3.7.4 Findings of Field Inspection and Definition of Representative Routes

The I-70 corridor and its secondary corridors present major engineering challenges for the development of any high-speed fixed guideway system. While the topography of the Rockies present significant challenges, access to downtown Denver from the east and west is also difficult. As a result, defining an efficient passenger rail route in the I-70 corridor has the following challenges to overcome:

- Downtown Denver Access
- Access to Black Hawk and Central City
- Steep I-70 grade to El Rancho
- Georgetown to Silver Plume
- The Continental Divide
- Vail Pass
- Glenwood Canyon

The geological and environmental conditions in the mountains make any passenger rail route very expensive, particularly if a technology is limited to a maximum of 4 percent gradient, which requires a greater use of tunnels. As a result, a passenger rail route in the mountains needs several elevated and tunnel sections to provide efficient passenger rail service. For the secondary routes to Steamboat Springs/Craig and Aspen, as well as the main railroad corridor from Dotsero to Grand Junction, planning in coordination with the owners of the existing rail rights-of-way is critical to providing efficient passenger rail service at a reasonable capital cost.

Due to the extreme topography between Denver and Grand Junction, a series of new tunnels are needed to maintain the grade of the high-speed rail route to 4 percent or less. The constrained high-speed rail route within the I-70 rights-of-way has geometry similar to the highway geometry with abrupt curves and 7 percent grades.

It should be noted that a branch line connecting from I-70 to Winter Park was considered, but screened very early in the analysis process. Such a line would have to either cross over or tunnel under Berthoud Pass, introducing a second major crossing of the Continental divide to serve only one ski resort. The cost of this could not possibly be economically supported. However, the development of the existing rail line via the Moffat Tunnel could provide a viable way to provide service not only to Winter Park, but also possibly to Steamboat Springs in the future. This should be evaluated in a future study.

Representative routes for the I-70 corridor have been defined as follows:

From downtown Denver to Golden, the main alternative proceeds south along the BNSF/UPRR joint line (existing rail) onto the US-6 corridor to vicinity of the I-70/C-470 intersection. An alternative representative route proceeds north from downtown Denver on the BNSF Golden subdivision through Arvada to its end at Ford St in Golden. This existing rail route connects with a greenfield route that parallels SH-58 to the Clear Creek Canyon entrance.
From Golden to Floyd Hill, the constrained alternative with 7 percent grades follows I-70 via the El Rancho area to the west intersection of I-70 and US-6. The unconstrained alternative with 4 percent grades follows the Clear Creek Canyon along US-6 to Floyd Hill. Both routes feature a connection to Black Hawk either along SH-119 from US-6 or a tunnel from I-70.

From the interchange of I-70 and US-6 at Floyd Hill, the representative route is either within or contiguous to the I-70 corridor through Idaho Springs and Georgetown. At Georgetown, the route continues either within the I-70 right-of-way or via a new tunnel on the south side of I-70 beginning at the western boundary of Georgetown and exiting on the south side of I-70 west of Silver Plume.

The route continues either within or contiguous to the I-70 corridor to east of the Eisenhower Johnson Memorial Tunnel near the Loveland Pass interchange. At this point, the constrained route continues through a new bore west within or contiguous to the I-70 Corridor to Silverthorne, while the unconstrained alignment would use a new North Fork Tunnel to the Keystone area, with a connecting line following US-6 back to Silverthorne and Dillon.

From the Keystone area the unconstrained route continues to the Breckenridge area south of Lake Dillon to SH-9 with a possible short branch line connection south to Breckenridge. From SH-9, the route either continues through a new Breckenridge tunnel to Copper Mountain or north to Frisco through a short tunnel and continues either within or contiguous to the I-70 corridor to Copper Mountain.

From Copper Mountain, the constrained route either is within or contiguous to the I-70 corridor to Vail, while the unconstrained route proceeds south along SH-91 with a segment through the National Forest to the UPRR Tennessee Pass subdivision at Pando. The route proceeds within or contiguous to the UPRR right-of-way (existing rail but currently not in use) north to Minturn with a branch connection to Vail. The route continues to Avon either within or contiguous to the UPRR right-of-way (lightly used existing rail).

West of Avon to Glenwood Springs and Grand Junction, the representative route includes a segment either within or contiguous to the UPRR right-of-way (existing rail corridor). The representative routes west of Avon also include a possible connection to Yampa, Steamboat Springs, and Craig either within or contiguous to the UPRR right-of-way (existing rail) from Dotsero to Bond to Craig. For this existing rail alternative, a new elevated structure is required at Bond to connect the Glenwood Springs subdivision from Dotsero onto the Moffat Line subdivision to Phippsburg. A potential greenfield alternative route, the “131 cutoff” would run from Wolcott to Bond either within or contiguous to SH-131.

These representative routes also include a segment to Aspen either using a long tunnel from the Gypsum area to the Basalt area connecting to the Roaring Fork Transit Authority (RFTA) right-of-way to Aspen, or the connection to the RFTA line to Aspen can be made by following the existing rail line through Glenwood Canyon to Glenwood Springs.
3.7.5 Proximity of Representative Routes to Intermodal Sites

The I-70 corridor serves Denver International Airport and downtown Denver. The proposed high-speed passenger rail service in the I-70 corridor west of Denver is planned to serve intermodal sites. Use of the BNSF Golden subdivision connecting to the greenfield route through Clear Creek Canyon misses an optimum location for an intermodal site at the C-470 interchange with I-70. Both the constrained I-70 route and the unconstrained route west of this interchange can be positioned near future intermodal sites by using the US-6 corridor west of Denver.

3.7.6 Proximity Representative Routes to Population Centers

The US-6 route from the Denver metropolitan area misses the center of Golden, but adds a valuable suburban stop. The only route that serves the center of Golden is the existing rail route of BNSF Golden subdivision. The constrained I-70 corridor route misses the important resort traffic generators of Keystone and Breckenridge. These areas could still be served by branch lines from I-70. Similarly, the unconstrained greenfield route through Keystone misses Silverthorne and Dillon and serves these communities with a branch line. Secondary corridors, or branch lines, are needed to serve Aspen, Steamboat Springs, Craig, and Black Hawk.

3.7.7 Geometry of Representative Routes

The geometry of the representative routes within the I-70 corridor is complex and challenging: the topographic conditions require numerous horizontal and vertical curves combined with grades up to 7 percent along the constrained alignment. While maglev trains could in theory handle the steep grades, their speed would still be restricted by sharp curves on the mountain corridor. In an attempt to optimize the operations as much as possible, unconstrained routes were developed to improve the geometry and hold the grades to 4 percent or less requiring the use of tunnels at strategic locations along the route.

3.7.8 Route Capacity

The capacity of the greenfield routes is not an issue since the routes are developed for the frequency of service necessary to serve the users, with the exception of the US-6 route between downtown Denver and the C-470 interchange with I-70. RTD proposes to implement light rail transit service that will occupy a portion of the US-6 right-of-way from the Government Center to the Jefferson County Courthouse. However it has been assumed that the construction of a double-tracked intercity rail alignment would still be feasible on this segment through use of elevated structures, if necessary.

The capacity of the existing rail routes is a concern. Both railroad companies need assurance that current and future freight operations will not be harmed by the introduction of passenger rail service. Furthermore, railroad companies have indicated objection to use of their rights-of-way for use by maglev service at grade level because of the use of FRA non-compliant vehicles.

The existing rail route using the BNSF Golden subdivision between downtown Denver and Golden has severe capacity issues from freight operations and the planned implementation of the Gold Line
commuter rail service by FasTracks. Using the alignment of the BNSF Golden subdivision through Arvada would likely require the construction of a tunnel or covered trench to mitigate concerns expressed by the residents. Similarly, the existing rail route using the BNSF/UPRR Consolidated Main Line from downtown Denver connecting to the greenfield route on US-6 near the I-25 interchange is capacity constrained.

The existing rail route of UPRR between Dotero and Grand Junction has capacity issues due to the volume of freight traffic and Amtrak service. Topographical features physically constrain the route from adding additional capacity without a huge cost for infrastructure improvements. The existing UPRR route between Dotero and Bond is also constrained due to the topographical features of the route. Nonetheless a cost estimate has been prepared for adding an additional track to this segment. The UPRR route from Bond to Steamboat Springs and Craig has sufficient right-of-way to add track capacity needed for the introduction of passenger rail service.

The existing rail route from Pando to Minturn and west to Dotero has no current capacity issues related to the introduction of passenger rail service with the exception of a small amount for freight traffic between Dotero and Gypsum. However, this could change in the future. Capacity planning for this corridor must treat it as an active freight line.

3.8 Typical Infrastructure Needs for Steel Wheel/Steel Rail Technology

3.8.1 Trackwork Elements

Existing Rail Routes

Where passenger and freight are expected to share track, it is generally recommended that the existing track be improved with either a 33 percent or 66 percent tie replacement depending on the existing track condition and planned track speed. Where rail conditions are not suitable for passenger operations, the capital cost estimates provide for rail replacement with 136 lb continuous welded rail (CWR). For 110-mpg rail operations in single-track territory, 10-mile long passenger sidings are provided at nominal 50 mile intervals to allow passenger and freight trains to pass. Additional freight sidings are provided between passenger sidings as needed to support whatever level of freight operations are anticipated for the corridor. Shared track is only assumed for adding passenger service to light-density branch lines such as the Milliken and GWRCSO lines. On higher density freight main lines, passenger service may share the right-of-way but usually provides its own dedicated track.

A key engineering assumption adopted for this Study involves the centerline offset between an existing high density freight track and a new FRA Class 6, 110-mpg track. Both UP and BNSF have requested that new tracks be constructed with a minimum 25-foot centerline offset from the adjacent track, where feasible. However, in order to accommodate possible future capacity expansion, especially in congested urban areas, the 25-foot offset will be increased to a 28-foot centerline offset. The 28-foot offset would allow a future siding with 14-foot track centers to be constructed between the new passenger track and the adjacent freight track. Based on the field reviews the costs
associated with the 28-foot offset will be estimated and included under the line item “High-Speed Rail (HSR) on New Roadbed and New Embankment.” Wherever the 28-foot centerline offset is not feasible due to inadequate right-of-way or other constraints, new track would be added at the standard 14-foot centerline offset from the adjacent freight track, but the proposed passenger train speed would be limited to 79 mph.

New turnouts and crossovers would be provided as necessary for operating the passenger service. Physical forces on the passengers, rolling stock and track serve to limit the speed at which a train can safely or comfortably operate through curves. The overall track standard for mixed freight operations is to increase super-elevation to as much as 4½ inches where necessary to achieve desired passenger speeds. For lines with very light freight operations or for high-speed intermodal trains, additional increases in super-elevation might be possible, but in no case will superelevation exceed the value that balances freight speed at 60 mph or be greater than 6 inches. Where heavy freight operations (e.g., slow coal trains) predominate, lower levels of super-elevation must be used. Because of the high density of freight operations on most Colorado rail lines, shared track is rarely feasible for this study, which has assumed practically all dedicated track.

Greenfield and Highway Routes

The I-70 and I-25 highway corridors (constrained) were examined to determine the feasibility of placing high-speed guideways within or near them. Unconstrained greenfield alignments were also developed for the assessing the feasibility of constructing high-speed guideways. The engineering assessment developed and plotted alignments on a scaled map to optimize the vertical and horizontal geometry needed to ensure efficient high-speed rail operation and to quantify infrastructure needs for determining the significant cost elements. Capital cost estimates are presented in Chapter 8.

Vertical geometry is an essential ingredient to maximizing speed, and the type of infrastructure section needed to obtain minimize vertical curves is directly related to the terrain. A rolling terrain may require elevated structures of several types to eliminate sudden dips or drop-offs. The profile of vertical alignment for high-speed rail must use smooth long vertical curves to ensure that the technology used can travel at its optimum speed. Other elements, such as roadway crossings, stations, and railroad bridges are specific to the greenfield and technology evaluated. The cost of many high-speed rail system components in greenfields is a direct function of the length (track, signals, communications, and electrification) and topography.

Track Work Typical Sections

Exhibit 3-50 is typical of the rail section that is required for a double track rail section. Unit costs will be presented in Chapter 8.
Rail sections are constructed on embankment with the depth of embankment used to even a rolling terrain. Double track retained earth fill is used to even the gradient and build the alignment to the planned profile. For development of cost estimates, scaled topographical maps were used to quantify the need for retained earth fill along the greenfield routes. Exhibit 3-51 is a photograph of double track retained earth fill.
Exhibit 3-51: Double Track Retained Earth Fill

Source: Reinforced Earth Company

The medians of both the I-25 and I-70 corridors are considered for use as high-speed rail greenfield alignments. The Tampa–Orlando High-Speed Rail Study conducted in 2003 used the median of I-4. The Federal Highway Administration and Federal Railroad Administration mandated the use of Type 6 median barriers on curves between the highway and median in order to keep highway vehicles from entering onto the high-speed rail track structure. Exhibit 3-52 depicts an approved NCHRP Class 6 Barrier.

3.8.2 Structures – Approaches, Flyovers, Bridges, and Tunnels

Existing Rail Routes

A complete inventory of bridges was developed for each existing rail route from existing track charts. For estimating the quantity and costs of new structures along existing rail routes, conceptual engineering plans and per lineal foot cost estimates developed on previous studies were used.

Greenfield Routes

As noted in the trackwork section, maintaining an alignment with minimal vertical and horizontal curves is the key to operating an efficient high-speed rail service. Where the change in elevation between the planned profile and the ground exceeds 40 feet, the use of flyovers and bridges is necessary. The bridge approaches begin with retained earth fills up to 15 feet onto approach embankments. Exhibit 3-52 shows an example of an approach embankment on retained earth fill. If the difference between the alignment profile and the ground is greater than 40 feet then an elevated structure is required. Exhibit 3-53 is an example an elevated rail structure that can be used up to
heights of 60 feet. For heights greater than 60 feet, a high level bridge structure is necessary, as shown in Exhibit 3-54.

Exhibit 3-52: Example of Approach Embankment for Double Track

Source: Reinforced Earth Company

Exhibit 3-53: Example of Low Level Double Track Elevated Structure

Source: Reinforced Earth Company
Exhibit 3-54: Rail Section: High Level Structure for Double Track

Source: Tampa to Miami Feasibility Study, Florida HSRA, March 2003
The representative greenfield routes would include tunnels to minimize grades or reduce distance between stations. Rail alignment alternatives through the Rocky Mountains would require a significant amount of tunneling to maintain operable and safe grades, avoid areas prone to rock falls and avalanches, and provide the shortest routes. The recommended configuration for long term operations of high-speed system would dictate twin parallel tunnels, connected with cross-passages and bores large enough to provide safe egress and supply proper ventilation and ventilation controls in the event of a fire or mishap in the tunnels. Exhibit 3-55 shows a section of the Gotthard Base Tunnel in Switzerland and demonstrates the complexity of tunnels. Aside from the short tunnels proposed route on US-6 through Clear Creek Canyon, the major tunnels along the I-70 corridor and their proposed lengths are as follows:

- Black Hawk Tunnel 6,000 LF
- Georgetown Tunnel 14,000 LF
- North Fork Tunnel 30,000 LF
- Swan Mountain Tunnel 12,000 LF
- Frisco Tunnel 6,000 LF
- Breckenridge Tunnel 22,000 LF
- Aspen Tunnel 51,000 LF

A technical memorandum, Rail Tunnel Evaluation for the Rocky Mountain High-Speed Rail Feasibility Study prepared by Myers Bolke Enterprise, LLC is included in the Appendix G.

Exhibit 3-55: Tunnel section showing crossovers, connecting galleries, and emergency stations

Source: The New Gotthard Rail Link, AlpTransit Gotthard, LTD, November 2005
3.8.3 Systems

Modern train control and communication systems safely coordinate train operations to permit bi-directional use of a track network. On heavily used lines, railroads have installed Centralized Traffic Control (CTC) to maximize track capacity. CTC is a system of signal blocks, track circuits, controlled switches, wayside signals (or cab signals), interlockings and communications to a central control facility that enable trains moving in a common direction to follow closely on a common main track or pass opposite direction traffic on siding tracks. Under CTC, a remotely located dispatcher can control train routing. However, train speeds are limited to 79 mph.

FRA regulations require that trains operating in excess of 79 mph employ advanced signal systems that provide cab signaling and automatic train protection or automatic train stop functions. Such track circuit based systems in use today are very expensive to construct and maintain. To develop a more cost-effective technology, FRA and the rail industry have turned to Positive Train Control (PTC), a new communication-based strategy that does not depend on track circuits to establish train location. Multiple research and development efforts in the United States are currently evaluating advanced train control systems:

- ITCS: The Michigan DOT, FRA, and Amtrak are advancing a project to implement an Incremental Train Control System (ITCS) in Michigan. The ITCS system, developed by General Electric Transportation Systems, is being tested on a 60-mile portion of the Chicago-Detroit High-Speed Rail Corridor between Kalamazoo and Niles, MI. The system has been in commercial operation since January 2002 and speeds have been gradually increased from 79 to 95 mph and are expected to reach 110 mph in January 2008.

- NAJPCT: The Illinois DOT, the Association of American Railroads (AAR), Union Pacific and FRA have tested a Positive Train Control project (PTC) on a 123-mile segment of the Chicago-St. Louis High-Speed Rail Corridor from Mazonia to Springfield, IL. The contractor, Lockheed Martin, successfully demonstrated 110-mph passenger operations in a field trial in 2002. The system has been removed from operation and transferred to AAR’s Transportation Technology Center in Pueblo, CO for further development.

- BNSF, CSX and NS have developed systems independently to provide PTC functions, principally for freight applications.

The capital cost estimates used in Chapter 8 for this study will include costs to upgrade the train control and signal systems. Under the 79-mph scenario, capital costs will include the installation of CTC with interlockings and electric locks on industry turnouts and a PTC overlay system suitable for operation at that speed. Under the 110 mph or higher speed scenarios, the signal improvements include the added costs for a vital PTC system that can replace cab signal functionality.

The system element for magnetic levitation systems consist of propulsion, control, and communications systems including: civil structures for substations and cable trenches; propulsion blocks; propulsion equipment for low, medium, and high power; motor windings; wayside equipment; propulsion maintenance equipment; operation control subsystems for communication and data collection; and associated civil structures.
3.8.4 Curves

Track alignment curvature is normally expressed in degrees. Two measures can actually be used to determine the degree of curvature. The first is the number of degrees of rotation from a tangent or straight line that the track curves in 100 feet length. The second measure is the inches of variation on the outer rail from the center of a 60-foot chord stretched along the track. For the wide curves employed for fixed guideway systems, these two measures are essentially equal. Curves in a slow-speed yard environment may be as tight as 12 to 15 degrees, with 15 degrees representing the practical sharpest radius of curves used by modern heavy-duty freight locomotives. Many of the former narrow gauge lines in Colorado routinely used curves of 15 degrees or even more, some of those lines that were standard-gauged, such as sections of the UP Joint Line and Tennessee Pass route, are still in service today. Modern mainline track or Maglev guideway generally is laid at three degrees of curvature or less, in the interest of maximizing allowable speed and minimizing friction and drag. Exhibit 3-56 shows the relationship between the measurement of curvature in degrees, and the radius of the curve in feet.

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<thead>
<tr>
<th>Degree</th>
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<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>2,865 feet</td>
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<tr>
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<td>5</td>
<td>1,146 feet</td>
</tr>
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<td>6</td>
<td>955 feet</td>
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The very large difference in radius between a three degree and a one degree curve is about three-quarters of a mile. In most cases, if a restrictive curve on an existing rail or highway alignment were eased to a larger radius to increase running speeds, the new alignment would require the acquisition of an entirely new right-of-way.

An additional engineering feature of curves on high-speed track and guideway is a spiral. This is simply a transition area coming into and out of a curve, so the curvature gradually increases in tightness and in super-elevation so that there is not a sudden lurch or sideways acceleration caused by an abrupt change. Properly designed spirals permit curves to be operated at maximum speed. Improperly designed spirals can cause a lurching effect as trains enter curves, degrading ride quality and possibly even limiting trains to slower speeds.

One method for increasing speed through curves is to cant or bank the track or guideway as on a highway curve or a speedway embankment. This is known as super-elevation. It is measured in inches of difference between the inner and outer rail, based on a level line across the rails or guideway, or in degrees of inclination, which turns out to be practically equivalent measures. The
banking offsets the train’s centrifugal force in the curve with an offset in the car’s center of gravity. Significant speed improvements can result, especially for passenger equipment.

The stable characteristics of rail passenger equipment allow for under-balancing, which allows a train to go around a curve faster than its balancing speed. “Cant deficiency” is defined as the amount of additional track superelevation that would be needed to completely cancel out the sideways force in a curve. Riders on the train or maglev going faster than the balancing speed would then feel a centrifugal force towards the outside of the curve. Heavy bulk freight rail lines use minimal superelevation because of the relatively slow speed of the freight trains – often limited to one and one-half inches maximum super-elevation. Shared passenger and high-speed freight mains are often laid with four to five inches of super-elevation which is the commonly accepted limit for freight trains. However, dedicated passenger tracks can have six or even more inches of super-elevation.

- For rail equipment, tilt technology raises the allowable under balance (or cant deficiency) for passenger trains. For conventional non-tilting rail equipment, passenger comfort limits the allowable deficiency to four inches. (The train could safely go around the curve faster than this without jumping the track, but the sideways force could throw some passengers off their feet.) Tilting the vehicle allows trains to go around curves faster while still maintaining passenger comfort. Typically the sideways force is not completely cancelled, because leaving a small feeling of going around a curve helps prevent motion sickness. So instead of being limited to four inches of deficiency, passive tilt systems allow this to be increased to six or seven inches of deficiency with about four inches of tilt. Some European trains with active tilting systems have utilized as much as twelve inches of cant deficiency with nine inches of tilt going around curves. This tilt works in addition to the amount of super-elevation that has been physically built into the tracks to ensure passenger comfort.

- Maglev performance is similarly affected by curves, since maglev vehicles, unlike rail, do not provide for any internal tilt mechanism. All superelevation for a maglev has to be provided by the guideway itself. Presently both the HSST and Transrapid maglev systems limit superelevation to 12 degrees, which provides essentially the same speed around curves as that of a tilting rail vehicle on conventional track.

As a result, the curving performance of existing maglev and rail technologies are essentially the same. Some maglev advocates have suggested tilt capability greater than 12 degrees, but applying this level of super-elevation may start to give ride characteristics similar to that of an aircraft, which is allowed up to 20 degrees of superelevation. However, this imposes operating cost penalties in terms of having additional safety staff, seat belts, and seating requirements.

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4 However, on shared freight tracks as will likely occur in the I-25 corridor, excessive super-elevation can create a tipping force on slow freight trains towards the inside of the curve. This can lead to excessive wear on the inside rail and a shift in the rail and roadbed, where the inner rail sinks further because of loads and impacts, worsening the effect. In extreme cases, it could cause slow-speed derailments in the curve.

5 The remaining uncompensated deficiency, which passengers feel as an outward force going around curves is about 3 inches, slightly less than the 4 inches they would have experienced on conventional non-tilting equipment. This is perceived as an improvement in ride quality.

6 Six inches superelevation plus six inches of tilt on a rail vehicle produces the same lateral force as 12° of superelevation on a non-tilting maglev. By comparison, Amtrak’s Acela’s active tilting system can provide almost seven inches of tilt, so Acela already exceeds the curving capability of the maglev.
The following table illustrates the effect of varying applications of super-elevation on passenger train or maglev speeds. The speeds in the first part of Exhibit 3-57 are for conventional, non-tilting passenger trains. They allow the passenger train to go through a curve slightly faster than the actual balancing speed for the curve. For example a two-degree curve with four inches of super-elevation and 3.5 inches of under balance (or cant deficiency) produces an effective capability to go around the curve based on the equivalent balancing speed for 7.5 inches of superelevation. Higher speeds are attainable by a train that has a passive tilt system installed, like the Talgo T-21.

### Exhibit 3-57: Passenger Reference Speeds*

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</table>

*Note: Superelevation above is the "Actual Superelevation" and "Superelevation Under balance" or Cant Deficiency is assumed to be 3.5 inches and 6 inches

As a result, it can be seen that a two-degree curve for conventional equipment limits train or maglev speed to only 73 mph\(^7\). For tilting equipment on a dedicated track, this can be increased to 93 mph\(^8\). Curves greater than two degrees start to impose severe speed limits on operations. For example, a 3-degree curve pushes the speed down to only 56 mph\(^9\). A 6-degree curve, which is common along the I-70 alignment, would limit the speed of either a tilting train or maglev vehicle to just 53 mph\(^10\). A few isolated curves of this degree will not have that much impact on overall system performance but to the degree that the curves are closely spaced, the vehicle will not have the ability to accelerate back to high-speed before it has to start slowing down again for the next curve.

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\(^7\) Four inches of supererelevation with 3.5 inches of cant deficiency  
\(^8\) Six inches of supererelevation with 6 inches of cant deficiency  
\(^9\) Three inches of supererelevation with 3.5 inches of cant deficiency  
\(^10\) Six inches of superelevation with 6 inches of cant deficiency
The conclusion is that it is practically necessary to limit curves to 2-degrees or less, except in special instances, to support 90-mp operation along the corridor. This is equally true for either rail or maglev technologies. The issue of curvature rather than gradient therefore, may in fact prove to be the most limiting factor for attaining high-speeds along the I-70 alignment. It is best dealt with by allowing the rail or maglev alignment to deviate from the existing highway alignment, where necessary and possible, by reducing the curvature to 2-degrees or less. For train performance evaluation in this study:

- Diesel-powered trains used for the 110-mp evaluation limit cant deficiency to 6” along with a maximum of 6” superelevation on dedicated tracks. This is consistent with the diesel tilting trains assumed in previous studies such as the Midwest and Ohio systems. It is also consistent with Exhibits 3-15 and 3-19, and with the capabilities of passive tilt trains such as the Talgo T-21.

- Electric-powered tilting trains assume a slightly higher level of 7” of cant deficiency along with a maximum of 6” superelevation on dedicated tracks. This is consistent with the tilting Acela electric train that utilizes an active (computer controlled) tilting system, and is currently certified by the FRA for operation in the Northeast Corridor at up to 7” of deficiency.

### 3.8.5 Highway Grade Crossings

The treatment of grade crossings to accommodate 110-mp operations is a major challenge to planning a high-speed rail system. Highway/railroad crossing safety will play a critical role in future project development phases and a variety of devices will be considered to improve safety, including roadway geometric improvements, median barriers, barrier gates, traffic channelization devices, wayside horns, fencing and the potential closure of crossings.

FRA guidelines require the use of four quadrant gates with constant warning time activation at public crossings for 110-mp passenger operations. Constant-warning time systems are essential to accommodate the large differential in speed between freight and passenger trains. The treatment and design of improved safety and warning devices will need further development to identify specifications and various approaches that may be advanced as part of an integrated program in Colorado.

There are numerous grade crossings through urban areas. For many of these, speed restrictions will be assumed, but there are others where high-speed operations are essential to the success of the rail system.

Grade crossing improvements are a significant component of the capital cost estimates for passenger rail service in this study. The following strategy has been employed to develop the cost estimates:

- Where passenger speeds are greater than 79 mph, 25 percent of the existing private crossings on the route will be closed.
- Where speeds do not exceed 79 mph, private crossings will not be affected.
Where passenger speeds are greater than 79 mph, public crossings will be upgraded to four quadrant gates with constant warning time, and remaining private crossings will be upgraded to four quadrant gates.

Where passenger speeds do not exceed 79 mph, public crossings warning systems will be upgraded to standard two quadrant gates, and flashers with constant warning time and remaining private crossings will be upgraded to standard two quadrant gates and flashers.

Precast panels will be installed at all public crossings.

Where new track and embankment are constructed, precast panels will be installed and roadway surfaces improved at public crossings.

### 3.9 Infrastructure Needs for Maglev Technology

Maglev technologies have slightly different structural needs than do rail technologies. Maglev vehicles tend to be lighter, so somewhat lighter structures can often be employed. Even so the vehicle itself requires guideway support, which requires a beam structural element be provided even on level ground. Essentially the maglev guideway requires a continuous bridge structure although some cost savings are still possible if the beam can be brought down as close to ground level as possible. At-grade maglev systems of course, since the access to the right-of-way must be totally controlled, must have complete fencing to prevent any incursions on the right-of-way.

#### 3.9.1 At-Grade Guideway

The at-grade maglev guideway section shown in Exhibit 3-58 was used in this study at locations allowing the guideway placement at or near ground level. The precast concrete or steel beams have typical spans of 25 feet. The section can be curved or superelevated to meet alignment requirements. At each support, grade beams serve as either pile caps or spread footings.

![Exhibit 3-58: At-Grade Guideway](image)

**Aerial Guideway – Type A, Single Columns**

Source: SANDAG Maglev Study Phase 1, Final Report
The aerial guideway section shown in Exhibit 3-59 was used in the constrained and unconstrained greenfield routes to maintain the planned profile in mountainous areas of I-70 and the rolling terrain of the Front Range and Eastern Plains of the I-25 corridor. This section was used when the difference between the planned profile and ground is less than 65 feet. The typical span is 100 feet. The structure is usually continuous over multiple spans but can be curved and super elevated to meet geometric and lateral acceleration requirements.

Exhibit 3-59: Aerial Guideway, Type A

![Aerial Guideway, Type A](source)

Source: SANDAG Maglev Study Phase 1, Final Report

### 3.9.2 Aerial Guideway – Type B, Straddle Bents

The constrained greenfield routes in the I-70 corridor have numerous horizontal curves. In order to minimize the curvature, the geometric alignment crosses over I-70 several times making it impossible to use the Type A section. Therefore, a straddle bent was used to laterally span the travel lanes of I-70. Exhibit 3-60 depicts the straddle bent.

Exhibit 3-60: Straddle Bent over Highway Lanes

![Straddle Bent over Highway Lanes](source)

Source: SANDAG Maglev Study Phase 1, Final Report
3.9.3 Bridge Structures
Bridge structures for maglev are required for spans exceeding 100 feet or column heights greater than 65 feet. Since these limits are exceeded primarily in remote mountainous terrain, precast concrete segmental structures constructed using the balanced cantilever method was assumed. In order to minimize deflection, the spans are limited to 200 feet. The bridge structure supports at grade girders that are mounted to the deck of the bridge with small pedestals. Exhibit 3-61 depicts this bridge structure.

Exhibit 3-61: Bridge Structure, SANDAG Maglev Study Phase 1, Final Report

3.9.4 Tunnels
In order to improve maglev operations in mountainous areas, tunnels are necessary to reduce unreasonable grades and maintain a smooth profile with long vertical curves. Two types of tunnels were considered in this study. Type A, as shown in Exhibit 3-62, is a two bore tunnel for use in shallow or short tunnels. Type B, as shown in Exhibit 3-63, is a two bore tunnel with a third bore for service and relief for use in deep or long tunnels. Within the tunnel, girders are still required to support the train and associated propulsion system. Each bore requires separate 37 ft. diameter tunnel due to the high train speeds. For long Type B tunnels, an additional 20 ft. diameter ventilation shaft with ducts periodically connects to the riding tunnels for pressure equalization.
Exhibit 3-62: Type A Shallow or Short Maglev Tunnel

Exhibit 3-63: Type B Deep or Long Tunnel

Source: Maglev Study Phase 1, Final Report
3.9.5 Maglev Propulsion, Communication and Controls

Wayside components are needed in the right-of-way to provide basic operations of the maglev system and are of five distinct types, each with its own size/space requirements and specialized technical functions. These types include:

- Propulsion system switching stations
- Transformer stations
- Radio transmission masts/transceivers
- Guideway switch stations
- Cable routes/trenches

Exhibit 3-64 shows the components that comprise wayside equipment for maglev operations under both elevated and surface conditions.

**Exhibit 3-64: Maglev Propulsion, Communication and Controls**

Source: SANDAG Maglev Study Phase 1, Final Report

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3.9.6 Operations and Maintenance Facilities: Rail and Maglev

When planning for maintenance facilities, the size of the facility is an important consideration and will vary depending on the purpose and available locations along the route. Normal maintenance functions include daily cleaning, washing, inspection, repairs, scheduled and unscheduled maintenance, condition monitoring, replacement of vehicle or facility components, and storage. For a first approximation, normal maintenance functions (vehicle parking, washing, preventive maintenance, inspection, etc.) were sized according to the length of complete consists or train sets. Therefore, the size of the maintenance facility needed is based on the train sets required. For example, the Draft Environmental Impact Statement for the Pittsburgh maglev project includes a drawing of a combined operation control center /maintenance facility that requires approximately 35 acres, as shown in Exhibit 3-65.12 Rail maintenance facilities are sized and configured very similarly.

Exhibit 3-65: Proposed Central Maintenance Facility (Pittsburgh, PA)

Source: Pittsburgh, PA Maglev Project website at www.maglevpa.com

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3.10 Summary

Representative routes were developed for the I-70 and I-25 corridors. These representative routes were based on the FRA route guidance manual. While the routes are not optimal and have not been subject to any formal environmental analysis, every effort has been made to avoid fatal flaws and develop routes that have a good prospect of being mitigated in any comprehensive environmental study. These routes were developed to support a Feasibility-level economic analysis to help Colorado understand the technology implications and development potential for a statewide intercity rail system. These routes are likely to be used as a possible input to a NEPA evaluation process. The options evaluated here were not intended to be an exhaustive list of all possible options, nor are any screening recommendations developed at this feasibility-level completely final. Rather there is still ample room for adjustment of route specifics during the NEPA process.