High-Speed Ground Transportation Feasibility Study: I-90 (Massachusetts Turnpike) Corridor—Boston, Massachusetts, to the New York State Line

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A preliminary evaluation of the compatibility of a high-speed ground transportation system with an existing Interstate highway corridor is documented. The evaluation considered the implementation of a single guideway with passing sidings and the Transrapid TR-07 vehicle technology. The feasibility of implementing this specific magnetically levitated ("maglev") technology is assessed by evaluating engineering, environmental, and operational parameters of two potential guideway alignments along the 216-km (135-mi) I-90 corridor. Alternative A is fully contained within the I-90 right-of-way. Alternative B is located both within and outside the right-of-way, optimizing operating speeds at 400 kmph (250 mph). Opportunities and constraints associated with the implementation of a maglev transportation system within the I-90 corridor are defined. The results presented are conceptual in nature and are intended to provide initial input into system planning efforts for providing high-speed ground transportation. These results indicate a significant trade-off between high-speed maglev operations and shared use of existing Interstate rights-of-way. To achieve the maximum operating performance of 400 kmph, the maglev guideway would be located outside the existing highway corridor for approximately 80 to 85 percent of its alignment. With the alignment located fully within the Interstate right-of-way, the operating speed averages 197 kmph. Implementation of maglev technology, or super-speed technology, may be perceived as both a transportation solution to the movement of goods and people in congested and highly traveled corridors and as a tool for social and economic development. No effort has been made to quantitatively or otherwise predict transportation demands (commodities or people) or socioeconomic benefits accruing from the implementation of high-speed ground transportation connections. Also, consideration of the financial aspects of this potential transportation system has not been undertaken.

For the past two decades, efforts to provide high-speed travel between the New York City and Boston metropolitan areas have focused on Amtrak's Northeast Corridor route. During the past 5 years, there has been interest in developing a second high-speed ground transportation corridor between these two areas. One of the other corridors investigated generally follows I-87 (the New York State Thruway) from New York City to Albany, New York. At Albany, the route turns eastward to travel along the I-90 corridor to Boston.

This study discusses the potential for providing a magnetically levitated maglev transportation system along the Massachusetts Turnpike section of the I-90 corridor. The design requirements of the Transrapid maglev technology and the available I-90 right-of-way are discussed to evaluate the potential for such a transportation system. Two potential alignments are considered along the corridor. The first, Alternative A, is fully contained within the I-90 right-of-way. The second, Alternative B, is located both within and outside the right-of-way, optimizing the operating speed at 400 kmph (250 mph).

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DESIGN GUIDELINES

The following discussion describes the parameters established for the evaluation of the two maglev rail alignment alternatives in the I-90 corridor. These parameters represent the unique engineering and operational guidelines necessary to construct and operate a maglev system based on currently available Transrapid maglev technology.

Vehicle and Operational Parameters

A two-car TR-07 train is approximately 50 m (168 ft) long and carries between 160 and 200 passengers. The maximum operating speed of the TR-07, a non-tilt vehicle, is 500 kmph (312 mph).

Engineering Design Parameters

The guideway system design criteria used for this assessment are summarized in Table 1 and discussed in the following paragraphs. The source for each criterion is noted in the individual discussions.

Ride Quality

When a vehicle accelerates, decelerates or traverses a horizontal or vertical curve, certain forces are exerted on the occupants of the vehicle. If the established levels are exceeded, the ride could become quite uncomfortable for the occupants. The primary criterion governing maglev operations involves passenger comfort. Table 1 summarizes the maximum allowable forces resulting from acceleration and rate of change of acceleration (jerk) used for this study (*1*). In compiling these criteria, the more restrictive Federal Railroad Administration passenger train comfort factors were incorporated rather than the Transrapid criteria.

The speed analysis examined an operation that would provide a comfortable ride within these established parameters, minimizing

TABLE 1 Guideway Characteristics

Ride Quality[a]		
Force	Acceleration (+g)	Jerk (+g/sec)
• Longitudinal	0.15	0.03
• Lateral	0.08	0.03
• Vertical	0.10	0.04
Guideway Geometrics[b]		
• Bank		12 degrees
• Roll		3 degrees/sec
• Maximum grade		10 percent
• Minimum length of spiral		440 meters
• Minimum radius (400 kmph)		5,898 meters
• Minimum vertical curve (400 kmph)		12,600 meters
Guideway Location[c]		
• Vertical elevation		12 meters average
• Horizontal off-set from travel way		6 to 12 meters

[a]Data compiled from Federal Railroad Administration criteria.
[b]Bank angle and maximum grade are Transrapid criteria.
Maximum roll rate is Federal Railroad Administration criteria.
Minimum length of spiral = (total cant/maximum roll rate) x Velocity where cant is in degrees, roll rate is degrees per second and velocity is meters per second.
Minimum radius is calculated using formula the following formula: $R=3.179V^2$ where R is radius in meters and V is velocity in meters per hour.
Minimum vertical curve is based on Federal Railroad Administration comfort criteria.
[c]Vertical elevation measured from edge of closest travel lane.
Horizontal offset is measured from edge of closest travel lane.

the discomfort from jerk motion and gravitational pull forces on curves. To achieve a satisfactory comfort factor, an acceleration speed of 1 m/sec^2 (3.25 ft/sec^2) and a deceleration speed of 1 m/sec^2 were used when speeding up or slowing down. For acceptable ride quality, the maglev guideway was set as flat as possible, with relatively infrequent vertical or horizontal accelerations or decelerations.

Guideway Geometrics

Bank Limits To reduce horizontal curve radii while still providing for higher speeds through curves, some degree of guideway banking is necessary. Previous studies of the maglev technology have concluded that a 12-degree bank is the maximum that can be built into the guideway when a non-tilting vehicle is used. A bank angle in excess of 12 degrees has been considered undesirable in this case because it causes greater discomfort for passengers when the curve is negotiated at less than the design speed or when the train stops in the curve. Bank angles in excess of 12 degrees are also considered too steep for a maintenance worker or a passenger departing a crippled vehicle to walk on the guideway (*1*). At present, the maximum superelevation used in the Transrapid maglev test track at Elmsland, Germany is 12 degrees (*2*).

Horizontal and Vertical Geometry The horizontal curvature requirements were established for this evaluation based on the maximum 12-degree guideway bank. The 12 degrees was assumed to be the maximum combined guideway and vehicle bank, since the TR-07 maglev vehicle does not have banking capabilities. Therefore, for any speed, a guideway bank angle up to the maximum 12 degrees attainable and the specified 0.08-*g* lateral acceleration limit define the minimum acceptable radius. At the Elmsland Transrapid Test Facility, the minimum horizontal curve requirement of 4,140 m (13,800 ft) is based on a maximum acceptable lateral force of 0.10 *g*.

Spiral curves were used in combination with the simple horizontal curves to provide a gradual transition from the tangent section of the guideway into the full curvature. A maximum 3 degree/sec roll rate was incorporated into the spiral curve design.

The vertical curvature requirements are also established by ride comfort. At maglev speeds, the guideway profile must be flat over long distances to minimize changes in vertical direction and the imposition of uncomfortable vertical forces on passengers when traversing a vertical curve at high speed. These forces would be (*a*) the "pulling" forces felt when transitioning from a level grade to an upward grade, (*b*) the negative forces, or floating effect, at the summit of a vertical curve, and (*c*) the pulling forces on the downside of the vertical curve when returning to the original grade level. For any given speed, the 0.10-*g* vertical acceleration limit defines the minimum acceptable vertical radius.

Guideway Location

Elevation of Guideway Interstate highway characteristics vary considerably across the United States. In some sections of the country, such as Texas and Florida, the highways are straight and flat with wide medians due to the availability of right-of-way. Maglev guideways can be constructed at-grade in the median in these areas. In other sections of the country, such as the northeast and mid-Atlantic states, interstate highways have narrow medians and an abundance of curves, and they pass through rolling terrain. To adapt to the terrain and provide adequate horizontal clearances, it is necessary to elevate the guideway along the side of the road. The guideway elevation must meet the recommended AASHTO minimum vertical clearance of 4.35 m (14.5 ft) between the highest point on the roadway pavement and the underside of the overpass (*3*). Typically, if the guideway is elevated 12 m (40 ft) above the highway, there will likely be sufficient clearance for the guideway to pass over structures and clear utilities and trucks on it (*4*).

Two approaches are available to achieve the required 12-m clearance. The first approach is to have a relatively low guideway running about 4.5 to 6 m (15 to 20 ft) above the ground level. As the maglev vehicle approaches a bridge or other obstacle, the guideway height increases to clear the obstacle. With this change in vertical direction, a vertical acceleration (or pull of gravity) acts on the vehicle and the passengers as it moves upward on the vertical curve to clear the obstacle. This is followed by a downward acceleration, and finally an upward acceleration as the vehicle returns to its original line of motion. Passengers would probably find such a roller coaster ride uncomfortable.

The second approach is to set a constant 12-m elevation for the guideway relative to ground level. On terrain that is generally flat, the guideway would clear bridges and ramps without changes in the guideway height or profile and without vertical acceleration forces on passengers. On rolling terrain, the guideway would maintain a flat path, but the pier heights would change to adapt to differences in the ground profile. This reduces the number of grade changes, minimizing the roller coaster effect.

Horizontal Offset from Highway Any maglev guideway located within an interstate highway right-of-way will have to meet AASHTO design standards for horizontal clearances. Along I-90, a clear zone between 6 and 12 m (20 to 40 ft) is required from the edge of the travelway to a fixed object such as a guideway column (*5*). Fixed objects which cannot be located outside of the clear area must be made to break away or be protected by barriers or impact attenuations.

In addition to the AASHTO standards, maglev guideway design standards also dictate where the guideway can be located. Maglev alignments generally must be fairly straight, with gentle changes in horizontal alignment. If the guideway were placed in the median, vehicle speed would be limited at locations where the highway curvature is less than the required maglev guideway curvature. If the guideway were to leave the median at the points where flatter curves were required, long spans across the roadway would be necessary due to the flat angle between the guideway and highway alignment. These spans could extend for a long distance, resulting in costly construction techniques and undesirable impacts on highway traffic (*3*).

In locating the maglev alignment along the edge of the interstate roadway, the guideway structure should be placed far enough away to minimize distractions to the motorist. Some of these potential distractions include the following:

1. Visual distractions: To minimize the visual distraction to the motorist on the adjacent highway, the maglev structure should be placed away from the motorist's cone of vision, thus making the moving maglev train less visible to the motorist. Drivers tend to look ahead to a vanishing point, or constant-distance point at the center of the highway, rather than to the right or left away from the highway.
2. Noise: Noise produced by aerodynamic drag from a passing maglev train at 320 kmph (200 mph) would be less than 80 dBA at roadside and would last for less than 4 sec. The noise level generated by an automobile traveling 104 kmph (65 mph) is about 76 dBA. The additional level of audible noise from a passing maglev train that would penetrate the cabin of an automobile is estimated to be between 5 and 10 dBA. Noise is perceptible to the average human ear at about 3 dBA. More research should be conducted on the startle effect and sudden onset of the aerodynamic noise emanating from a maglev train traveling at speeds above 200 kmph (124 mph) (*1*).
3. Induced wind velocity: The induced wind velocity from a maglev train moving 400 kmph (250 mph) on a guideway located between 6 and 12 m away horizontally and also elevated 12 m would be negligible at the roadway (*3*).

On the basis of these data, the guideway was held along the south side of the roadway except where the horizontal alignment of I-90 and the proposed guideway were conducive to short span crossings.

CORRIDOR DESCRIPTION

The I-90 study corridor, which extends from the New York state line to I-93 in Boston, Massachusetts, is shown in Figure 1. Existing conditions data were compiled along the 216 km corridor from as-built plans provided by the Massachusetts Turnpike Authority (MTA). These plans included right-of-way; pavement and median width; horizontal and vertical geometry; the number, location, and clearance of structures crossing over the I-90 right-of-way; and existing air rights development locations. Other information collected included land use, topographic maps, and planned air rights developments. To corroborate structure heights, clearances, land use and topographic information, a windshield survey was conducted of the entire corridor.

Right-of-Way Width

The right-of-way is up to 120 m (400 ft) wide in the mountainous terrain of western Massachusetts, where often the directional travelways of the highway are at different elevations because of the rugged terrain. Along the central and eastern segments, the average right-of-way width between interchanges is 90 m (300 ft). From I-95 in Weston east to the termination of the I-90 corridor at I-93 in Boston, the right-of-way varies between 42 and 60 m (140 and 200 ft). At interchange areas, the right-of-way expands significantly.

Land Use

The land use data presented in Table 2 were summarized from U.S. Geological Survey topographical maps. In general, I-90 passes through mountainous, rural areas in western Massachusetts. The first densely developed segment occurs from Chicopee to Palmer. From Palmer to Auburn the corridor again travels through moun-

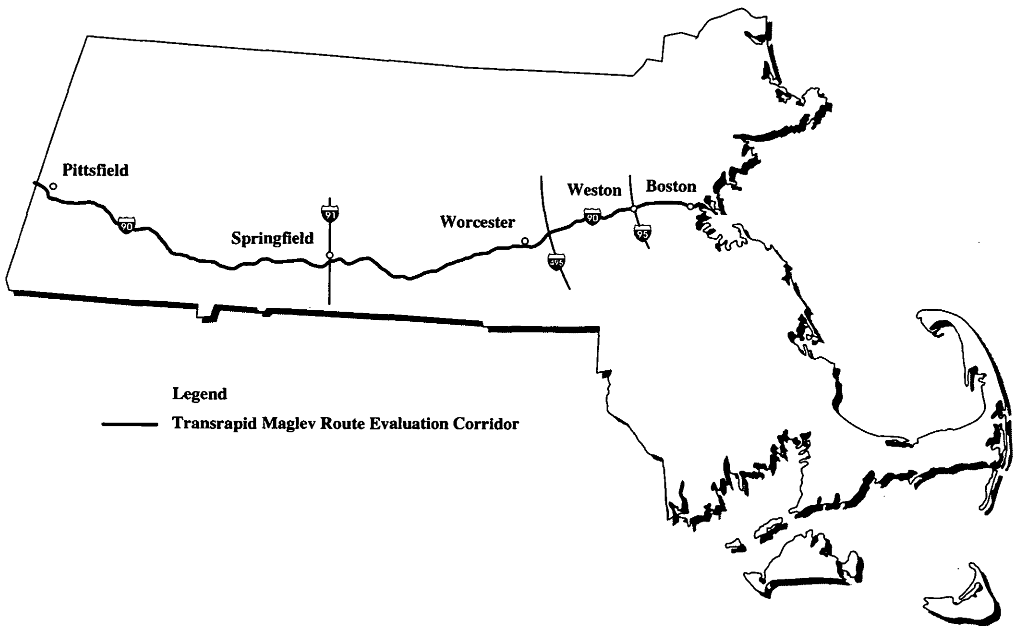

FIGURE 1 Study area.

TABLE 2 Land Use Summary, I-90 (Massachusetts Turnpike)

Section	Kilometer post Location	Description of Land Use
State Line to Lee	KMP 0 to KMP 18	rural, mountainous, some wetlands in the valleys
Lee to Blandford	KMP18 to KMP 45	state forest, rural, mountainous, some wetlands in valleys
Blandford to Westfield	KMP 45 to KMP 64	mountainous, semi-rural, rural
Westfield to Chicopee	KMP 64to KMP 69	mountainous, semi-rural
Chicopee to Palmer	KMP 69 to KMP 88	hilly, urban area
Palmer to Sturbridge	KMP 88 to KMP 125	hilly, some wetlands in the valleys, rural
Sturbridge to Auburn	KMP 125 to KMP 144	mountainous, rural
Aurburn to Westborough	KMP 144 to KMP 171	hilly, developed on both sides, wetlands west of Westborough
Westborough to Framingham	KMP 171 to KMP 181	hilly, wetlands east of Westborough, urban developments between Westborough and Framingham, urban areas both sides in Framingham
Framingham to Weston	KMP 181 to KMP 197	urban, rolling topography
Weston to Boston	KMP 197 to KMP 216	developed, limited right-to-way

1.6 km = 1 mile

tainous territory with limited rural development located along it. In Auburn, the roadside character returns to an urban nature which mixes with rural pockets to Weston. From I-95 in Weston to the corridor terminus in downtown Boston, I-90 is abutted by dense urban development. In Newton, two air rights developments have been built spanning the corridor. In the Back Bay section of Boston, the Prudential Center Complex, which includes a 52-story office tower, spans I-90. The possibility of several other air rights developments have been discussed along this section of I-90. There are also several sections of corridor between Weston and Boston where high retaining walls are close to the edge of the travelway. From the Route 16 interchange in Newton to I-93, the existing Conrail railroad corridor shares the I-90 right-of-way.

Pavement Width

Two travel lanes and a full-width shoulder are provided in each direction of travel between the New York state line and Sturbridge. From Sturbridge to Weston, three travel lanes and a full-width shoulder are provided in each direction. Three lanes are provided in each direction from Weston to Allston along with short emergency turnouts instead of shoulders. From Allston to I-93 in downtown Boston, four to five lanes in each direction are provided without a shoulder. Additional lanes are added at several major interchanges. The median width varies from 2.4 m (8 ft) in the urbanized areas to over 30 m (100 ft) in the rural areas.

Horizontal and Vertical Geometry

The horizontal and vertical alignment data obtained from the MTA are not presented in this study due to the volume of information. The data have been formatted in AutoCAD files along with the right-of-way data, which were used extensively in the evaluation process.

Bridge Structures

There are a total of 103 overhead and 104 undergrade bridges along the I-90 corridor. Fifty-three of the overhead and 39 of the undergrade bridges are located along the 19 km (12 mi) from Weston to downtown Boston. Generally, both the overhead and undergrade bridges have a minimum clearance between the underside of the structure to the top of the pavement at the highest point of 4.35 m (14 ft 6 ins.). In some instances, the clearances are greater depending on the topography on either side of I-90.

ROUTE EVALUATION

The use of interstate rights-of-way for maglev systems provides an opportunity to limit land acquisition costs, particularly in urban areas where land costs are at a premium. In evaluating the compatibility of the I-90 corridor and a maglev transportation system, the key issues focus on speed and the ability of the guideway to use the existing right-of-way.

For this assessment, the I-90 right-of-way was examined in detail from the New York state line to I-95/Route 128 in Weston. The remaining section of I-90 from I-95 to I-93 in downtown Boston underwent a preliminary review. Through the 19-km (12-mi) section between Weston and Boston, the right-of-way becomes quite constrained, varying from 42 to 60 m (140 to 200 ft). There are also three air rights developments with several other potential developments being discussed. An initial examination of this segment indicated that there was no practical location for a guideway. This included consideration of sharing the Conrail railroad corridor which is a part of the I-90 corridor from Newton to Boston. Examination of alternate corridors was not part of the effort.

Two single guideway alignment alternatives using existing Transrapid technology were considered. The first, Alternative A, maximized operating speeds for an alignment fully contained within the existing I-90 right-of-way based on the design criteria previously established. The second alternative, Alternative B, examined the impacts of providing a guideway alignment which permitted a sustained operating speed of 400 kmph. The following paragraphs provide a summary of each alignment and a description of the impacts.

Alignment Alternative A (Within Right-of-Way)

Alignment Alternative A represents a guideway located within the existing I-90 right-of-way. The alignment is located to conform as closely as possible with the design guidelines established for the assessment. The guideway was located generally along the south side of I-90, offset from the travel way approximately 12 m (40 ft). In a few select locations where the highway alignment permitted and it was conducive to maximizing the guideway alignment, the guideway crossed the I-90 travelway. To insure passenger comfort, the maximum applicable force and the maximum guideway bank of 12 degrees were used to set the horizontal and vertical curvature. Operating speeds between (both horizontal and vertical) curves were optimized based on passenger comfort factors.

Horizontal Alignment

Use of the median for the guideway does not appear to be practicable since the median becomes extremely narrow in several areas. Also, the roadway curves at a faster rate in many locations than a high-speed maglev alignment would be able to follow. In these instances, the guideway would have to leave the median and go over the travelway with a curve radius that would permit a higher speed than the highway alignment. The relatively flat horizontal curve requirements of the maglev alignment, however, would generally result in unacceptable span lengths across the travelway. This would produce an undesirable "tunnel" effect over the travelway and possible shadow/light problems to some drivers. Therefore, the guideway was placed primarily on the south side of I-90 since it appeared to present fewer obstacles than the north side.

In two locations it was determined that the alignment could cross the I-90 travel lanes to allow increased operating speeds. At these two locations, the angle between the highway and guideway was sharp enough to produce a relatively short guideway span. Additional locations may exist to cross the travelway to achieve higher operating speeds but identification of all these locations was beyond the scope of this effort.

The guideway's horizontal geometry basically models the existing I-90 geometry. Spiral curves were used in combination with the simple horizontal curves to provide a gradual transition from the tangent section of the guideway into the full curvature. Use of spiral curves and a banked guideway through all horizontal curves maximizes operating speeds along the Alternative A alignment.

The elevated guideway structure was offset approximately 12 m from the edge of the travelway. With travel lanes and the median occupying approximately 30 to 39 m (100 to 130 ft) of the 90-m right-of-way, variances are minor since 21 to 30 m (70 to 100 ft) remain between the edge of the travelway and the right-of-way line in rural sections.

Vertical Alignment

The existing I-90 alignment travels through generally hilly terrain along the central section and through mountainous terrain along the western section. These changes in vertical alignment require frequent changes in vertical direction. Where changes in the elevation of the I-90 profile are not too frequent or great, the guideway can be constructed to permit a gradual transition into an upwards acceleration into a vertical curve within the comfort level of less than 0.1g. Similarly, a gradual transition can be constructed from a downward acceleration when returning to the original grade. Along the hillier and more mountainous sections, the guideway can also be adapted to provide a ride within the acceptable comfort limits. Vertical curve requirements do not appear to be a constraint towards optimizing operating speeds.

What is not readily apparent from this current analysis is the height of the supporting guideway columns. There are numerous instances where the side slope along the edge of the travelway descends rapidly, making the column length required significantly greater to maintain the 12-m elevation. In practice, guideway heights will depend on local conditions. A detailed study would be required to determine the range of column lengths.

In addition to adjusting column heights to meet terrain conditions, the guideway intersects with bridges, ramps and other physical features along I-90. Although none of these obstacles are likely to be insurmountable, some, like the gorges west of Springfield, will require special engineering to span.

Right-of-Way

There are no deviations from the I-90 right-of-way to attain higher operational speeds. Future review of this alignment may identify locations where deviations are desirable and practical to attain higher operating maglev speeds.

Design Speed

The design speed along the alignment was set to maximize operating speed while minimizing rider discomfort. Along certain sections of the alignment between limiting horizontal curves, the maglev vehicle was not accelerated to the potential maximum speed in an effort to reduce the "jerk" effect. Where possible, the vehicle was allowed to accelerate to the highest speed practical over a sustained section of track. No attempt was made to accelerate the vehicle to the maximum allowable speed, then immediately decelerate. This type of activity produces a "spiked" speed profile which theoretically maximizes operating speeds but creates an undesirable effect on passenger comfort. Rather, speeds were set to optimize operating speeds and passenger comfort. This results in plateaus on the speed profiles.

Environmental Impacts

The Alternative A alignment is contained entirely within the existing right-of-way and generally follows the I-90 alignment. The guideway would span rivers, streams, gorges and roads in the same general locations as I-90. In that respect, the impact of the guideway will be similar to that of the highway. Given the guideway's location along the edge of the highway, new impacts may be generated as the guideway passes over wetland areas that the highway passes around. The impacts in these areas should be limited to the construction of the supporting guideway columns. Once the guideway is in operation, the impact of the maglev operations should be no greater than that of the highway.

Land Use Impacts

A number of homes, businesses, and office buildings abut the corridor, particularly in the urban areas. Between Framingham and Weston, a number of homes are located adjacent to the right-of-way. Office buildings are also present around the interchanges in Framingham, Natick, Auburn, and Springfield. In these areas, it may be necessary to reduce the maglev operating speed and move the guideway away from the development, reducing potential impacts. There are a number of examples in the urbanized areas along the highway where the guideway could have these types of impacts. Each one would need to be evaluated on an individual basis to determine the appropriate engineering solution. Between these urban areas, development is less dense. In most cases the impacts in the rural areas on existing land uses should be less than in the more-developed urban areas.

Highway Safety Impacts

The location of the guideway along the south side of I-90 should not cause additional highway safety concerns. The 12-m offset and elevation of the guideway should generally minimize the visual, noise, and wind-induced impacts on highway traffic. In critical locations, such as where the travelway and the guideway intersect, traffic safety barriers can be constructed to protect highway traffic from potential safety hazards.

Alignment Alternative B (400 kmph)

Alternative B represents a maglev guideway alignment optimized to allow operating speeds of 400 kmph. As a result, a majority of the guideway (approximately 80 to 85 percent) is located outside of the existing I-90 right-of-way. The alignment crosses the I-90 travelway in approximately two dozen locations to minimize the deviation from the right-of-way. In some areas the alignment is approximately 720 to 1,020 m (2,400 to 3,400 ft) outside the highway alignment.

Horizontal and Vertical Alignment

A consideration in establishing the horizontal alignment for Alternative B is the hilly terrain which results in a generally winding existing highway configuration, particularly west of Springfield. To enhance the alignment for 400 kmph operations requires deviation from the right-of-way to accommodate large radius curves. This deviation is greatest in areas west of Springfield and in Auburn.

A second consideration is the level of development adjacent to I-90. Development on both sides of the right-of-way in the urbanized areas restricts the distance the alignment can deviate in order to maintain speed using a radius of curvature greater than the interstate radius of curvature. The speed of the TR-07 maglev vehicle in these urban areas may have to be less than for those sections of the alignment in rural areas, where large radius curves do not impact developed or environmentally sensitive areas.

A full assessment of the alignment's horizontal and vertical characteristics is difficult, given that a majority of it is located outside the I-90 right-of-way. Existing conditions assessments in the areas outside the right-of-way were limited to USGS maps. By establishing the horizontal alignment for 400 kmph and superimposing it on the USGS base data, an initial assessment of the impacts of an optimized alignment can be undertaken. As with the Alternative A alignment, spiral curves have been used in combination with the simple horizontal curves to provide both a gradual transition from a tangent section into the curve and to maximize speeds through curves. Also, the guideway crosses the highway in approximately two dozen locations to minimize deviation. At these locations, the deviation would have been much greater [up to 1,820 m (6,000 ft)] if the alignment were held on the south side of I-90. There may be additional locations to cross the highway and reduce deviation. Identification of all possible locations is beyond the scope of this current effort.

Similar to the Alternative A assessment, it is difficult to evaluate the guideway column or pier heights. It is more difficult with the Alternative B alignment since the only available information is USGS base mapping. There may be locations where the required height of supporting columns exceeds design standards and other locations where the vertical curve requirements cannot be met for this alignment due to the existing ground profile. This can only be determined by a more detailed assessment of the vertical alignment outside the I-90 right-of-way, which is not part of this effort.

Right-of-Way

The Alternative B alignment is located outside of the I-90 right-of-way for 80 to 85 percent of its alignment. The amount of deviation ranges from as little as 30 m (100 ft) up to a maximum approximate deviation of 1,030 m (3,400 ft.) This amount of deviation permits 400 kmph operations over the entire 197-km (123-mi) route. The deviation would be much greater (up to approximately 1,800 m if the alignment were held along one side of the right-of-way. Figure 2 summarizes the right-of-way requirements for Alternative B.

Design Speed

The design speed for horizontal and vertical geometry along the Alternative B alignment was set at 400 kmph. No speed reductions were imposed on the alignment.

Environmental Impacts

By deviating over approximately 85 percent of its route, the Alternative B alignment is essentially creating a new right-of-way. In some areas, particularly between the New York state line and Springfield, the right-of-way appears to be traversing previously undeveloped or minimally developed areas, which could cause environmental concerns. The guideway itself should be relatively unobtrusive once it is completed. The construction of it through relatively undeveloped areas, however, could result in some impacts. One example where impacts were identified is at the western end of the alignment between West Stockbridge and Beckett. In West

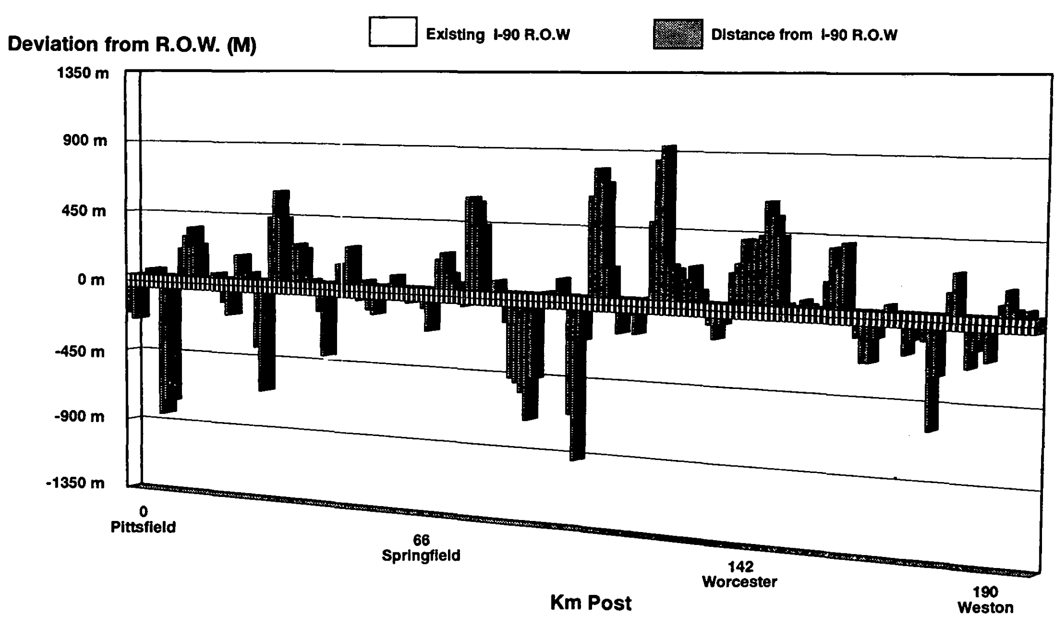

FIGURE 2 Right-of-way requirements for 400 kmph.

Stockbridge, the alignment is located north of the highway and would pass through a series of interconnected wetlands and streams. Just east of this area, the guideway crosses a local mountain. As the guideway passes through Beckett, its path again takes it across a series of interconnected streams, wetlands and ponds.

Between Springfield and Weston, the impacts are similar. In several areas the alignment passes through sensitive environmental areas. One example is in Framingham where the alignment crosses a river, lake and reservoir as a compromise between urban land impacts and environmental impacts. These areas have been highlighted because construction of the guideway would disrupt them at least temporarily. This is not to suggest that the guideway and environment cannot coexist. Rather, it is to highlight the construction issues which will be raised and the potential that operating speeds in some areas may need to be reduced so as to avoid sensitive environmental areas. As previously documented, the operation of a maglev system can coexist with the environment. There is a tradeoff between operating speeds and the environment, which must be defined for this alignment along I-90.

Land Use

By deviating from the I-90 right-of-way, the Alternative B alignment generates additional land use impacts. These impacts occur along both the rural and urban sections of the alignment. Specific references to land use impacts can be cited in numerous locations particularly in Springfield, Auburn, and Weston. Rural land use impacts are easier to address since the area is generally less developed, making it easier to reduce the impact. In urban areas, however, the guideway cuts a path through densely developed neighborhoods and industrial areas. As the French National Railway (SNCF) has discovered with the construction of new high-speed rail lines for the TGV, it may be easier in urban areas to accept lower operating speeds in order to stay within the existing alignment (*6*).

Safety Impacts

In the areas where the alignment is contained within the I-90 right-of-way, the guideway structure should not present any additional safety impacts. In areas where columns would be located in the highway clear zone, appropriate barriers or crush cushions can be installed. At locations where the guideway crosses the highway, guideway spans appear to be of a reasonable length so as not to create a "tunnel vision" effect.

Speed and Travel Time Estimates

Speed and travel time estimates were generated for both alignments using a spreadsheet application for calculations. Train Performance Simulator (TPS) software for maglev vehicles was not available at the time of this study from the U.S. Department of Transportation Volpe Transportation Systems Center.

The route evaluation criteria included terminals in Pittsfield and Weston and off-line stations in Springfield and Worcester. For the station stops, a dwell time of two minutes was used. High-level platforms for rapid discharge and pick-up of passengers were assumed at all four stations. An acceleration rate of 1 m/sec^2 and a deceleration rate of 1 m/sec^2 were used when starting up or slowing down for a station stop. Express services were also evaluated. The speed profiles and travel time bars are shown in Figure 3 for the two alignments.

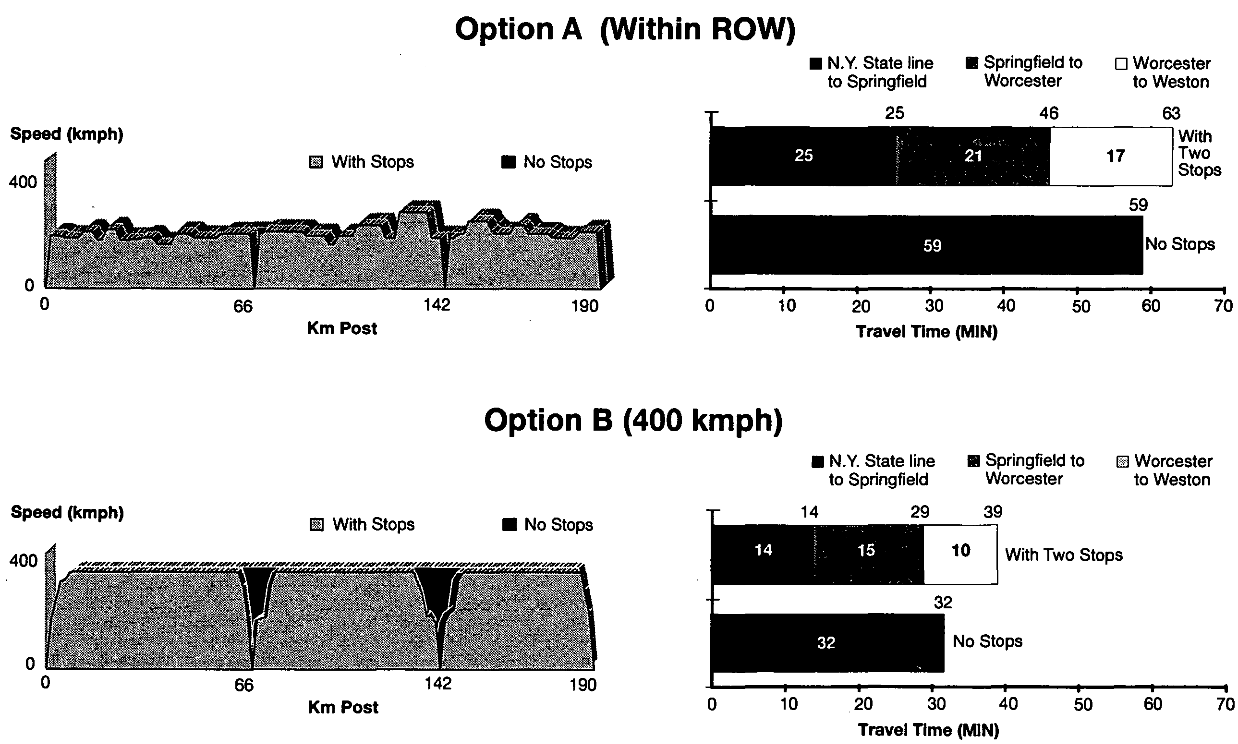

FIGURE 3 Maglev speed profile and travel time.

TABLE 3 Operating Speed Ranges

Speed Range (kmph)	Cumulative Distance In Range (km)	Percent of Total Distance
162 to 176	6.5	3
177 to 192	42	21
193 to 208	61	31
209 to 224	30	16
225 to 240	14	7
241 to 256	6.5	3
257 to 272	0	0
273 to 288	13	7
Accel/decel between ranges	14	7
Accel/decel for stops	10	5
	197	100

1.6 km = 1 mile

In developing the speed and travel time estimates, no attempt was made to adjust for train meets along the single guideway. The purpose of this study was to evaluate the potential speeds along the two alignments given the geometric and vehicle design parameters. Calculation of delays due to scheduled train meets would be part of an overall operating plan which was not part of this study.

Alternative A (Within Right-of-Way)

Along the Alternative A alignment total trip time was 64 min with two station stops for an average speed for 187 kmph (115 mph). Nonstop service took 60 min at an average speed of 197 kmph (123 mph). For both service options, the maximum operating speed attained was 288 kmph (180 mph). This speed was sustained for a distance of 10 km along one section of the alignment. The operating speeds between station stops ranged between 168 and 288 kmph (105 and 180 mph). Table 3 summarizes the operating speed ranges along the Alternative A alignment.

Alternative B (400 kmph)

The Alternative B alignment was developed to sustain an average running speed of 400 kmph over the entire 197-km route. For nonstop service, this represents a travel time of 32 min. With two stops, the trip would be completed in 39 min, representing an average operating speed of 302 kmph (190 mph).

CONCLUSIONS

This preliminary engineering assessment indicates that it is practical to construct a maglev guideway completely within the existing right-of-way between the New York state line and Weston using the Transrapid TR-07 maglev technology. This alignment produces an overall travel time of 64 min (184 kmph) with two intermediate stops and a travel time of 60 min (197 kmph) without any stops. The impacts of constructing the guideway are expected to be similar to the highway since it follows the same general alignment. Impacts on existing adjacent land uses may be generated in the more developed urban areas.

A second alignment which optimized operations at 400 kmph was also considered. This alignment produces an overall travel time of 32 min (376 kmph) without any stops and 39 min (302 kmph) with two stops. To achieve 400 mph operations, the guideway deviates from the I-90 right-of-way over approximately 80 to 85 percent of the route. This deviation raises some significant environmental and land use issues in both urban and rural areas. There is a definable trade-off presented between travel time and potential environmental and land use impacts.

In summary, additional study is recommended along the I-90 corridor to further assess the compatibility of a maglev transportation system. Items which should be addressed include the selection of a right-of-way for the last 19 km of the route from Weston to Boston, the full impact of both alignments on the environment, ridership and revenue estimates, financing options, and other high-speed ground transportation options currently under development.

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