of Material Cost.
Cable Tray (6"x24", Aluminum, covered)	ft	3300	$26.85	$88,605	
LIGHTNING PROTECTION (INC GROUNDING)	Lump Sum	1	$15,000.00	$15,000	
SUBTOTAL FOR GUIDEWAY POWER	km			$313,560	
WAYSIDE CONTROL & COMMUNICATION					
SUBTOTAL FOR WAYSIDE CONT. & COMMO	m			$870	Parsons Brinckerhoff Cost Model
SUBTOTAL PER KM	km			$869,565	Parsons Brinckerhoff Cost Model
INVERTER STATION					
EQUIPMENT UNIT					
Transformer (34.5-8.5 kV, 15 MVA)	ea	1	$143,000.00	$143,000	
Circuit breaker (35 kV, 300 amp, 3 phase)	ea	1	$33,000.00	$33,000	
Surge arrestor (34.5 kV, 3 Pole, with isolation switch)	ea	1	$5,000.00	$5,000	
Capacitor (2.4 MVAR, 8.5 kV, 3 phase)	mvar	2.4	$4,000.00	$9,600	
Metal Clad Switch Gear (10 kV)					
Surge arrestor (10 kV, 3 Pole)	ea	2	$5,000.00	$10,000	
Input circuit breaker (1200 amps, 3 pole)	ea	2	$32,000.00	$64,000	
Metal Clad Switch Gear (5 kV)	ea	2	$23,000.00	$46,000	
Input circuit breaker (1200 amps, 3 pole)	ea	2	$32,000.00	$64,000	
Tie breaker (3 pole)	ea	1	$23,000.00	$23,000	
Capacitor (3MVAR, 2100 V, 3 pole)	ea	6	$4,000.00	$24,000	
Capacitor switch (800 amp, 3 pole)	ea	2	$23,000.00	$46,000	
Resister Load Bank (7.5 MVA)	ea	2	$50,000.00	$100,000	
Resister Switch (5 kV, 2000 amp, air, CB)	ea	2	$29,000.00	$58,000	
Output Circuit Breaker (1200 amp, 3 pole)	ea	2	$32,000.00	$64,000	
RECTIFIER/INVERTER (12-pulse,7.5mva plus constant current inverter 2300v output. VVVF)	each	2	$1,610,000.00	$3,220,000	

Table 49 (cont'd). Grumman system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
STATOR SWITCHES (1200 amps, 5000 V, 3 pole, WP)	each	4	$32,000.00	$128,000	
SUBSTATION (480 V, double-ended)	ea	1	$65,000.00	$65,000	Equipment and Installation
BUILDING					Rectifiers and Inverters Inside.
Structure (Concrete Block)	sf	5500	$55.00	$302,500	
Equipment Cooling	lot	1	$161,000.00	$161,000	
UPS System (5 KVA)	ea	1	$17,000.00	$17,000	Assumed Size - Not in SCD Estimate.
GROUNDING	lot	1	$10,000.00	$10,000	
SECURITY LIGHTING	lot	1	$10,000.00	$10,000	
SUBTOTAL FOR INVERTER STATION				$4,603,100	Per Direction
SUBTOTAL FOR DUAL GUIDEWAY				$9,206,200	
SUBTOTAL PER KM (SUBTOTAL/8km)	km			$1,150,775	
COST SUMMARY					
					PERCENT OF TOTAL:
SUBTOTAL GUIDEWAY STRUCTURE	km			$4,933,944	45.26
SUBTOTAL GUIDEWAY MAGNETICS	km			$3,632,550	33.32
SUBTOTAL FOR GUIDEWAY POWER	km			$313,560	2.88
SUBTOTAL FOR WAYSIDE CONTROL & COMMO	km			$869,565	7.98
SUBTOTAL FOR INVERTER STATION	km			$1,150,775	10.56
TOTAL GUIDEWAY (PER KM)				**$10,900,394**	100.00
TOTAL GUIDEWAY (PER MILE)				**$17,552,970**	

Table 50. Foster-Miller system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
GUIDEWAY STRUCTURE					
FOOTING/COLUMN/COLUMN CAP					Adjusted to 11 m. height.
Concrete (20.69MPa (3000 psi))					
Footing	cu. yds.	1,100	$152.00	$167,200	
Column	cu. yds.	2,297	$477.00	$1,095,669	
Reinforcement (Assumed 60 ksi rebar)	lbs.	394,283	$0.75	$295,712	
BEAM BEARING PADS (4 per Span)	ea.	74	$760.00	$56,240	Unit Cost per Single Span.
GIRDER (Span length 27m (88 ft.))					
Concrete (55.16MPa (8000 psi))	cu. yds.	6,280	$530.00	$3,328,400	
Reinforcement(Assumed 60ksi)					
prestressed	lbs.	140,240	$2.91	$408,098	
FRP(fiberglass reinforcement)					
Post tensioned	lbs.	48,100	$6.00	$288,600	
SUBTOTAL GUIDEWAY STRUCTURE	km			$5,639,920	
GUIDEWAY MAGNETICS					
PROPULSION					
Propulson Coil	each	4,652	$225.00	$1,046,700	FRP incl. in Cost of Coils.
Coil Installation (Materials)	lot	1	$31,401	$31,401	3% of Material Cost (Incl. bolts, brackets, etc).
Coil Installation (Labor)	each	4,652	$25.00	$116,300	
LEVITATION & GUIDANCE					
Figure 8 Coil (copper, FRP matrix)	each	3,077	$1,140.00	$3,507,780	FRP incl. in Cost of Coils.
Figure 8 Coil Installation (Materials)	lot	1	$105,233	$105,233	3% of Material Cost (Incl. bolts, brackets, etc).
Figure 8 Coil Installation (Labor)	each	4,652	$50.00	$232,600	
CROSS CONNECT. CABLE (1/0, Cu, 5 kV, 40 ft. ea.)	ft.	186,080	$3.32	$617,786	
SUBTOTAL FOR GUIDEWAY MAGNETICS	km			$5,657,800	

Table 50 (cont'd). Foster-Miller system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
GUIDEWAY POWER DISTRIBUTION					
GUIDEWAY POWER					
DC Bus (Copper, 2.6 in. diam.)	lb.	267,976	$2.25	$602,946	
Cable Tray (6" X 30", Aluminum, Covered)	lf	3,300	$33.36	$110,088	
Disconnect Tap	each	4,652	$30.00	$139,560	
Sectional Sizing Switch (8000 amps, 2pole)	each	1	$33,000.00	$16,500	One per each 2km of track; not commercially available.
LIGHTNING PROTECTION (INC. GROUNDING)	lot	1	$15,000.00	$15,000	
INVERTER (311 kV, 1410 V, 221 amp)	each	2,326	$1,000.00	$2,326,000	
SUBTOTAL FOR GUIDEWAY POWER	km			$3,210,094	
WAYSIDE CONTROL & COMMUNICATION					
SUBTOTAL FOR WAYSIDE CONT. & COMMO	m			$870	Parsons Brinckerhoff Cost Model
SUBTOTAL PER KM	km			$869,565	Parsons Brinckerhoff Cost Model
RECTIFIER STATION					
EQUIPMENT UNIT (Every 8 km)					
Transformer (40 MW,34.5 kV, w/auto tap changers)	each	2	$380,000.00	$760,000	
Oil Circuit Breaker (34.5 kV, 800 amp)	each	2	$40,000.00	$80,000	
Secondary Surge Arrester	each	6	$2,000.00	$12,000	
Circuit breaker (8 kV, 4500 amp)	each	2	$30,000.00	$60,000	Not commercially available in this size.
RECTIFIER (2100 V DC; output 60 MVA (40 MVA nominal))	each	2	$6,840,000.00	$13,680,000	Size and Input Voltage Not Given.
SWITCHGEAR-METAL CLAD (4.2 kV)	each	2	$45,000.00	$90,000	

Table 50 (cont'd)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
Switch (DC rating, 2900 amp, 2 pole)	each	6	$33,000.00	$198,000	Not available in this size.
Surge Arrester	each	6	$2,000.00	$12,000	
SUBSTATION (480 V, double ended)	lot	1	$65,000.00	$65,000	Equipment and Installation.
BUILDING					
Structure (Concrete Block)	sf	2000	$55.00	$110,000	Rectifiers Only.
Equipment Cooling	lot	1	$627,000.00	$627,000	
UPS System (5KVA)	ea	1	$17,000.00	$17,000	Assumed Size - Not in SCD Estimate.
GROUNDING	lot	1	$10,000.00	$10,000	
SECURITY LIGHTING	lot	1	$10,000.00	$10,000	
SUBTOTAL FOR RECTIFIER STATION				$15,731,000	
SUBTOTAL PER KM (SUBTOTAL/8KM)				$1,966,375	
COST SUMMARY					
					PERCENT OF TOTAL:
SUBTOTAL GUIDEWAY STRUCTURE	km			$5,639,920	32.52
SUBTOTAL GUIDEWAY MAGNETICS	km			$5,657,800	32.62
SUBTOTAL FOR GUIDEWAY POWER	km			$3,210,094	18.51
SUBTOTAL FOR WAYSIDE CONTROL & COMMO	km			$869,565	5.01
SUBTOTAL FOR RECTIFIER STATION	km			$1,966,375	11.34
TOTAL GUIDEWAY (PER KM)				**$17,343,754**	100.00
TOTAL GUIDEWAY (PER MILE)				**$27,928,750**	

Table 51. Bechtel system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
GUIDEWAY STRUCTURE					
FOOTING/COLUMN/COLUMN CAP					
Concrete (27.58MPa (4000psi))					Adjusted to 11 m. height.
Footing	cu. yds.	2,770	$152.00	$421,040	
Column	cu. yds.	1,080	$477.00	$515,160	
Cross beams	cu. yds.	800	$580.00	$464,000	
Reinforcement (Assumed 60 ksi conventional rebar)	lbs.	1,011,800	$0.75	$758,850	
BEAM BEARING PADS (4 per Span)	ea.	80	$360.00	$28,800	Unit Cost per Single Span.
GIRDER (Span length 25m (82 ft.))					
Concrete (69MPa (10,000 psi))	cu. yds.	3,348	$530.00	$1,774,440	
Reinforcement (Assumed 60ksi)					
Conventional	lbs.	39,690	$0.75	$29,768	
Prestress	lbs.	211,680	$2.91	$615,989	
FRP(fiberglass reinforcement)					
Post tensioned	lbs.	141,120	$6.00	$846,720	
Embedded	lbs.	130,100	$2.00	$260,200	
SUBTOTAL GUIDEWAY STRUCTURE	km			$5,714,966	
GUIDEWAY MAGNETICS					
LSM WINDING					
Propulson Coil (800 MCM,15 kV, Aluminum).	ft.	204,000	$5.36	$1,093,440	Length per Bechtel
Coil Installation (Materials)	lot	1	$109,344.00	$109,344	10% of Material Cost.
Coil Installation (Labor)	ft.	204,000	$1.81	$369,240	
VERTICAL LIFT LADDER, AL. (includes FRP)	Kg.	53,681	$25.50	$1,368,866	
NULL FLUX GUIDANCE COILS	ea.	6,153	$130.00	$799,890	FRP Frame Included.
Coil Installation (Materials)	lot	1	$39,994.50	$39,995	5% of Material Cost.
Coil Installation (Labor)	ea.	6,153	$25.00	$153,825	
SUBTOTAL FOR GUIDEWAY MAGNETICS	km			$3,934,599	

Table 51 (cont'd).

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
GUIDEWAY POWER DISTRIBUTION					
DC DISTRIBUTION (Direct burial, inc. trenching)					
Cable (2000 MCM, 15 kV, Copper, Single Conductor, 2-2000 MCM per pole.)	LF	13,800	$21.33	$294,354	
Cable (1000 MCM, 600 V, Aluminum, Single Conductor)	LF	3,500	$4.15	$14,525	
SPLICE VAULT	each	1	$1,000.00	$1,000	
LIGHTNING PROTECTION (INC. GROUNDING)	lot	1	$15,000.00	$15,000	
SUBTOTAL FOR GUIDEWAY POWER	km			$324,879	
WAYSIDE CONTROL & COMMUNICATION					
SUBTOTAL FOR WAYSIDE CONT. & COMMO	m			$870	Parsons Brinckerhoff Cost Model
SUBTOTAL PER KM	km			$869,565	Parsons Brinckerhoff Cost Model
RECTIFIER STATION					
EQUIPMENT UNIT (per 20 km of guideway)					
Transformer (3 phase, 34.5 kV, 50 MVA)	each	2	$476,000.00	$952,000	May not be in this size with low voltage secondary
69 kV Bus	each	1	$20,000.00	$20,000	
Oil Circuit Breaker (1000 amp, 3 pole)	each	4	$90,000.00	$360,000	
Surge Arrester (69 kV, 3 pole)	each	2	$10,000.00	$20,000	
HV Disconnect Switch (69 kV, 1000 Amps)	each	2	$15,000.00	$30,000	
Circuit Breaker (13.8 kV, 1000 amp, 3 pole)	each	4	$31,000.00	$124,000	Not shown in preliminary design.
Surge Arrester (3.8 kV, 3 pole)	each	2	$5,000.00	$10,000	Not shown in preliminary design.
Switchgear (25 kV, 2000 amp, DC bus)					See the following items.
Circuit Breakers (12 kV, DC, 4000 amp)	each	4	$110,000.00	$440,000	
Circuit Breaker (25 kV, 2000 amp, 3 pole)	each	2	$60,000.00	$120,000	
Circuit Breaker (12 kV, DC,1200 amp)	each	1	$31,000.00	$31,000	For load resister bank.
Lightning Arrestors	each	2	$5,000.00	$10,000	
Switchgear Controls	lot			$20,000	

Table 51 (cont'd). Bechtel system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
RECTIFIER (12 Pulse, +12 kV, -12 kV)	each	2	$4,000,000.00	$8,000,000	
LOAD BANK (8MW, 30 kV, IDC)	each	1	$100,000.00	$100,000	
SUBSTATION (480 V, Double-Ended)	each	1	$65,000.00	$65,000	
BUILDING					
Structure (Concrete Block)	sf	2700	$55.00	$148,500	Rectifiers and Load Banks Only.
Equipment Cooling	lot	1	$356,000.00	$356,000	
UPS System (5 KVA)	ea	1	$17,000.00	$17,000	Assumed Size - Not in SCD Estimate.
GROUNDING	lot	1	$10,000.00	$5,000	
SECURITY LIGHTING	lot	1	$10,000.00	$10,000	
SUBTOTAL FOR RECTIFIER STATION				$10,838,500	
SUBTOTAL PER KM (SUBTOTAL/20KM)				$541,925	
INVERTER STATION (per 4 KM)					
ISOLATION SWITCH (25 kV (L-L), 60 amp,1 pole)	each	4	$15,000.00	$60,000	
Fuse (25 kV, 800 amp) & holder	each	4	$13,000.00	$52,000	
Surge Arrester (12 kV, 1 pole)	each	4	$1,000.00	$4,000	
Inverter (var. volts & amps, 12 kV in, 12 kV out)	each	2	$2,000,000.00	$4,000,000	
SOLID STATE SWITCH (15 kV, 500 amp, 3 pole)	each	16	$8,000.00	$128,000	
SUBSTATION (480 V., Double-Ended)	each	1	$65,000.00	$65,000	
BUILDING					
Structure (Concrete Block)	sf	1500	$55.00	$82,500	Inverters Only.
Equipment Cooling	lot	1	$227,000.00	$227,000	
UPS System (5 KVA)	ea	1	$17,000.00	$17,000	Assumed Size - Not in SCD Estimate.

Table 51 (cont'd).

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
LIGHTNING PROTECTION	lot	1	$5,000.00	$5,000	
SECURITY LIGHTING	lot	1	$10,000.00	$10,000	
SUBTOTAL FOR INVERTER STATION				$4,650,500	
SUBTOTAL PER KM (SUBTOTAL/4km)	km			$1,162,625	
COST SUMMARY					
					PERCENT TOTAL:
SUBTOTAL FOR GUIDEWAY STRUCTURE	km			$5,714,966	45.54
SUBTOTAL FOR GUIDEWAY MAGNETICS	km			$3,934,599	31.35
SUBTOTAL FOR GUIDEWAY POWER	km			$324,879	2.59
SUBTOTAL FOR WAYSIDE CONTROL & COMMO	km			$869,565	6.93
SUBTOTAL FOR RECTIFIER STATION	km			$541,925	4.32
SUBTOTAL OF INVERTER STATION	km			$1,162,625	9.27
TOTAL GUIDEWAY (PER KM)				$12,548,560	100.00
TOTAL GUIDEWAY (PER MILE)				$20,195,024	

Table 52. TR07 system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
GUIDEWAY STRUCTURE					
FOOTING/COLUMN/COLUMN CAP					
Concrete (27.58MPa (4000psi))					
Footing	cu. yds.	1,960	$152.00	$297,920	
Column	cu. yds.	2,050	$477.00	$977,850	
Column Cap	cu. yds.	400	$530.00	$212,000	
Reinforcement (Assumed 60 ksi rebar)	lbs.	1,050,000	$0.75	$787,500	
Beam Bearing Pad (4 per span)	each	165	$750.00	$123,750	
GIRDER (Span Length 25m (82 ft))					
Concrete(37.92 MPa (5500 psi))	cu. yds.	3,650	$800.00	$2,920,000	Tight Construction Tolerances.
Reinforcement(steel)					
prestressed	lbs.	267,000	$2.91	$776,970	
conventional	lbs.	490,000	$0.75	$367,500	
SLIDING SURFACE PLATE	lbs.	415,000	$0.41	$170,150	
SUBTOTAL GUIDEWAY STRUCTURE	km			$6,633,640	
GUIDEWAY MAGNETICS					
GUIDANCE STATOR PACK CORE(laminated iron)	lbs.	1,758,500	$0.90	$1,582,650	
GUIDANCE RAIL	lbs.	847,220	$0.41	$347,360	
MOTOR COIL (600 MCM, 6 kV, CU, 1 conductor, 300 mm2)	ft.	88,715	$6.00	$532,290	
Coil Installation (Material)	lot	1	$26,614.50	$26,615	5% of Material
Coil Installation (Labor)	ft.	88,715	$1.70	$150,816	
SUBTOTAL GUIDEWAY MAGNETICS	km			$2,639,730	

Table 52 (cont'd).

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
GUIDEWAY POWER DISTRIBUTION					
FEEDER CABLE (1250 MCM, 6 kV, Aluminum)	ft.	53,000	$8.92	$472,760	
Feeder Cable Installation (Labor)	ft.	53,000	$2.83	$149,990	
CABLE TRAY (4"X12", Solid)	ft.	6,550	$20.90	$136,895	
LIGHTNING PROTECTION	lots			$15,000	
MOTOR VACUUM BKRS., 2000 A (Approx. 10 kV, WP)	each	4	$33,000.00	$132,000	
SUBTOTAL FOR GUIDEWAY POWER	km			$906,645	
WAYSIDE CONTROL & COMMUNICATION	m			$870	Parsons-Brinckerhoff Model
	km			$869,565	
SUBTOTAL FOR WAYSIDE CONTROL & COMMO	km			$869,565	
INVERTER STATION (Every 20KM)					
Disconnect Switch (69 kV)	each	2	$15,000.00	$30,000	
Transformer (50MVA, 60 kV)	each	2	$475,000.00	$950,000	
Transformer (25 MVA, Intermediate volt., 2 winding secondary, y & delta).	each	4	$305,000.00	$1,220,000	Current Split Into Two Directions.
Output Transformer (25 MVA, special).	each	4	$305,000.00	$1,220,000	
Switch (5000 amp, 5 kV, 3 pole)	each	2	$10,000.00	$20,000	
Switch (2500 amp, 5 kV, 3 pole)	each	4	$10,000.00	$40,000	
AC-AC Inverter, (25 MVA, 12 pulse)	each	4	$5,375,000.00	$21,500,000	
Output Circuit Bkr (3000 amp, AC)	each	8	$7,000.00	$56,000	
Misc. Bus (high voltage)	lot			$20,000	
Surge Arrestor (69 kV, 3 pole)	each	2	$10,000.00	$20,000	
HV Feeder Breaker (480 V, 100 amp)	each	2	$20,000.00	$40,000	
5kv Surge Arrestor (5 kV, 3 pole)	each	6	$1,500.00	$9,000	
Switch Gear Controls	lot			$20,000	

Table 52 (cont'd). TR07 system concept cost estimate.
(Elevated guideway)

COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL	REMARKS
SUBSTATION (480 V)	each	1	$65,000.00	$65,000	
BUILDING					
Structure (Concrete Block)	sf	5500	$55.00	$302,500	
Equipment Cooling	lot	1	$1,025,000.00	$1,025,000	
UPS System (5 KVA)	ea	1	$17,000.00	$17,000	
SECURITY LIGHTING	lot	1	$10,000.00	$10,000	Rectifiers and Inverters Inside.
GROUNDING	lot	1	$10,000.00	$10,000	
SUBTOTAL FOR INVERTER STATION				$26,574,500	
SUBTOTAL PER KM (SUBTOTAL/20)	KM			$1,328,725	
COST SUMMARY					
SUBTOTAL GUIDEWAY STRUCTURE	km			$6,633,640	53.59
SUBTOTAL GUIDEWAY MAGNETICS	km			$2,639,730	21.33
SUBTOTAL FOR GUIDEWAY POWER	km			$906,645	7.32
SUBTOTAL FOR WAYSIDE CONTROL & COMMO	km			$869,565	7.02
SUBTOTAL FOR INVERTER STATION	km			$1,328,725	10.73
TOTAL GUIDEWAY (PER KM)				**$12,378,305**	100.00
TOTAL GUIDEWAY (PER MILE)				**$19,932,859**	

Table 53. Technology cost summary ($1000 per mile).

Subsystem	*Magneplane*	*Grumman*	*Foster-Miller*	*Bechtel*	*TR07*	*U.S. Maglev*
			a. Elevated.			
Guideway structure	18,000	7,900	9,000	9,200	10,700	8,700
Guideway magnetics	3,600	5,800	9,100	6,300	4,200	5,200
Guideway power distribution	700	500	5,200	500	1,500	600
Wayside control and communication	1,400	1,400	1,400	1,400	1,400	1,400
Converter station	1,400	—	—	—	—	—
Inverter station	—	1,900	—	1,900	2,100	2,000
Rectifier station	—	—	3,200	900	—	—
Total	25,100	17,500	27,900	20,200	19,900	17,900
			b. At grade.			
Guideway structure	4,400	1,500	5,600	3,200	8,500	3,700
Guideway magnetics	3,600	5,800	9,100	6,300	4,200	5,200
Guideway power distribution	700	500	5,200	500	1,500	600
Wayside control and communication	1,400	1,400	1,400	1,400	1,400	1,400
Converter station	1,400	—	—	—	—	—
Inverter station	—	1,900	—	1,900	2,100	2,000
Rectifier station	—	—	3,200	900	—	—
Total	11,500	11,100	24,500	14,200	17,700	12,900

these components could bring the LCLSM cost in line with the other concepts.

In the case of Magneplane, the guideway structure is complicated and requires an extremely large amount of aluminum. It is not an efficient structure for large spans, and, thus, it requires close column spacing. This requirement becomes very expensive for the standard 11-m elevation used in this analysis, yet optimizing the beam design for 11-m elevation was beyond our scope. We, therefore, did not include the Magneplane guideway cost in our U.S. maglev estimate.

With these exceptions removed, subsystem costs are quite similar across the U.S. concepts. For example, excluding the Magneplane guideway, the SCD elevated guideway structure costs vary less than 10% from the average value. In general, some cost variability naturally exists because of technological differences. Also, some variability exists because contractors focused their efforts on different subsystems and thus did not optimize all subsystems uniformly. Nevertheless, examination of Table 53 supports the conclusion that the broadly defined function of each subsystem generally governs its cost. Thus, for current efforts to forecast maglev market performance, the derived U.S. Maglev costs should be meaningful despite technological differences among concepts.

It is interesting to compare the subsystem costs for U.S. Maglev with those for TR07. For both elevated and at-grade guideways, essentially the entire cost advantage for U.S. maglev derives from its lower guideway-structure cost. Indeed, TR07's guideway structure is the most expensive of all, except Magneplane's elevated guideway. The difference is particularly striking for at-grade guideways, where TR07's $4,800,000 / mile cost disadvantage represents about 40% of the total U.S. Maglev technology costs. Apparently, this cost penalty reflects the need to maintain very tight construction tolerances for the small-gap TR07 system.

Comparison of the Government and SCD cost estimates

The cost estimates prepared by the contractors were compared to the GMSA estimates above. The components in the contractors' estimates were

Table 54. Comparison of cost estimates ($1000).

Subsystem	Government estimate	Contractor estimate	Remarks
a. Magneplane International.			
Guideway structure	18,000	14,100	Contractor estimate is based on 5.2-m height. Unit costs are different. Reinforcing is not a separate item in contractor estimate.
Guideway magnetics	3,600	4,900	Contractor used higher unit costs.
Guideway power distribution	700	900	Contractor estimate was taken as a percentage (15%) of the total electrification costs.
Wayside control and communication	1,400	500	Government applied a standard unit cost to all SCD concepts.
Converter station	1,400	1,400	
Inverter station	—	—	
Rectifier station	—	—	
Total	25,100	21,800	
b. Grumman Aerospace.			
Guideway structure	7,900	5,700	Contractor estimate is based on 11.3-m height. Unit costs are different.
Guideway magnetics	5,800	5,300	
Guideway power distribution	500	700	Contractor estimate is per meter of dual guideway. It was not in sufficient detail to determine differences.
Wayside control and communication	1,400	300	Government applied a standard unit cost to all SCD concepts.
Converter station	—	—	
Inverter station	1,900	400	Contractor estimate is per meter of dual guideway. It was not in sufficient detail to determine differences.
Rectifier station	—	—	
Total	17,500	12,400	
c. Foster-Miller.			
Guideway structure	9,000	7,600	Contractor estimate is based on 7.6-m height. Contractor estimate was not in sufficient detail to determine differences.
Guideway magnetics	9,100	3,300	Unit costs for magnetic components were too low.
Guideway power distribution	5,200	3,500	Unit costs for inverters were too low. Contractor estimate was not in sufficient detail to determine differences.
Wayside control and communication	1,400	500	Government applied a standard unit cost to all SCD concepts.
Converter station	—	—	
Inverter station	—	—	
Rectifier station	3,200	200	Contractor estimate is for one station; two are required for dual guideway.
Total	27,900	15,100	

Table 54 (cont'd).

Subsystem	*Government estimate*	*Contractor estimate*	*Remarks*
		d. Bechtel.	
Guideway structure	9,200	12,700	Unit costs are different. Estimated quantities are different.
Guideway magnetics	6,300	6,800	
Guideway power distribution	500	1,100	Contractor estimate was not in sufficient detail to determine differences.
Wayside control and communication	1,400	1,800	Government applied a standard unit cost to all SCD concepts.
Converter station	—	—	
Inverter station	1,900	2,000	
Rectifier station	900	0	Contractor assumed that power utility would provide this station.
Total	20,200	24,400	

reallocated to subsystems in accordance with the procedures used in the Government estimate. The results are shown in Table 54. The reasons for any discrepancy greater than 15% in the two estimates is shown in the remarks column.

The tables show that there are some substantial discrepancies between the two estimates. The primary reasons include differences in unit costs, errors in calculated volumes, and items that were left out of the contractors' estimates. In many cases, the contractors' estimates were not provided in sufficient detail to determine where the differences were.

Except for Bechtel's concept, our estimates are higher than those of the contractors. Based on the information available, the government effort represents a reasonable cost estimate of the technology for each guideway concept.

Conclusions

Much of our cost-estimating effort focused on simple "bookkeeping." We estimated costs based on a common set of guideway parameters and consistent allocation of components into subsystems. More importantly, however, we developed independent guideway cost estimates for all four SCDs and TR07 using common procedures and unit costs. This allows us to draw several general conclusions based on a comparison of these costs and the associated performance characteristics of these systems.

To facilitate this comparison, we may first group systems of similar performance characteristics. Grumman's baseline design meets the SCD system criteria and slightly out-performs TR07 on the SST. Magneplane and Foster-Miller's baseline design have greater banking capability and more powerful motors, and they achieve incrementally better performance along the SST. A U.S. maglev system would also fall into this category. Lastly, Bechtel's baseline design possesses the most powerful motor and the completes the SST is the shortest time. On the basis of this rough grouping, we may draw the following conclusions regarding guideway cost and performance:

- For elevated guideways, the Grumman concept can provide slightly better performance than TR07 at significantly less cost ($17,500,000 / mile vs. $19,900,000 / mile). In addition, the Bechtel concept and U.S. maglev can provide enhanced performance at similar or lower cost ($20,200,000 / mile for Bechtel or $17,900,000 / mile for U.S. maglev vs. $19,900,000 / mile for TR07).
- For at- or on-grade guideways, the Grumman concept is approximately 60% of the cost of the TR07 system ($11,100,000 / mile as compared to $17,700,000 / mile). Also, the Magneplane and Bechtel concepts and U.S. maglev would provide enhanced performance at significantly lower cost ($11,500,000 / mile for Magneplane, $14,200,000 / mile for Bechtel or $12,900,000 / mile for U.S. maglev as compared to $17,700,000 / mile for TR07).
- With two specific exceptions, we found relatively little variability in subsystem costs among U.S. concepts, despite significant dif-

ferences in technology. Apparently, the broadly defined function of each subsystem generally governs its cost. This allowed us to estimate a U.S. maglev cost based on averages of the SCD subsystem costs. This estimate should be meaningful for forecasting market response to maglev in the U.S. and for comparing maglev with existing foreign HSGT systems.

- For both elevated and at-grade guideways, essentially the entire cost advantage for U.S. maglev relative to TR07 derives from its lower guideway-structure cost. The difference is particularly striking for at-grade guideways, where TR07's $4,800,000 / mile cost disadvantage represents about 40% of the total U.S. maglev technology costs. Apparently, this cost penalty reflects the need to maintain very tight construction tolerances for the small-gap TR07 system.

Like all cost estimates, the numbers developed here contain a degree of uncertainty. In particular, the U.S. concepts are not fully developed into system designs, and we had limited access to detailed TR07 data. Nevertheless, because we used a common procedure and a common set of unit costs for all systems, these general conclusions are relatively insensitive to this uncertainty.

3.4 OTHER EVALUATION CRITERIA AND ANALYSES

The SCD-RFP system criteria were intended to guide the contractors in the development of their concepts. However, other characteristics of maglev systems may influence their technical viability in the U.S. We, therefore, developed additional evaluation criteria and applied them as cross-checks on each concept in a similar way to the SCD-RFP system criteria (section 3.1). The results of this effort follow.

3.4.1 Mission flexibility*

The market response to maglev in the U.S. is not well known or easy to forecast. If a given concept can serve a variety of transportation missions, it improves its chances of being a commercial success. Suitability to other missions reduces the risk that the originally envisioned mission is not where the greatest market response lies. Also, if a maglev network begins to develop, its ability to serve broader portions of the Nation's travel market will increase ridership and improve economic viability. The adaptability of the technology may also be important for export sales to countries with different transportation needs than those of the U.S.

Table 55. Second numerical rating scheme for each concept.

Rating	*Score*
Highly suited to attribute	2
Capable of attribute	1
Poorly suited to attribute	0
Not capable of attribute	–1

Given the above rationale, we elaborated several mission statements appropriate for maglev; we then listed the primary technological attributes that a concept should possess to serve these missions. Note that the mission defined in the SCD-RFP is essentially that currently performed by short-haul aircraft: short-to-medium distance intercity trunk service. Earlier studies of maglev and the NMI's own market and economic studies view this as the most promising initial market for maglev. By using the SCD system criteria as an evaluation step (section 3.1), we have considered in depth the suitability of each HSGT system to intercity trunk service. Thus, we do not repeat that evaluation here.

Given below is a description of four alternative HSGT missions, their attributes, and the results of our evaluation of each concept against these attributes. We adopted the numerical rating scheme in Table 55 to apply for each technological attribute.

This subsection concludes with Table 60, showing the rating of each concept for each mission, and a rating of each concept's overall mission flexibility. We view mission flexibility as a high-priority criterion for the success of maglev.

Mission 1—Regional airport connector

Objectives.

- To permit multiple airports located within a relatively small region to serve as separate terminals of a distributed "mega-port."
- To facilitate transfers between airports and improve network efficiency.

* Written by Christopher J. Boon, Canadian Institute of Guided Ground Transportation, and Dr. James H. Lever, CRREL.

Table 56. Rating concepts as regional airport connectors (mission 1).

Attribute	*TGV*	*TR07*	*Bechtel*	*Foster-Miller*	*Grumman*	*Magneplane*
Efficient at moderate speeds	1	1	1	0*	1	0*
Brisk acceleration / deceleration	0	0	2	2	0	2
High peaking capability	–1	1	1	1	1	2
Transit-style doors, baggage space, and seating	0	1	2	1	1	–1
Tight-radius capability	1	0	0	0	0	0
Electromagnetic compatibility	1	1	1	1	1	1
Total	2	4	7	5	4	4

* High liftoff speed.

Table 57. Rating concepts as a regional commuter trunk (mission 2).

Attribute	*TGV*	*TR07*	*Bechtel*	*Foster-Miller*	*Grumman*	*Magneplane*
Efficient at intermediate speeds	2	2	2	1	2	1
High capacity	2	2	2	2	2	2
Moderate-high accleration	0	1	2	2	1	2
Moderate curving performance	0	1	2	2	2	2
Total	4	6	8	7	7	7

- To improve ground access between population centers and airports.

Examples.
- Dulles–Washington National–BWI–downtown Baltimore.
- LaGuardia–JFK–Newark–Manhattan.
- Midway–downtown Chicago–O'Hare–Milwaukee.

Service characteristics.
- Short distances, moderate speeds (50–60 m / s).
- Frequent service with peaking demands.
- Intermodal passengers and baggage transfers.
- Substantial growth in demand.
- Easy terminal access.
- Constrained ROW.

Table 56 presents the numerical ratings of each concept.

Mission 2—Regional commuter trunk

Objectives.
- To improve regional transportation efficiency.
- To reduce pollution associated with congested commuter highways.
- To reduce or delay investment in highway capacity to cope with peak commuter travel.

Examples.
- Long Island–New Jersey–Connecticut–New York.
- Los Angeles basin.
- Major metropolitan commuter regions (Boston, Chicago, etc.).

Service characteristics.
- 60- to 100-km routes, 8- to 16-km station spacing.
- Intermediate speeds (70–80 m / s).
- Strongly peaked demand.
- Substantial growth in demand.

Table 57 presents the numerical ratings of each concept.

Mission 3—Short to medium distance point-to-point service

Objectives.
- To improve intercity transportation efficiency (similar to SCD mission).
- To improve airport terminal congestion associated with short-haul air.
- To service more diffuse origin–destination pairs than is possible with large airports.

Examples.
- Northeast corridor.
- California corridor.
- Detroit–Chicago–Milwaukee–Minneapolis.

Service characteristics.

- 200- to 1000-km routes, 50- to 200-km station spacing.
- High speed (to 134 m/s).
- Numerous, convenient station locations.
- Smaller vehicles, modest peaking.
- Good interconnection with other public transit.

Table 58 presents the numerical ratings of each concept.

Mission 4—Long-haul trunk service

Objectives.

- To provide surface interconnections among the three major north-south corridors (Boston–Miami, Chicago–Houston, Seattle–San Diego), thereby creating a national HSGT network.
- To supplement long-haul air capacity.
- To reduce pollution generated by aviation and motor vehicles.

Examples.

- New York–Detroit–Chicago–Minneapolis–Salt Lake City–Seattle
- Washington–St. Louis–Denver–San Francisco
- Miami–Atlanta–New Orleans–Dallas–Phoenix–Los Angeles

Service characteristics.

- 2000- to 4000-km routes, 500- to 1000-km station spacing.
- Very high speed (more than 150 m/s).
- High traffic density.
- Long trips, more comfortable cabins, more amenities.
- Larger vehicles (large single or multiple-consist vehicles).
- Interconnections to major airports, maglev hubs.

Table 59 presents the numerical ratings of each concept.

Summary. Table 60 summarizes the ratings for each concept against the four missions. The number of attributes (and hence the maximum rating possible) in each mission generally reflects our priority of each mission in an overall rating of the flexibility of these HSGT concepts to serve missions beyond that identified in the SCD-RFP (intercity trunk service). We applied a final rating to this evaluation using the same rating scheme as in section 3.1 so that we could add the results together. This criterion is a high-priority one (weighting = 3).

This evaluation shows clear separation among the HSGT concepts in overall mission flexibility. TGV is the least flexible. Its fixed-consist, nontilting trains, lower cruise speed, and lower overall acceleration–deceleration render it poorly suited to meet other transportation needs beyond intercity trunk service. TR07 is an improvement over TGV in this regard, but is limited by its nontilting vehicles, modest acceleration, and limited speed potential. By comparison, the SCD maglev concepts show considerable potential to serve additional missions beyond intercity trunk service. Furthermore, they perform that primary

Table 58. Rating concepts for short to medium distance point-to-point service (mission 3).

Attribute	*TGV*	*TR07*	*Bechtel*	*Foster-Miller*	*Grumman*	*Magneplane*
High speed	1	2	2	2	2	2
High acceleration	0	1	2	2	1	2
Good curving performance	0	1	2	2	2	2
Small vehicles	–1	1	2	2	2	2
Short headway, fast switches	1	1	1	2	1	2
Total	1	6	9	10	8	10

Table 59 Rating concepts for long-haul trunk service (mission 4).

Attribute	*TGV*	*TR07*	*Bechtel*	*Foster-Miller*	*Grumman*	*Magneplane*
Very high speed	–1	0	1	1	0	1
Low power at high speed	–1	0	1	1	1	1
Large vehicles, good amenities, and comfort	1	1	1	1	1	0
Total	–1	1	3	3	2	2

Table 60. Summary of ratings for all four missions.

Mission	*TGV*	*TR07*	*Bechtel*	*Foster-Miller*	*Grumman*	*Magneplane*
Regional airport connector	2	4	7	5	4	4
Regional commuter trunk line	4	6	8	7	7	7
Intercity point-to-point service	1	6	9	10	8	10
Long-haul trunk service	–1	1	3	3	2	2
Total (max. 36)	6	17	27	25	22	23
Mission flexibility rating*	–1	1	1.2	1.2	1.2	1.2

*–1 doesn't meet, 1 meets, 1.2 exceeds criterion

Table 61. Assessments of tilting vehicle body.

System	*Evaluation comments*	*Rating*
TGV	None	–1
TR07	None	–1
Bechtel	Internal tilting cabin, 15° banking Aerodynamically clean, low interior noise Weight and complexity penalties—redundant structure, doors, and windows	1
Foster-Miller	Simple cabin construction, circular cradles, 12° banking No feedback correction for tilt—preprogrammed according to route and speed Requires complex fairing between bogies and tilting cabin	1
Grumman	Struts and linkages needed for each bogie, 9° banking Complex bogie–body fairing requirements	1
Magneplane	Passive vehicle banking, magnetic keel (i.e., no mechanical tilting mechanism) 35° banking May be able to pre-roll and correct tilting actively using aerodynamic control, but control not as positive as mechanical means	1

mission, on average, much better than TGV and somewhat better than TR07. This provides some confidence that U.S. maglev concepts will, overall, fulfill a broader spectrum of U.S. transportation needs than either of the two foreign HSGT systems.

3.4.2 Tilting vehicle body

A tilting body allows a broader speed range through curves while maintaining ride comfort. It also provides some flexibility in route alignment and speed profile by permitting pre-roll (i.e., initiating roll in advance of curves). A tilting body also permits a vehicle to return to a near-horizontal position if it is stopped in a curve, thereby easing passenger movement and evacuation. Its disadvantages are basically cost, reliability, maintenance, and weight. Provisions for tilting should maximize the advantages and minimize the disadvantages. This is a medium priority item. We checked the range of tilt and the complexity and weight of the vehicle. Table 61 gives the evaluation comments and ratings for tilting vehicle body.

3.4.3 Energy efficiency*

Energy efficiency is an important performance indicator for HSGT, and we rated it as a high-priority criterion. Here, we summarize energy consumption for all systems and compare the results to that for short-haul air. We show these results normalized per seat-meter, a measure known as energy intensity (EI). Our evaluation used short-haul air as a baseline: –1 for EI higher than air, 1 for comparable EI to air, 1.2 for EI substantially lower than air.

We used two measures of energy consumption—along the SST and at steady cruise. Results for the SST include energy consumed repeatedly accelerating a vehicle, particularly in the first, twisty segment but also for the two intermediate stops. However, the SST simulations did not incorporate energy savings from regenerative braking, the primary braking mode for all maglev concepts. The purpose of regenerative braking is to recover kinetic energy lost during deceleration.

* Written by Dr. James H. Lever, CRREL.

One way to approximate this benefit is to examine energy consumption at steady cruise speed on a level guideway. This value will also approximate vehicle energy consumption on a fairly straight, high-speed guideway.

We obtained cruise energy consumption values for all HSGT concepts by matching vehicle thrust requirements to motor thrust. We then used LSMPOWER and an estimate of converter station efficiency (see section 3.3.2) to obtain electrical energy consumed from a utility. The SST simulator SSTSIM (section 3.3.1) computed energy consumption along the SST route using the motor and resistance data for each concept. We then applied a converter station efficiency to obtain total electrical energy consumed for one trip along the route. These values are "base" energy consumptions—joules of electrical energy consumed at the system connection to an electric utility.

We selected the Boeing 737-300 aircraft to compare the energy efficiencies of HSGT and short-haul air. This aircraft is among the most fuel efficient in the U.S. short-haul fleet, and its energy intensity is about 70–80% that of the fleet, depending on trip length. With about a 30-year replacement cycle for aircraft, the fleet-averaged energy intensity will likely approach that of the 737-300 by the time maglev becomes a significant alternative mode. This is consistent with the estimate by Johnson et al. (1989) that fleet-averaged energy intensity for intercity air travel will drop by about 75% over this period.

Commercial airlines file data on fuel consumption with the USDOT for all flights. We used these data for 737-300 aircraft for the period ending June 1991, and conducted a regression analysis to obtain average fuel consumption per flight as a function of trip length. By converting jet-fuel volume to its energy equivalent (1 U.S. gal = 1.35×10^5 BTU = 1.42×10^8 J Higher Heating Value), we obtained a very good fit of the data to the following equation:

$$EI_{\text{base}}\,(\text{J/seat-m}) = \frac{1.39\times10^5}{S} + \frac{4.69\times10^{10}}{S\bullet D} \quad (22)$$

where EI_{base} = base energy intensity in J/seat-m derived from actual fuel consumed

S = the number of seats

D = trip length (m).

As with maglev electrical energy, this estimate derives from energy consumed at the system connection (i.e., at the airport). As reflected in eq 22, idling, taxiing, and takeoff energy requirements cause the energy intensity for short-haul air travel to strongly depend on trip length.

Commonly, energy intensity is calculated on a per-passenger basis. Although experience with foreign HSGT suggests that maglev would operate at higher load factors than short-haul air, we compared energy intensities on a per-seat basis. However, we did correct for differences in cabin space allocated per seat for each system. As discussed in Chapter 2, we defined a standard passenger (SP) as 0.80 m^2 of cabin space (including lavatories and galleys). We then used this definition to determine the number of seats for each system for use in calculating EI.

This is an important correction. The 737-300 allocates 0.54 m^2 of cabin floor area per seat for its 140-seat arrangement. This is slightly less than the Magneplane vehicle, the least spacious of the HSGT systems studied here. Conversion to standard passengers gives this airplane 96 seats.

By using a standard passenger, we acknowledge that seat spacing is a variable easily altered by vehicle designers and operators. Provision for flexibility in seat pitch or changes from spacious five-abreast to compact six-abreast seating is well within the technology of the SCD concepts. Thus, it would be relatively simple for the more spacious concepts to increase their number of seats and hence improve their energy intensities. Although our choice of 0.80 m^2 per SP is somewhat arbitrary, use of a different value simply involves multiplying the EI values here by the appropriate ratio. Comparisons between systems would not change.

Table 62 shows the base energy intensities for each HSGT system at steady cruise, on a level guideway. We show two values for TGV—at its commercial cruise speed of 83 m/s, and projected for 134 m/s based on its parameterized drag. The latter number demonstrates a benefit in EI associated with large consists. Also shown in Table 62 are EI_{base} values for maglev vehicles making 400- and 800-km trips along the SST (TGV cannot complete the SST). The two values shown for the 400-km trip are for the first and second halves of the route, respectively (from terminal 1 to terminal 2, and from terminal 2 to terminal 4, including a stop at terminal 3). The average of these two values equals that of the full 800-km SST. For routes of similar geometric alignment, maglev EI is essentially independent of trip length.

The Foster-Miller concept has the lowest SST

Table 62. Energy intensities for each HSGT system at steady cruise speed, and for 400- and 800-km trips along the SST. These derive from base energy consumed at the utility connection.

System	*Cruise speed (m/s)*	*Standard passengers (SP)*	*Cruise* EI_{base} *(J/SP-m)*	*400-km SST* EI_{base} *(J/SP-m)*	*800-km SST* EI_{base} *(J/SP-m)*
TGV	83	700	130	—	—
	134	—	310	—	—
TR07	134	160	460	590 / 480	540
Bechtel	134	110	560	840 / 600	720
Foster-Miller	134	140	390	510 / 400	450
Grumman	134	120	340	600 / 380	490
Magneplane	134	110	400	690 / 460	580
Average of all SCDs	134	—	420	660 / 460	560
Average of best two SCDs	134	—	370	560 / 390	470

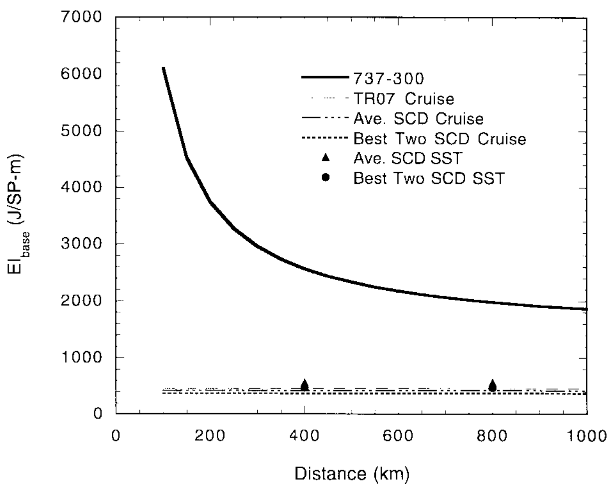

Figure 119. Base energy intensity at system connection (airport or electrical supply).

EI of the maglev concepts studied. It has the most efficient motor (the LCLSM), a fairly small frontal area, and low magnetic drag. Interestingly, Foster-Miller chose relatively conservative aerodynamic drag coefficients (see section 3.4.6), based on existing high-speed trains. TR07, Grumman, and Bechtel have vehicles that wrap around the guideway, resulting in a larger frontal area. All three concepts have low magnetic drag. However, TR07's aerodynamic drag coefficients derive from full-scale tests and thus reflect currently achievable values. Grumman appears to have anticipated drag reductions resulting from thorough study of all vehicle drag sources. Because aerodynamic drag predominates at high speed, Grumman's low cruise EI results primarily from its choice of these lower drag coefficients. Magneplane used aerodynamic drag coefficients similar to Grumman's. However, its magnetic drag at cruise speed is comparable to its aerodynamic drag, and this substantially raises its EI.

Figure 119 compares these base EI values with that of a 737-300 (eq 22) as a function of trip length. To represent U.S. maglev, we use the average of all SCD concepts and the average of the two most efficient ("best") concepts. Based on energy consumed at the system connection (i.e., airport or electrical supply), maglev EI values range from about 13 to 25% of that of a 737-300 for 200- to 1000-km trips. The very large difference for short trips highlights maglev's suitability for serving more closely spaced stations than is practical with aircraft.

Clearly, electricity and jet fuel are different commodities, and their values per joule are different. Energy cost is one way to compare energy consumption for these different fuels, essentially relying on cost to reflect differences in the value of resources used to produce each fuel. The Department of Energy produces annual estimates of fuel prices based on forecasts of supply and demand under different sets of overall economic assumptions. The baseline or "reference case" forecast for the year 2010 (DOE 1993a) predicts a jet fuel price of \$0.89 / gal. and an electricity price for transportation of \$0.065 / kWh in 1991 dollars. That is, on a per-joule basis, electricity is expected to be about three-times more expensive than jet fuel (roughly the same ratio as currently exists). Using these forecast prices, maglev would realize energy-cost savings compared to air travel of 60 to 30% for the 200- to 1000-km trip range.

Another way to reflect the difference in value between jet fuel and electricity is to account for the energy consumed to produce and deliver each fuel. Indeed, this approach has been used in previous comparisons of EI between maglev and air

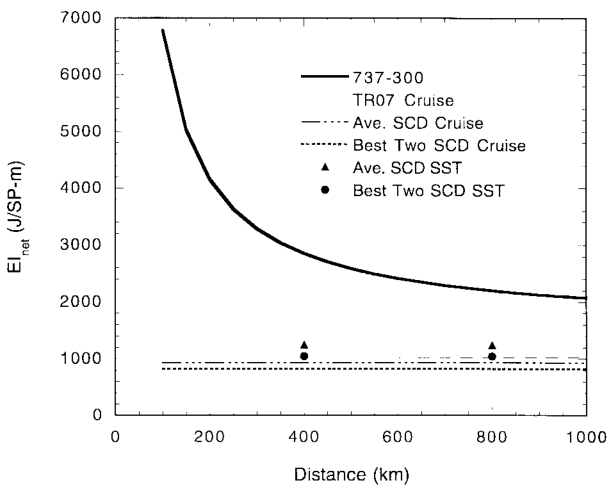

Figure 120. Net energy intensity including energy supply efficiency (90% jet fuel, 45% electricity).

travel (e.g., Johnson et al. 1989). Essentially, this approach identifies possible savings of gross energy by diverting passengers from air travel to maglev. We also did this calculation, but it is not as straightforward as it seems.

The predominant factor in this second approach is the net thermal efficiency of electrical power generation (joules-electrical output/joules-heat input). In effect, applying this factor implies that a unit of jet fuel saved in air travel is burned in a power plant to produce electricity for maglev. It places no direct value on the flexibility of electrical power production. Natural gas, coal, hydro, nuclear, solar, wind, and trash are electrical power sources that simply cannot be used to fuel commercial aircraft. What is the equivalence factor between air travel and maglev using hydro power as the energy source? Furthermore, refined petroleum powers all commercial aircraft and indeed practically all U.S. transportation. Maglev can decouple intercity travel from this dependence on petroleum, and applying simple efficiency factors does not capture this distinction.

Recognizing that it hides this important distinction, we nevertheless applied efficiency factors for energy supplied to aircraft and maglev. For jet fuel, Johnson et al. (1989) applied an efficiency of about 90% to account for transportation, refining, and distribution losses. We adopted this value as the only correction applicable for air travel. For electrical power generation and transmission, Johnson et al. used efficiencies of 35 and 95%, respectively. We also chose a 95% factor for transmission efficiency. However, 35% efficiency for power generation reflects a national average for fossil-fuel plants of varying ages and technologies. Modern natural gas-, oil-, and coal-fired plants are much more efficient than this.

Modern natural gas- and oil-fired combine-cycle plants (gas turbine with steam-turbine bottoming cycle) commonly achieve base-load efficiencies of 47–48%, based on the conservative Higher Heating Value of the fuel (Farmer 1992, Gas Turbine World 1992, DOE 1993a). Modern coal-fired plants are also approaching such efficiencies (Bajura and Webb 1991, DOE 1993b). These power plants have lower capital-cost-per-unit capacity than single-cycle plants, and they produce very low emissions. Indeed, DOE (1993a) forecasts that from 1990 to 2010, combined-cycle generating capability will grow at about 20 times the total growth rate of electrical-generating capability. Furthermore, utilities will add modern, efficient equipment to meet additional demands beyond current forecasts, such as needed to supply a major maglev network. We thus selected an electrical generation efficiency of 47%. Combined with a 95% transmission efficiency, this yields an electrical supply efficiency of 45% for maglev.

Figure 120 shows resulting net EI values for air and maglev as functions of trip length. These are the same data as in Figure 119 with the aforementioned efficiencies applied. Electrical supply efficiencies bring the EIs closer, but the results still overwhelmingly favor maglev. For 200- to 1000-km trips, maglev EI ranges from about 25 to 50% of that of a 737-300. And as noted, this comparison ignores the flexibility of power-plant fuel afforded by maglev's electrical propulsion. In terms of energy consumption and flexibility, maglev is clearly superior to short-haul air travel. TGV also shares these benefits, albeit with at a much lower performance level. Thus, all HSGT concepts studied here earn a rating of 1.2 for energy consumption.

To complete this comparison, we examined maglev trip times achieved along the SST and compared them to those for air travel. The line-haul (station-station) trip times for the SST's two 400-km segments average about 64 minutes for all SCDs. The corresponding value for the full 800-km SST is about 130 minutes. Use of the trip times for the two most energy efficient SCDs does not change these numbers significantly. Airline schedules indicate line-haul (departure–arrival) trip times of about 60 minutes for a 400-km trip and 100 minutes for an 800-km trip. Thus, line-haul trip times are comparable at 400 km, and favor air at 800 km (trip times for trips shorter than 400 km favor maglev). However, access time for maglev should be much less than for air because maglev facilitates smaller, more conveniently located stations. That is, we would expect maglev and short-haul air to yield comparable total trip times for an 800-km trip; shorter trips should favor maglev.

In summary, maglev can provide intercity travel at much lower energy usage than aircraft, with comparable or shorter trip times, and with flexible choice of power-plant fuel. Average maglev EI would be about 50% of that of short-haul air for an 800-km trip, yet offer a comparable total trip time. As trip length reduces, maglev's energy advantage over air increases dramatically, and it offers an increasingly significant trip-time advantage. For a 200-km trip, maglev would consume about 25% of the energy of a short-haul aircraft and complete the trip in about 25% less time. From the view of energy consumption, fuel flexibility, and trip time, maglev is clearly superior to air for intercity travel.

3.4.4 Use of existing infrastructure

Use of existing highway and railroad ROW improves the likelihood of nationwide implementation of HSGT. This is a high priority item. We checked the following:

- Minimum curve radii.
- Maximum acceleration and grade capability.
- Time to go from 0 to 134 m/s.

Table 63 gives the evaluation comments and ratings for using the existing infrastructure.

3.4.5 Potential for expansion

It may be desirable to expand system capacity beyond 12,000 seats/hour. Here, we rate each concept's ability to expand capacity easily. Note that all the maglev concepts studied are propelled by an LSM. This considerable investment ultimately limits motor thrust and, hence, capacity for all systems. Its replacement with a larger LSM would be very expensive. Fortunately, most concepts can achieve very large capacity using their current LSM, so that this is not generally a serious limit. This has a medium priority. Table 64 provides the evaluation comments and ratings for expansion potential.

3.4.6 Aerodynamics

Aerodynamic drag is the predominant vehicle drag at high speeds for all HSGT systems. It, thus, is the primary source of energy consumption for maglev vehicles along high-speed routes. Both TGV and TR07 have experience with full-scale vehicles to determine drag contributions from various sources. To check the reasonableness of the SCD estimates, we cast all aerodynamic drag estimates into a common format. We also enlisted the help of Dr. D.M. Bushnell, Fluid Mechanics Division, NASA Langley Research Center. He based his comments on existing literature for high-speed trains (Hammit 1974; Railway Technical Research Institute of Japan 1984, 1989; Brockie and Baker 1990) and his broad experience with aerodynamics of aircraft and other vehicles.

Table 63. Assessments of how the concepts can use existing infrastructure.

System	*Evaluation comments*	*Rating*
TGV	Can run directly on existing rail lines, although high-speed service requires dedicated lines Large, 6000-m minimum curve radius at 83 m/s Poor grade capability Not normally elevated (grade crossings, crossing of ROW require elevated structures)	–1
TR07	5800-m minimum curve radius at 134 m/s 0.006-g reserve acceleration (0.6:100) at 134 m/s (present design cannot climb 3.5:100 grade at cruise) 320 s to 134 m/s	1
Bechtel	2600-m minimum curve radius at 134 m/s 0.12-g reserve acceleration at 134 m/s 89 s to 134 m/s	1.2
Foster-Miller	2800-m minimum curve radius at 134 m/s 0.044-g reserve acceleration (4.4:100) at 134 m/s 120 s to 134 m/s	1.2
Grumman	4100-m minimum curve radius at 134 m/s 0.048-g reserve acceleration (4.8:100) at 134 m/s 180 s to 134 m/s	1.2
Magneplane	2200-m minimum curve radius at 134 m/s 0.039-g reserve acceleration (3.9:100) at 134 m/s 130 s to 134 m/s	1.2

Table 64. Assessments of potential for system expansion.

System	*Evaluation comments*	*Rating*
TGV	Very large consists possible Bilevel cars now in production Effort to increase speed to 97 m / s now underway Rail clearance envelope limits vehicle width	1.2
TR07	Wrap-around vehicle permits width increase (although beam width fixed—limits strength) Stator slot width limits conductor current, hence motor thrust Levitation force limited by stator pack size	1
Bechtel	Slots for extra magnets in vehicle to increase payload capacity Wrap-around vehicle permits width increase (although beam width fixed—limits strength) Potential for electromagnetic switch Potential for multi-car consists	1.2
Foster-Miller	LCLSM provides great potential for reduction in headway distance Eight-car trains at 55-s headways possible Passive EM switch is very fast Channel guideway easier to strengthen, but harder to increase vehicle width	1.2
Grumman	Slots for extra magnets in vehicle to increase payload capacity More powerful motor already considered by using copper LSM winding (although slot width eventually limits capacity) Wrap-around vehicle permits width increase (although beam width fixed—limits strength)	1.2
Magneplane	Some flexibility to increase both vehicle and guideway widths Passive EM switch is very fast Very short headways possible (20 s)	1.2

Despite small differences in the methodology used for each system, we may cast each aerodynamic drag estimate in the following form:

$$D_a / q = A_x C_d + P L_n n C_f \tag{23}$$

where: D_a = aerodynamic drag (kN)
q = dynamic pressure (11 kN / m^2 at 134 m / s)
A_x = vehicle frontal area (m^2)
C_d = drag coefficient for pressure drag (nose, base, protuberances, gaps, etc.)
P = vehicle wetted perimeter (m)
L_n = vehicle wetted length (m)
n = number of cars per consist (we used the baseline number)
C_f = skin friction coefficient.

Table 65 shows the values for these parameters for each HSGT system. Except as noted, we extracted these values directly from TGV and TR07 published literature and reports, and from the SCD final reports. Also shown is the aerodynamic drag per standard passenger (D_a / SP) for

Table 65. Parameters used for estimating aerodynamic drag for each concept.

System	A_x *(m^2)*	C_d	P *(m)*	L_n *(m)*	n	C_f	D_a/SP (N) *at 134 m/s*
TGV-A	11	0.18	13	20	12	0.0039	220
TR07	12	0.18	16	27	2	0.0037	360
Bechtel	15	0.11	18	36	1	0.0040	430
Foster-Miller	9.4	0.21	12	27	2	0.0025	280
Grumman	13	0.11	14	18	2	0.0022	240
Magneplane	7.1	0.10	10	38	1	0.0016	130
Magneplane*	8.0					0.0020	160

*We increased the estimated frontal area for Magneplane based on its revised vehicle shape; we increased Magneplane's skin friction coefficient because 0.0016 appears to be too low for the Reynolds number of the vehicle. We used these revised values to model Magneplane's performance along the SST.

each system at 134 m / s, which is a measure of the aerodynamic efficiency of the vehicle. For comparison, we have calculated D_a / SP for TGV-A at 134 m / s, although its maximum cruise speed is 83 m / s.

Bushnell's literature review suggested that the state-of-the-art for high-speed trains justifies use of C_d = 0.15 and C_f = 0.004. These values are quite close to those for TVG and TR07; the C_d value is also about midrange for the SCD estimates. However, three of the four SCDs use a much lower skin friction coefficient than that justified by the state-of-the-art. According to Bushnell, careful design and detailed attention to drag sources can yield 25% (perhaps 50%) reductions in both C_d and C_f. It thus appears that some SCD concepts incorporated such anticipated reductions. While this places some concepts at a comparative disadvantage, our aim here is to assess technical viability of U.S. concepts generally. Thus, SCD average drag values appear to be achievable almost immediately, and the lower SCD estimates appear to be achievable with solid technical effort (as would likely be part of U.S. maglev development).

Bushnell also briefly discussed sources of drag and issues affecting drag reduction. Many of these points were also noted in the SCD reports. We list them here for consideration as part of further work in this area.

Drag minimization requires thorough evaluation of all sources, including:

- Three-dimensional nose–base drag, including effects of atmospheric turbulence.
- Frictional drag, including actual surface roughness and guideway channel drag.
- Additional pressure drag components, including:
  - –Protuberances.
  - –Gaps between vehicles or components.
  - –Wake effects attributable to crosswinds or yaw.
  - –Drag ascribable to lift (caused by asymmetrical shapes and boundary conditions).
  - –Magnet bogies.
  - –Compressibility effects from passing vehicles.
  - –Trim drag (of aerodynamic control surfaces).
- Tunnel drag.
- Effects of air flow through open channel guideways and guideway outriggers.

Bushnell suggested that computational fluid dynamics models or wind tunnel tests with a moving ground plane could yield drag estimates for maglev vehicles within 10–20% of their actual values. Naturally, finer details of vehicle geometry would be needed. Present SCD estimates based on analogies with high-speed trains and aerodynamic handbooks are probably within 25–50% of actual values. Given this level of uncertainty and lack of detail, we chose not to rate the systems for aerodynamic performance.

3.4.7 Criteria summary

We may combine with the above other criteria our ratings of each concept against the SCD-RFP criteria (Table 24). This provides an overall evaluation of the ability of each concept to meet transportation needs for the U.S. market. That is, this overall rating assesses the "mission suitability" aspect of each concept's technical viability. Table 66 shows these results.

Interestingly, application of additional evaluation criteria did not change the relative ranking of the concepts. However, the gap between TGV

Table 66. Overall assessment of mission suitablity of HSGT concepts studied.

Parameter	*Weight*	*TGV-A*	*TR07*	*Bechtel*	*Foster-Miller*	*Grumman*	*Magneplane*
RFP system criteria subtotal	53	38	48	46	56	56	56
Other Criteria							
Mission flexibility	3	–1	1	1.2	1.2	1.2	1.2
Tilting	2	–1	–1	1	1	1	1
Energy efficiency	3	1.2	1.2	1.2	1.2	1.2	1.2
Existing infrastructure	3	–1	1	1.2	1.2	1.2	1.2
Expansion	2	1.2	1	1.2	1.2	1.2	1.2
Aerodynamics	0						
Subtotal	13	–2	10	15	15	15	15
Total	66	36	58	61	71	71	71

and the maglev concepts widened substantially. This technology does not meet as extensive a set of U.S. transportation needs as do the maglev technologies. Also, this assessment revealed a somewhat greater capability of the U.S. maglev concepts vs. TR07 to meet U.S. transportation needs. TR07 suffered primarily for its lack of a tilting vehicle and its modest motor capability. Except for Bechtel's selection of a fuel cell for onboard power supply and its incomplete suspension description, all U.S. concepts met or exceeded all criteria and yielded essentially identical scores.

As with the SCD system criteria, evaluation of the concepts against the additional criteria in this section was a helpful step in our technical viability evaluation process. The mission-flexibility criterion forced us to consider transportation needs beyond those served by intercity trunk service. Similarly, our aerodynamic assessment placed the concepts in a common format and improved our understanding of the various procedures used to estimate aerodynamic drag. Perhaps most insightful was our energy-efficiency assessment. This comparison required data from several of our analyses (motor and power, system simulation, aerodynamics) and helped to reveal maglev's role relative to existing short-haul air service. We may now draw upon the insight gained here to discuss the overall technical viability of maglev for the U.S.