4 Route and Technology Options

This chapter will establish “base case” alternatives used for both the technology and routes to be evaluated as part of the RMRA High-Speed Rail Feasibility Study. For each alternative the aim is to produce a reasonable representative option for the type of technology. In the case of the slower speed alternatives (79-110 mph), the most effective option is to use existing railroad rights-of-way and where the volume of freight rail traffic is limited, to share tracks with freight traffic. As speeds and frequency of passenger rail service increase, first the ability to share tracks with freight becomes more limited, although the right-of-way may still be shared. For very high-speeds the ability to even use existing railroad rights-of-way is lost. Of course, sharing track or using freight rail right-of-way may still occur (at lower speeds) in urban areas to gain access to downtown stations, but away from the urban area true high-speed service is likely to require a greenfield route -- since high-speed rail operation need long stretches of straight track and very gentle curves to achieve high-speed. Exhibit 4-1 shows that higher speed routes usually have fewer stations since the distances needed to get up to speed and to stop are much longer. In general, faster systems have fewer stops. A compromise may be needed to ensure all key communities are served, but this results in a trade-off between end-to-end speed and connecting communities. Each station stop takes three to seven minutes (including deceleration, stop time and acceleration back to speed) so multiple stops soon dramatically increase end-to-end running times.

In terms of the route and technology framework, three sets of scenarios need to be identified:

1. Station locations
2. Representative technologies
3. Representative routes

4.1 Potential Stations

Station selection determines where the tracks have to go, and thus constrains the alignment choices. For this study, Exhibit 4-2 shows the potential stations that have been considered. The large green stations define the major production and attraction locations that must be served; the smaller red stations show what is thought to be desirable if possible. Red stations could be bypassed if necessary without undermining the financial viability of the system. Service to the green stations is considered vital to maintaining the ridership base of the system. (Exhibit 4-2 is a simplified schematic that focuses on the definition of station locations. It does not include junctions or route alternatives that were developed later in the study.)
Increased Speed Means Greater Station Spacing

Exhibit 4-1: Station Spacing Increasing with Speed

- **Local Bus (10 mph)**: 2-4 blocks
- **Commuter Rail (30-50 mph)**: 3-7 miles
- **High-Speed Rail (90-120 mph)**: 10-30 miles
- **Very High-Speed Rail (120-200 mph)**: 20-50 miles
- **Maglev (250 mph)**: 20-100 miles
Denver CBD and DIA are the largest producers and attractors of trips, while the three Denver suburban stations (North, South, and Golden) reflect the fact that individuals tend to drive towards their destinations, and do not like to drive backwards to take a train. For example, individuals traveling to Colorado Springs from Denver, who live in southern suburbs such as Littleton, Lone Tree or Parker are likely to want to drive to a southern suburban station located on E-470, rather than drive to the Denver CBD. These may well be large stations with significant car parking needs. Ft. Collins, Colorado Springs, and Pueblo are all major production and attraction centers along the I-25 corridor, while Loveland, Greeley, Longmont, Boulder, Castle Rock, Monument, and Trinidad are secondary stations.

Along the I-70 corridor it is the ski, casino and tourist resorts that are the major attractions. These resorts attract millions of visitors each year, which in any intercity context makes them attractors as large if not larger than the major towns and cities of the Front Range with the exception of Denver. Service to the small red stations is likely to be more limited than to the green stations and may only receive four to six trains per day in both directions compared with the twelve to twenty-four trains per day in both directions for the green stations.
The selection of station stops was largely market driven (i.e., the stop represents a major attraction or destination, as described in Chapter 2.) However, the study team received input on acceptability from the public outreach workshops, the I-70 Coalition and Colorado MPO’s and other major transportation authorities such as Denver International Airport and RTD.

4.2 Representative Technologies

For the purpose of evaluation, vehicle technologies have been clustered into five generic technology categories, where each category corresponds to a specific vehicle technology and performance capability. The five categories that have been used as the basis of the evaluation are shown in Exhibit 4-3. It shows that four different rail technology groups and two maglev groups have been established, based on the maximum speed capability of the vehicle type on straight-and-level track.

Exhibit 4-3: Generic Technology Categories by Speed Range

<table>
<thead>
<tr>
<th>Speed Range</th>
<th>79 mph</th>
<th>110-130 mph</th>
<th>150 mph</th>
<th>220 mph</th>
<th>250-300 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Maglev</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

By defining Generic Technology categories, route evaluations are valid for a range of equipment options rather than only for one specific manufacturer’s train. To optimize the match of train equipment to the characteristics of the route, it is standard business practice in the transit industry to issue a Performance Specification as a part of a competitive equipment procurement process. Since the proposed Colorado I-70 corridor would be unique in the world, no existing or off-the-shelf train can reasonably be expected to meet all of Colorado’s requirements. (Appendix J gives AGS performance criteria specified by the I-70 Coalition for EIS planning.) Even so, all of the features or components that need to be combined to create a Colorado train have been proven and are operational in revenue service in numerous applications throughout the world. Furthermore, for specifying train performance (e.g., rates of acceleration, performance on grades, and tilting capability through curves) the approach adopted is one of reasonable conservatism. Doing this in the equipment Performance Specification ensures that the operational analysis and financial projections are also conservative, increasing confidence that the system can be realized in practice.

Use of a Performance Specification will ensure the ability to maintain a competitive equipment procurement process, since in most cases several manufacturers could meet the performance criteria that are specified for each generic category. Therefore, each defined equipment category can be considered an appropriate basis for development of an RMRA equipment performance specification. The vehicle technology analysis is based on this performance specification, which represents a composite of proven equipment technologies, rather than on the characteristics of any single specific existing or “off-the-shelf “train.
As shown in Exhibit 4-3, there are four categories to reflect rail (steel wheel) vehicles, while two categories are for maglev technologies. The top two rail categories are very similar reflecting modern high-speed train designs, the main difference being that the 150-mph category is electric locomotive-hauled, whereas the 220-mph category has distributed power under the train (Electric Multiple Unit, or EMU).

For both rail and maglev, an important criterion for this study is that the technology must be proven in revenue service. All four kinds of steel wheel vehicles are in revenue service today. With respect to high-speed maglev, the Transrapid system is in revenue service today. The Tobu Kyuryo Line in Nagoya, Japan demonstrates the feasibility of the low-speed maglev concept that was envisioned by the 2004 Colorado Maglev Study, although this concept would require considerable additional development to achieve the 110-130 mph speed capabilities that were envisioned by the 2004 report.

A key requirement of this study is that all proposed technologies should be capable of receiving required regulatory approvals within the implementation time scales of the project. This section will assess relevant proven technology options and their potential speed, focusing on existing technologies that have been proven in actual revenue service, and clustering the technologies into generic categories.

Some have advocated new or “novel” technologies for potential application to the Colorado corridors. However, the funding grant from the Colorado Department of Transportation specifically excluded detailed consideration of novel technologies from this study, restricting application of funds only to proven technologies. Per direction from the RMRA and CDOT, novel technologies can not be evaluated at the same level as proven technologies because:

- The CDOT Transportation Commission Resolution Restricting Front Range Commuter Rail Study passed 6 to 1 in November 2006.
- DMU, EMU, Diesel Locomotive Hauled or Magnetic Levitation are the only technologies allowed by the Transportation Commission because of work done previously in I-70 Draft PEIS.

As part of this study, however, a technology survey was conducted that includes novel technologies so their development potential for possible long-run implementation in Colorado can be understood. It is important to note that the main focus of this study was to conduct a market and economic assessment for existing technology. To the degree that any novel technology can fully satisfy the vehicle performance requirements assumed by a generic category, then the market and economic assessment developed by this study should be applicable to that technology. The key results of the Novel technology survey are summarized in Appendix K.

### 4.3 Generic Technology Categories

This section addresses the speed ranges that characterize rail and maglev technology capabilities. Within these ranges any number of specific technologies could be chosen depending on how practical and cost effective they are for achieving any given speed.
**Conventional Rail** - 79 mph or less: Conventional trains, as shown in Exhibit 4-4, can operate at up to 79 mph on existing freight tracks. 79 mph represents the highest speed at which trains can legally operate in the United States without having a supplementary cab signaling system on board the locomotive. The key characteristics of these trains are that they:

- Are designed for economical operation at conventional speeds
- Can be diesel or electric powered
- Are non-tilting for simplified maintenance

Because of the focus on economy these trains sacrifice performance; for example, the decision to employ non-powered “Cabbage Cars” rather than powered locomotives on Talgo trains currently operated by Amtrak in the Pacific Northwest. Double deck trains such as operated in California also seek to minimize cost rather than maximize speed but in the process, they sacrifice the time-competitiveness of the rail service as compared to driving, except in the most extremely congested highway corridors.

Both FRA compliant and non-compliant equipment fall into this conventional rail category. Representative trains include the conventional Amtrak train, compliant Colorado Railcar DMU and non-compliant Stadler FLIRT EMU, all pictured in Exhibit 4-4 on next page. (Colorado Railcar has gone out of business but the production rights to the DMU vehicle have been purchased by a firm called US Railcar, who is establishing a new production facility in the Midwestern US.)

**Exhibit 4-4: Conventional Rail – Representative Trains**

![Conventional Amtrak](image1)

![Colorado Railcar DMU](image2)

![Stadler FLIRT EMU](image3)
High-Speed Rail - 110-130 mph: A 110 to 130-mph service can often be incrementally developed from an existing conventional rail system by improving track conditions, adding a supplementary Positive Train Control safety system, and improving grade crossing protection. Tilt capability, built into the equipment by allowing trains to go around curves faster, has proven to be very effective for improving service on existing track, often enabling a 20-30 percent reduction in running times. Trains operating at 110 mph, such as those assumed for the Midwest and Ohio Hub systems, have generally been found to produce auto-competitive travel times, and are therefore able to generate sufficient revenues to cover their operating costs. High-speed trains:

- Are designed for operation above 100 mph on existing rail lines
- Can be diesel or electric powered
- Are usually tilting unless the track is very straight

In the United States, 110-mph service provides a low cost infrastructure option by using existing railroad rights-of-way, and quad-gating crossings, which are relatively low cost options. The costs of grade separation for 125 mph can easily double the capital cost of a project, as the number of public and private crossings can be as many as two per mile. Once full grade separation has been accomplished however, speeds can be pushed up to 150 mph or even higher to improve the economic return on that investment.

Representative trains include the Talgo T-21 diesel locomotive hauled trains, the Flexliner DMU, the X-2000 Electric locomotive hauled train and the ICE-T EMU, all pictured in Exhibit 4-5 below. It should be noted that the ICE-T is a derivative of the higher-powered ICE-3 train that operates at 186 mph on dedicated new tracks. The ICE-T extends the reach of Germany’s high-speed train network into the Swiss Alps. It is included in this category because of its tilting capability.

Exhibit 4-5: High-Speed Rail – Representative Trains

<table>
<thead>
<tr>
<th>Talgo T21</th>
<th>Flexliner DMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>X 2000</td>
<td>ICE-T EMU</td>
</tr>
</tbody>
</table>
**High-Speed Maglev** - 110-130 mph: For this evaluation, the 2004 *Colorado Maglev* proposal represents the High-Speed category. At present, this type of system has been implemented only in a low-speed urban transit application. Whereas high-speed maglev systems place the linear motor on the guideway (Linear Synchronous Motor, or LSM), low-speed systems place the motor on board the vehicle (Linear Induction Motor, or LIM) to reduce cost. Because of this, a LIM vehicle must be heavier than a LSM vehicle of equivalent capacity. The Japanese HSST is the best example of this type of urban maglev with a 5.5-mile operating line in Nagoya, Japan (see Exhibit 4-6). American Maglev and General Atomics both have similar urban maglev concepts on test tracks. The current HSST was designed as an urban transit mode, not as a high-speed system. It has a top speed of 65 mph\(^1\). The HSST technology would have to be adapted significantly to meet the speed requirements needed for high-speed service in Colorado. The key characteristics of these trains are:

- They are high-speed derivatives of urban maglev designs, as opposed to systems that were designed from the beginning to go as fast as possible.

- The HSST urban maglev system is operational and others are on test tracks, but the modifications needed to prove high-speed capability are still in the R&D phase.

For evaluation purposes in this study, however, both systems are treated as if they were operational today, on the basis of the system specifications as outlined in the 2004 *Colorado Maglev Study*.

**Exhibit 4-6: High-Speed Maglev – Representative Trains**

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**Very High-Speed Rail** - 150-220 mph: This category covers two types of electric trains. The early French TGV and German ICE were locomotive-hauled trains. These operated initially at 150 mph and were improved to 186 mph. To go even faster, up to 220 mph, as well as improve the hill-climbing capabilities of the trains, both the French and Germans have shifted towards Electric Multiple Unit (EMU) designs with their latest generations of Alstom’s AGV and Siemens’ ICE-3 trains.

Rather than using locomotives, the EMU design places traction motors underneath each individual railcar. This has the advantage of eliminating the dead weight of the locomotive, increasing the number of traction motors leading to an increase in power, improving adhesion since half or more of the train’s axles are powered, and making more effective use of station platform length. However, when high-speed services are extended beyond the reach of the high-speed tracks using conventional lines, tilting capability can still prove very advantageous. The key characteristics of these trains are:

- High-Powered for operation at 150 mph or higher on new lines.
- Electric only
- For trains that operate on conventional tracks beyond the new lines, tilting versions of Very High-Speed trains have been developed to allow them to go around curves faster.

Some representative trains are shown in Exhibit 4-7.

**Exhibit 4-7: Very High-Speed Rail – Representative Trains**

<table>
<thead>
<tr>
<th>Siemens ICE-3 EMU</th>
<th>TGV Atlantique</th>
<th>Amtrak Acela</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Siemens ICE-3 EMU" /></td>
<td><img src="image2" alt="TGV Atlantique" /></td>
<td><img src="image3" alt="Amtrak Acela" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shinkansen</th>
<th>Eurostar</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4" alt="Shinkansen" /></td>
<td><img src="image5" alt="Eurostar" /></td>
</tr>
</tbody>
</table>
Ultra High-Speed Maglev - 250-300 mph: For speeds above 250 mph the only current technology is Maglev. (Rail has demonstrated speeds above 250 mph but only on experimental trial runs.) Such speeds are routinely attained by the Shanghai airport maglev in revenue service, as shown in Exhibit 4-8. This system is fundamentally different from a rail technology in that it does not use a steel wheel/steel rail contact, but rather uses magnetic levitation to float above a concrete guideway, as well as to propel the train. For ultra high-speed maglev, only Siemens’ Transrapid shown in Exhibit 4-8 is in commercial operation. These maglev trains are capable of rapid acceleration up to their design limits and typically operate in consists of two to five cars. Seating capacity is generated by operating the trains at higher frequency than normal steel wheel/steel rail trains, or by linking car sets together if platform lengths permit. The key characteristics of these trains are:

- They were designed from the beginning for ultra high-speed.

There is only one existing operational system (Transrapid) in this class today, although there are additional high-speed concepts in R&D throughout the world. For example, the Japanese MLX01 superconducting Maglev is operating on a test track in the Yamanashi province, and it has recently been announced that the technology will be made available in the North American market. However, detailed cost and performance specifications for this technology were not available within the time frame needed for the RMRA study. For evaluation purposes the Transrapid system has been assumed.

Exhibit 4-8: Ultra High-Speed Maglev – Representative Train

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4.4 Technical Characteristics of Steel Wheel Technology

North American passenger train operators have benefited from the extensive global technology development as railways around the world have upgraded their passenger systems to high-speed rail operations. Over the past few years, true high-speed rail has become a reality in North America with the introduction of Bombardier’s Acela technology, shown in Exhibit 4-9, in the U.S. Northeast.

Exhibit 4-9: Acela Train Set

The next section of the report will discuss the technical characteristics of steel wheel (rail) technology that affect its ability to operate in Colorado corridors. Issues of FRA regulatory compliance, required power and traction will be addressed. Section 4.5 will address similar issues for maglev technologies.

4.4.1 FRA Regulatory Requirements

Under current regulation, compliance with U.S. Federal Railroad Administration (FRA) equipment standards is required to operate rail equipment on tracks that are connected to the US mainline freight rail network. If the tracks are not connected then the U.S. Federal Transit Administration (FTA) regulations may apply instead.

The FRA regulations may apply if there is a need to co-mingle operations with freight trains and/or RTD commuter rail equipment over some portion of the Colorado intercity rail network. It has been conducted so the regulatory issues associated with a possible Colorado equipment procurement can be understood, along with the current risks and uncertainties that are associated with that process. A review of the FRA regulations reveals two basic kinds of safety rules:

- **Basic safety rules** address requirements such as window glazing, configuration of car exits, interior lighting, and securement of baggage. These apply uniformly to all equipment, regardless of speed. These rules have been adapted from aviation as well as historical rail practice, and would likely apply to all types of vehicles, including Maglev.
• **The Tier I and Tier II rules** relate to specific “buff” strength requirements for rail vehicles that are intended to operate on the national freight and passenger rail network. Tier I standards apply to vehicles designed to operate at speeds up to 125 mph. More stringent Tier II standards apply above 125 mph to 150 mph. The FRA has not yet issued specific standards for trains operating above 150 mph.

Basic safety rules apply to all passenger equipment, since the FTA as well as the FRA enforces these regulations. These rules would still apply to non-compliant rail vehicles as well as to Maglev and novel technologies.

FRA’s Tier I and II rules have been controversial among some equipment manufacturers, who call into question the necessity of the regulation. However, another consideration is the economics of relatively small lot production of a customized product. Because fixed engineering and tooling costs have to be spread over the number of units produced, a sizeable (e.g., 50+ trains) equipment order is needed to obtain a reasonable unit cost for a customized train.

In terms of understanding Colorado’s implementation options, it should be noted that California is planning a new high-speed rail system that would operate on dedicated track at speeds up to 220 mph, and they are planning to request a waiver from the FRA to operate non-compliant trains. However, the issues involved are complex. It is not clear at this time whether California will actually prevail in their effort to obtain the waiver. Because the outcome of the California waiver application has not yet been decided, there is still some risk associated with assuming that it will be granted.

For the record, California’s current position on the issue of FRA compliance is:

“Although compatible, there are significant differences in the approach to safety and technical requirements between modern high-speed train systems and the state and federal regulations that govern existing railroad equipment and operations in California. The responsible regulatory agencies include the FRA who seeks assurance that the same or greater level of railroad safety is provided as required in the U.S. Code of Federal Regulations (CFR), and the California Public Utilities Commission (CPUC) who is responsible for the safety and reliability of the state’s electrical system, and for public railroad safety. The requirements within the Code of Federal Regulations are planned to be addressed by an FRA Rule of Particular Applicability (RPA) specific to the California High-Speed Train System. The RPA will address both dedicated high-speed routes and shared-track conditions. CPUC requirements regarding electrical system safety is anticipated to be addressed via their waiver process. It is important to note that the fully grade-separated feature of the California High-Speed Train alignment addresses many of the public safety concerns of both agencies.

“One of the key technical differences between successful high-speed train technology and current U.S. regulatory requirements governing passenger trains is the trainset specification. Current U.S. trainset regulations are based more on a “crash worthiness” approach to safety, while a “collision avoidance” philosophy is used to design high-speed train systems in Asia and Europe. Due to this differing approach to system safety, the Code of Federal Regulations
currently requires all existing U.S. passenger trains to be at least twice as strong than the lightweight vehicles used in European and Asian high-speed trains. In order to meet this strength requirement, high-speed train manufacturers would have to structurally redesign their trains, adding significant development time and cost, resulting in higher costs to the Authority, but with uncertain effect on the ultimate safety of the operation. Such a redesign would make high-speed rolling stock heavier, require more energy for the same speed, and jeopardize the low axle loadings that effectively enable the high-speeds, low operating and maintenance costs, and positive cash flows enjoyed by high-speed train operations in Europe and Asia. In addition to being more costly to purchase and operate, heavier equipment will likely cause changes in other system components such as track or bridges and result in higher maintenance costs and shorter replacement cycles. In summary, it is unlikely that high-speed trainsets meeting current U.S. standards can be economically built and successfully operated at the 220 miles per hour speed targeted for the California High-Speed Train system.

“Trainset concerns are higher where the relatively light-weight high-speed trains might share track with much heavier conventional U.S. passenger trains. Shared track is being considered where existing tracks are available and a dedicated high-speed line is prohibitive due to environmental impacts, right-of-way impacts, and costs. Similar to railway systems in Asia and Europe, the California High-Speed Train System includes two short segments (Los Angeles to Anaheim in Southern California and Caltrain in the Bay Area) which are currently expected to share track with conventional rail providing a cost-effective way of bringing high-speed train service directly into major metropolitan business centers. In both segments, the high-speed trains will operate at reduced speeds no greater than 125 miles per hour. Passenger safety on high-speed systems, both dedicated track and shared-track, is achieved by a train signaling system that provides positive train control and separation, and automatic train-stop capabilities to monitor train traffic and avoid collisions. Crash-energy management components are also incorporated into the high-speed train design in the unlikely event of low speed collisions. It should be noted that high-speed train travel is the safest form of transportation in the world and that proven systems in Asia and Europe have been operating safely in shared-track conditions for over 40 years.”

The California system, as elsewhere, sees the need for sharing track and right-of-way with conventional trains on the final approach to urban centers. By assuming that they will be able to obtain an FRA waiver, California is basically assuming that the FRA will set aside the existing Tier I and II regulations and permit co-mingling of compliant and non-compliant trains on the same tracks. This creates a substantial implementation risk to their system, since there is no known historical precedent for this assumption.

Further, California’s stance on the use of non-compliant equipment has exacerbated its freight railroad relations. The freight railroads are understandably concerned about the potential liability implications for allowing the operation of non-compliant trains on or near their rights-of-way.

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Union Pacific\(^4\) has summarily concluded that “it was not in Union Pacific's best interests to permit any proposed high-speed rail alignment on our rights-of-way” and in item 12 that “HSR must comply with all applicable FRA regulations.”

For Colorado, to mitigate the project risk associated with the use of non-compliant equipment, TEMS has suggested that FRA compliant equipment be used. Such equipment could operate without restriction. In the *Existing Conditions Report*, TEMS conducted benchmarking analysis that suggested a probable weight penalty for FRA compliance would be only in the 5-10 percent range. The FRA reviewed this analysis and concurred with it\(^5\). An additional 5-10 percent in vehicle weight has been built into the operating cost basis for the Colorado system but positive financial operating results are still projected for the system.

Specifically, under current regulation, the FRA rules require:

- **Buff Strength**: The amount of compressive force that a railcar or locomotive must withstand without permanent deformation. For passenger coaches, Tier I and Tier II require the same buff strength, 800,000 lbs. For locomotives, 800,000 lbs. are needed under Tier I, but under Tier II locomotives need 2,100,000 lbs. buff strength.

- **Crash Energy Management**: This performance specification kicks in only for Tier II equipment, but does not per se require a heavier vehicle. The rule addresses such things as crush zones and failure modes that are designed for the safety of the occupants. Crash Energy Management principles are already built into the design of most modern rail vehicles.

- **No Occupied Lead Cars**: The Crash Energy Management regulation prohibits passenger-occupied lead cars in Tier II equipment as can be expected with Push Pull train designs. However, if an EMU technology were chosen, the lead car could still be used, for example, for baggage compartment space.

The main difference between European and US regulations lies not with the Tier II requirement, but rather the 800,000 lbs. Tier I buff strength. This requirement is already substantially greater than that needed for railcars overseas, which typically require only 440,000 lbs compressive strength\(^6\). Under current regulations, European or Japanese designs would have to be adapted to American conditions for operations at *any* speed, not just for *high-speed* service.

Some potential high-speed train manufacturers are aware of this issue and have put significant effort into developing U.S. compliant equipment. For example, the Talgo T-21 train was proposed as a fully Tier I compliant train suitable for operation in the United States, with no more than a 10 percent weight penalty over its European counterpart\(^7\). In addition, Bombardier has already

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\(^4\) See letter from Union Pacific to the California High Speed Rail Authority dated February 23, 2009
http://home.pacbell.net/mbrown5//UPRR/UPRR-2-23-09.doc

\(^5\) Personal correspondence, Federal Railroad Administration, November 6, 2008

\(^6\) Some European railways (British and German) are however specifying vehicle strengths above (in some cases significantly above) those required in the UIC codes. Source: Federal Railroad Administration, personal correspondence, November 6, 2008.

\(^7\) This 10 percent weight penalty has been validated by a direct benchmarking study, See Appendix E of the *Existing Conditions Report*, and by recent correspondence with Talgo. It has been further validated by Federal Railroad Administration studies that
produced a Tier II compliant passenger locomotive and coaches (the Acela). These coaches, which are very heavy (70 tons) weigh more than their European counterparts not because of the FRA regulations, but because of the use of carbon steel (rather than stainless steel or aluminum) in their construction. Because of this, the U.S. Acela is about 45 percent heavier than a comparable TGV.

In addition, the Acela’s internal seating configuration is low-density leading to unfavorable benchmark comparisons with the capacity of an equivalent TGV. As built, Acela weighs 567 metric tons with six passenger cars, for a capacity of only 328 seats. In contrast, TGV Atlantique weighs 484 metric tons for ten cars with a capacity of 485 seats. It is worth noting, however, that the latest European designs could likely reduce this weight penalty to 10-15 percent and that the internal seating arrangement could be tightened up for higher capacity.

The economic issue with the FRA Tier I and II regulations would appear not to be the technical feasibility of customizing equipment to comply with the rules, but rather the size of any order. A European or Japanese manufacturer simply needs a large enough order to make it worthwhile building a U.S. compliant train. The FRA agrees with this assertion.

4.4.2 Rail Acceleration Curves

This section will assess the ability of steel-wheel technologies to meet these unusual requirements for service in the I-70 corridor in Colorado. Any of the alignments that are selected for the I-70 corridor will have very large gradients that are way beyond any typical high-speed corridor. While maglev trains have the ability to deal with the 7 percent gradients that are common along the I-70 corridor, steel wheel trains are more restricted by gradients. Fortunately the latest generation of high-speed trains has both enough power to accelerate quickly, and enough traction to climb steep gradients without spinning wheels.

In terms of assessing rail technology, there are two main criteria that need to be considered: type of propulsion and source of power:

- **Type of Propulsion:** Trains can be either locomotive-hauled or self-propelled. Self-propelled equipment has each individual railcar powered whereas conventional coaches rely on a separate locomotive to provide the power. This is especially relevant in Colorado with its steep grades, because the issue of adhesion of a steel wheel on a steel rail limits the maximum amount of force that can be transmitted without spinning wheels.

- **Source of Power:** Trains can be either diesel or electrically-powered. Diesel or electric power can be used with either the locomotive hauled or self-propelled equipment options. (Turbine power has also been considered for high-speed trains, but does not offer any clear advantage over diesel at this time.)
As a rule, diesel locomotives are heavier than electric locomotives, because of the weight of the engine and also of the fuel. Electric equipment also can be more powerful since it is not limited by the on-board generating capacity of the engine. Train performance curves for representative equipment types are shown in Exhibit 4-10. The curves reflect the acceleration capabilities of various rail technologies starting with conventional locomotive-hauled trainsets (the P42 option) up through Maglev.

Purpose-built diesel high-speed trains, such as the Talgo T-21, can offer considerably improved performance over conventional diesel trains that are based on freight-derived designs. Conventional locomotive-hauled diesel trains have a practical top speed of about 100 mph, whereas purpose-built high-speed diesel trains can achieve 125 mph to 135 mph and can accelerate much faster. As can be seen in Exhibit 4-10, conventional diesel-powered trains are barely capable of reaching 100 mph and operate most practically at speeds of 79 mph or less. For speeds above 135 mph, electrified trains are needed. Some European diesel-powered 125-mph trains offer up to 500 seats, but if U.S. safety regulations were applied, the added vehicle weight (10-15 percent) would likely reduce the practical capacity of such trains down to 400-450 seats.

Up to its top speed of 150 mph, Exhibit 4-10 shows that the Acela accelerates as fast as a TGV due to its very high power to weight ratio. This implies that the Acela could go even faster if it were given a straight enough track to run on. Acela’s weight penalty however, expresses itself in terms of a higher operating cost and lower revenue generating capacity than a comparable TGV. However, this is not a serious problem in the special environment in which the Acela operates. Catering primarily to business clientele, the Acela is able to attract revenue yields exceeding 60¢ per mile. The train would need to be modified to be cost effective at the more typical levels of revenue yield obtainable in other corridors such as in Colorado, 30-40¢ per mile. The electric Eurostar train and Korean TGV offer 794 seats and 935 seats\(^{11}\), respectively, which represent practically the upper limit of today’s rail technology.

\(^{11}\) See: http://www.railfaneurope.net/tgv/formations.html
Exhibit 4-10: Train Type/Technology Acceleration Curves: Straight and Level Track

Source: TEMS LOCOMOTION™ Equipment Database showing typical technology performance parameters, as developed and validated over the course of previous rail studies.

Exhibit 4-11 compares the performance of the electric ICE train versus the diesel Talgo T-21 on a 4 percent grade versus on level track. Diesel equipment avoids the cost of the overhead electric wires, but because of their higher power, Exhibit 4-11 shows that electric trains give better performance at high-speeds and up steep grades. (The Talgo T-21 is also available in an electric version. The purpose of this comparison is to illustrate the difference between generic diesel and electric locomotive-driven technology on mountain grades, not to compare the performance of specific manufacturer’s equipment.)

- The electric locomotive-hauled ICE train can achieve over 180 mph on level track but is reduced to 80 mph on a 4 percent grade.
- The diesel T-21 can achieve 125 mph on level track but is reduced to 35 mph on a 4 percent grade.
From this, it can be seen that electric trains are really the only viable option for high-gradient rail lines. A diesel T-21 can perform adequately up to a maximum gradient of 2-3 percent but beyond this, electric power is needed. This is the reason why diesel options were screened for the I-70 corridor very early in the evaluation process, and only electric power options have been carried forward.

### 4.4.3 Rail Tractive Effort or Adhesion

A second issue is that of adhesion. Adhesion refers to the maximum amount of tractive effort, or pulling force that can be generated without spinning the wheels. Exhibit 4-12 states an equation that says the maximum pulling force that can be exerted by a wheel, or Tractive Effort \( (H) \), is equal to the amount of weight on the wheel \( (V) \), multiplied by the coefficient of adhesion \( (\mu) \). To increase the pulling force of a wheel \( (H) \) you can either add more weight \( (V) \) or else improve the friction (adhesion) coefficient \( (\mu) \) between the wheel and rail. Conservatively, a coefficient of adhesion \( \mu = 15 \) percent can be assumed for rail applications. For example, if the weight on the wheel \( (V) \) is 1,000 lbs. with a Coefficient of Adhesion of 15 percent, then the maximum pulling force \( (H) \) that could be generated is 150 lbs.

- Obviously, adhesion is not an issue for Maglev trains and has been cited as a major advantage of that technology.
- For rail equipment, the adhesion question determines whether a train set should be locomotive-hauled or self-propelled. Sometimes it is less expensive to have separate
locomotives and cars. Self-propelled units, however, have much better adhesion. Since traction motors are distributed along many more driving axles, and the weight of the train itself contributes to adhesion, self-propelled trains can have more power and climb steeper grades than locomotive-hauled trains.

**Exhibit 4-12: Definition of Coefficient of Adhesion**

\[
H = \mu V
\]

- \( V \) = Vertical Component, Vehicle Weight
- \( H \) = Horizontal Component, Tractive Effort
- \( \mu \) = Coefficient of Adhesion


Using two real-world train sets as examples, Exhibits 4-13 and 4-14 show the maximum tractive effort for two versions of the German ICE train. Both are powerful electric trains, the 1st generation ICE train is locomotive-hauled, whereas the 3rd generation ICE train is a self-propelled Electric Multiple Unit (EMU) train that has traction motors under every car. Applying the tractive effort equation to these two trains, it can be seen that their hill-climbing capability is vastly different:

- The 1st generation ICE-1 train in Exhibit 4-11 has two lightweight locomotives, which sharply limit this train’s hill climbing capability, because only the locomotive’s weight is available to provide tractive effort. The ICE-1 cannot manage even a 4 percent grade without spinning wheels. A possible solution may be to make the locomotive heavier; this is done for freight locomotives but is not appropriate for a high-speed passenger locomotive, because the combination of high-speed and weight can be too damaging to the tracks. By reducing the number of coach cars, the ICE-1 could barely go up a 4 percent grade, which is considered the practical upper limit for a locomotive-hauled train.
• In contrast, the 3rd generation ICE-3 train in Exhibit 4-12 can manage a 7.5 percent grade with only half the axles powered and it could manage a 15 percent grade with all axles powered. This difference is because the total weight of the train including passenger coaches, rather than just the weight of the locomotive, is available to contribute to tractive effort.

**Exhibit 4-13: 1st Generation Locomotive-Hauled ICE-1 Train – Maximum Gradient Capability**

- Weight of two locomotives: 187 tons
- Total train weight: 1,656,480 lbs. for 460 seats
- Assume $\mu = 15\%$ (A safe assumption for wet rails)
- Tractive Effort Capability = $187 \times 2000 \times 15\% = 56,100$ lbs.
- **Maximum Grade** = $56,100 / 1,656,480 = 3.4\%$

**Exhibit 4-14: 3rd Generation EMU ICE-3 Train – Maximum Gradient Capability**

- Train Weight: 1,000,000 lbs. (500 tons) for 404 seats
- 50% of axles powered
- Assume $\mu = 15\%$
- Tractive Effort Capability = $500 \times 2000 \times 50\% \times 15\% = 75,000$ lbs. (could be 150,000 lbs. if all axles were powered)
- **Maximum Grade** = $75,000 / 1,000,000 = 7.5\%$
  (could make 15\% if all axles were powered)

The ICE-1 shows the limitations of locomotive-hauled trains. Electric locomotives tend to be very lightweight for the amount of power they produce. This can lead to difficulties with adhesion and spinning wheels, especially on wet rail. A good solution is to distribute the traction motors underneath the train, as in a DMU or EMU, so the weight of the train itself can contribute to traction.

Where gradients can be held to 4 percent or less, a locomotive-hauled electric train can work. The train’s grade-climbing capability could be improved by adding a set of powered axles under the first or last coach car as the Eurostar train does, or by reducing the number of passenger coaches.

A T-21 diesel train could go up a 2 percent grade at about 65 mph. A diesel-powered train would not have problems with adhesion because of the added weight of the diesel engine, but because of its limited power, speed would be reduced to 35 mph on a 4 percent grade and only 21 mph on a 7
percent grade. These speeds are not auto-competitive and would probably not be acceptable in the marketplace. This rules out the diesel for grades much above 2 percent.

In summary, it can be seen that the following rail equipment options are available for Colorado corridors, depending upon the gradients. All of these options would be capable of maintaining a 60-mph speed climbing the grade:

- If gradients can be held to 2 percent or less, then any equipment option, including diesel, electric, locomotive hauled or self-propelled (DMU or EMU) train could be considered for the corridor.
- Any electric train option, either locomotive-hauled or EMU, could have enough power to maintain 60 mph on a 2-4 percent gradient.
- Only the EMU and Maglev option will work for gradients in the 4-7 percent range. An EMU train with 50 percent axles powered (like the ICE-3) could maintain 60 mph up a 4 percent grade whereas in theory an EMU with all axles powered or with a separate Power Car (electric locomotive) added to each end of the train could maintain 60 mph up a 7 percent grade, curvature permitting. (This would be a very powerful train. For perspective, this same EMU with all axles powered could do more than 220 mph on level track.)

### 4.5 Maglev Capabilities

Exhibit 4-15 details the technical capabilities of the Transrapid Maglev. In contrast with mechanical solutions used by traditional rail systems, Maglev technology uses innovative non-contact, electromechanical solutions to achieve traction, guidance and propulsion functions.\(^\text{12}\) As shown in Exhibit 4-16, high grades are likely to reduce performance.\(^\text{13}\)

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\(^\text{12}\) Baltimore-Washington MAGLEV, Project Description Report, MTA, 2000

\(^\text{13}\) See: [http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/maglev/Chap1+2(p1_16).pdf](http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/maglev/Chap1+2(p1_16).pdf). Exhibit 4-16 shows that the Transrapid system does offer a 10 percent grade climbing capability, but it can maintain only 30 mph up this grade; in contrast, the Transrapid could maintain 245 mph up a 3.5 percent grade. The RMRA Peer Review has noted that this result was derived from a 1992 government study based on the Transrapid TR07 prototype vehicle, which was retired in 1999. Although the study is the only one found that directly addresses Transrapid's ability to climb grades, it is considered out of date. The curve was based on an assumed guideway configuration, but if the power provided by the guideway could be increased, there would be no strict relationship between speed and grade owing to the off-board power supply characteristics of the non-contact maglev technology.
Exhibit 4-15: Technical Specifications for Transrapid Maglev

<table>
<thead>
<tr>
<th>Operating Parameters</th>
<th>Speed</th>
<th>Distance</th>
<th>Time</th>
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<tbody>
<tr>
<td>Design Speed</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Operating Speeds:</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rural areas</td>
<td>300 mph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban areas</td>
<td>150 mph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0- 60 mph</td>
<td>0.27 miles</td>
<td>31 s</td>
<td></td>
</tr>
<tr>
<td>0- 120 mph</td>
<td>1.07 miles</td>
<td>62 s</td>
<td></td>
</tr>
<tr>
<td>0- 180 mph</td>
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<tr>
<td>0- 240 mph</td>
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<td></td>
</tr>
<tr>
<td>0- 300 mph</td>
<td>11.99 miles</td>
<td>278 s</td>
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</tr>
<tr>
<td>Braking Performance</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0- 60 mph</td>
<td>0.28 miles</td>
<td>58 s</td>
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<tr>
<td>0- 120 mph</td>
<td>0.98 miles</td>
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<td></td>
</tr>
<tr>
<td>0- 180 mph</td>
<td>2.29 miles</td>
<td>115 s</td>
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</tr>
<tr>
<td>0- 240 mph</td>
<td>4.18 miles</td>
<td>146 s</td>
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</tr>
<tr>
<td>0- 300 mph</td>
<td>6.51 miles</td>
<td>176 s</td>
<td></td>
</tr>
</tbody>
</table>

Source: Baltimore-Washington Maglev Study, June 2000, see Appendix B.

Exhibit 4-16: Transrapid Maglev – Equilibrium Speed as a Function of Gradient

As shown in Exhibit 4-17, Transrapid’s tilting capability of 12° is approximately equivalent to that of a tilting train which can operate with 6” of tilt plus 6” of superelevation. (Superelevation is the physical tilt of the track in the curve whereas tilt is the equivalent additional banking that is provided by the vehicle.) As a result, Transrapid would be expected to have about the same speed limit in curves as a tilting train. This would reduce the advantage of Maglev over rail unless a very straight alignment could be built.

**Exhibit 4-17: Comparison of Tilt Capabilities – Maglev vs. Tilt Train**

Because of its LIM propulsion, the proposed 125-mph Colorado Maglev has to carry its power transformers and linear motors on board, as compared to the LSM motor of Transrapid, which is built into the guideway. Accordingly the LIM system is limited by the capabilities of the power equipment that is on board the vehicle, which also necessarily adds to the vehicle weight. Even so within the lower speed range up to 125 mph it has been assumed that the acceleration and braking performance of these two maglev vehicle types would be comparable. The LIM vehicle was assumed to consume more electrical power than the LSM vehicle; however, this is due both to the greater weight and lower electrical efficiency of the LIM vehicle.

### 4.6 Matching Equipment Capabilities to Representative Routes

A set of representative routes has been defined in Chapter 3. For the I-70 corridor, these options consist of “Constrained” or Highway Right-of-Way options as compared to an “Unconstrained” alignment that is allowed to deviate from the highway right-of-way. For I-25, the options consist either of existing rail or greenfield options.

Given this set of representative routes, the next step in network formulation was to pair the routes in some manner based on the basic capabilities of train technologies. As described previously:

- 110-mph diesel technology can only handle grades up to about 2 percent without severe degradation in performance.
- Locomotive-hauled electric trains can handle 2-4 percent gradients.
- Self-propelled Electric Multiple Unit (EMU) equipment is required for gradients in the 4-7 percent range. In order to climb a 7 percent grade at any reasonable speed, it is essential either to power all the axles of the EMU or else to provide supplementary power cars or...
electric locomotives to the train consist. On these heavy grades, locomotives could not haul
the train up the hill by themselves but could still provide a significant power boost to
improve adhesion capability and enable the train to go faster.

- Maglev trains are also capable of operating over 4-7 percent gradients.

For evaluation purposes, three main network options have been constructed based on the
capabilities and limitations of equipment types. These networks were constructed as logical
combinations of alignment options based on equipment capabilities. They are described as follows:

- **110-mph Rail on I-25 only.** This option uses diesel locomotive-hauled trains to offer
passenger rail service on upgraded conventional rail tracks paralleling I-25. This network
cannot be extended up I-70 since the diesels are not able to climb even 4 percent grades at
any reasonable speed.

- **I-70 Unconstrained.** This consists of the unconstrained I-70 alignment that uses the Clear
Creek canyon to bypass the heavy gradients on Floyd Hill. This I-70 network option limits
grades to 4 percent. The unconstrained I-70 alignment is coupled with conventional rail on
the I-25 corridor thus can be worked using electric locomotive-hauled trains with coach cars.
It also uses several segments of existing rail alignment for extensions west of Eagle County
Airport that are compatible with these equipment capabilities.

- **I-70 Right-of-Way.** This consists of the I-70 Right-of-Way alignment with grades up to 7
percent. It needs very powerful EMU equipment to climb the hill. This powerful equipment
is also the best for maintaining high-speed on a new I-25 greenfield. The I-70 Right-of-Way
alignment has therefore been coupled with greenfield alignments on I-25 and west of Eagle
Airport, to make the best possible use of this powerful equipment. This network was
assumed for both the Electric Rail EMU and Maglev equipment options.

These pairings of equipment to routes are only for evaluation purposes in the initial analysis in this
feasibility study. For example, self-propelled EMU equipment could be used on any alignment in
the network. The same is not true for other kinds of equipment; however, since an electric locomotive-
hauled train with conventional coaches is unable to operate on the I-70 Right-of-Way alignment
because of the steep grades. Similarly, diesel technology can go up the mountain only at a very low
speed that would be unacceptable in the marketplace.

The unconstrained versus I-70 right-of-way networks are shown in Exhibits 4-18 and 4-19. The route
and technology pairings assumed for evaluation purposes are shown in Exhibit 4-20. Exhibits 4-21
and 4-22 provide technical definitions of terms that have been used in this chapter and throughout
the report, defining equipment-related terms, and route and alignment-based vocabulary. The “I-70
Highway ROW Alignment” described in Exhibit 4-22 for the Constrained network evaluation shown
in Exhibit 4-19, and is based on the I-70 EIS alignment developed by J.F. Sato. This alignment was
used for both the El Rancho and Vail Pass segments of the route. From Floyd Hill to Loveland Pass,
an “I-70 Highway Corridor Alignment” was developed as part of the Unconstrained network
(Exhibit 4-18) evaluation. This does not preclude the possibility that an “I-70 Highway Corridor
Alignment” incorporating lower 4 percent grades may be developed in a future study of the El
Rancho or Vail Pass segments.
Exhibit 4-18: Unconstrained I-70 Network with Existing Rail in I-25 and West of Eagle
Exhibit 4-19: I-70 Right-of-Way Network with Greenfield’s in I-25 and West of Eagle
Exhibit 4-20: Equipment and Route Pairings Matrix

<table>
<thead>
<tr>
<th>Corridor</th>
<th>I-25 North Wyoming Border to North Suburban Station</th>
<th>I-25 South New Mexico Border to South Suburban Station</th>
<th>I-70 East Golden to Avon</th>
<th>I-70 West Avon to Grand Junction</th>
</tr>
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<tbody>
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<td>1 (a)</td>
<td>Diesel, 79-mph Track Speed Existing Rail with R2C2*</td>
<td>Diesel, 79-mph Track Speed Existing Rail with R2C2</td>
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<td>Not Applicable due to lack of power for gradients</td>
</tr>
<tr>
<td>1 (b)</td>
<td>Diesel, 79-mph Track Speed Existing Rail, without R2C2</td>
<td>Diesel, 79-mph Track Speed Existing Rail, without R2C2</td>
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<td>Not Applicable due to lack of power for gradients</td>
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<td>2 (a)</td>
<td>Diesel, 110-mph Track Speed Existing Rail with R2C2</td>
<td>Diesel, 110-mph Track Speed Existing Rail with R2C2</td>
<td>Not Applicable due to lack of power for gradients</td>
<td>Not Applicable due to lack of power for gradients</td>
</tr>
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<td>2 (b)</td>
<td>Diesel, 110-mph Track Speed Existing Rail, without R2C2</td>
<td>Diesel, 110-mph Track Speed Existing Rail, without R2C2</td>
<td>Not Applicable due to lack of power for gradients</td>
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*R2C2 refers to Colorado DOT’s Freight Rail Relocation Study*
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<tr>
<th>Corridor</th>
<th>I-25 North Wyoming Border to North Suburban Station</th>
<th>I-25 South New Mexico Border to South Suburban Station</th>
<th>I-70 East Golden to Avon</th>
<th>I-70 West Avon to Grand Junction</th>
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<td>3(b)</td>
<td>I-70 PEIS Advanced Guideway System Maglev, 125-mph Track Speed I-25 Highway Corridor Alignment</td>
<td>I-70 PEIS Advanced Guideway System Maglev, 125-mph Track Speed I-25 Unconstrained Alignment</td>
<td>I-70 PEIS Advanced Guideway System Maglev, 125-mph Track Speed I-70 Highway Corridor Alignment</td>
<td>I-70 PEIS Advanced Guideway System Maglev, 125-mph Track Speed I-70 Highway Corridor Alignment</td>
</tr>
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<td>3(c)</td>
<td>I-70 PEIS Advanced Guideway System Maglev, 125-mph Track Speed I-25 Highway Corridor Alignment</td>
<td>I-70 PEIS Advanced Guideway System Maglev, 125-mph Track Speed I-25 Unconstrained Alignment</td>
<td>I-70 PEIS Advanced Guideway System Maglev, 125-mph Track Speed I-70 Unconstrained Alignment</td>
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<td>Electric, Locomotive Pulled 150-mph Track Speed Existing Rail, with R2C2</td>
<td>Electric, Locomotive Pulled 150-mph Track Speed I-70 Unconstrained Alignment</td>
<td>Electric, Locomotive Pulled 150-mph Track Speed I-70 Unconstrained Alignment</td>
</tr>
<tr>
<td>Corridor</td>
<td>I-25 North Wyoming Border to North Suburban Station</td>
<td>I-25 South New Mexico Border to South Suburban Station</td>
<td>I-70 East Golden to Avon</td>
<td>I-70 West Avon to Grand Junction</td>
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<tr>
<td>5 (c)</td>
<td>Electric, EMU Tilting 220-mph Track Speed I-25 Highway Corridor Alignment</td>
<td>Electric, EMU Tilting 220-mph Track Speed I-25 Unconstrained Alignment</td>
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<td>Maglev, 300-mph Track Speed I-70 Highway Corridor Alignment</td>
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<tr>
<td>6 (b)</td>
<td>Maglev, 300-mph Track Speed I-25 Highway Corridor Alignment</td>
<td>Maglev, 300-mph Track Speed I-25 Unconstrained Alignment</td>
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### Exhibit 4-21: Technology Definitions

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<th>RMRA Technology - Definitions</th>
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<tr>
<td><strong>Diesel, 79-mph Track Speed</strong></td>
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<tr>
<td>Conventional Rail, FRA Compliant, Diesel Powered, Locomotive Pulled or Diesel Multiple Unit</td>
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### Exhibit 4-22: Route Definitions

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<th>RMRA Route - Definitions</th>
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<tr>
<td><strong>I-25 North-South Alignments</strong></td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
</tbody>
</table>
| **Not Applicable, Highway ROW unsuitable for high-speed rail.** | Rail alignment largely within the existing BNSF and UP railroad rights-of-way, with the assumption that through freight traffic is moved to a new alignment further east as evaluated in the R2C2 Study. | Rail alignment completely within the I-25 highway right-of-way including, but not limited to the shoulder to shoulder actual width of the existing highway. The alignment can be on-grade, elevated or tunneled to make the best use of the highway right-of-way in order to minimize grade changes and maximize curve radii. | Rail alignment capable of being within the highway corridor alignment as defined above, but can also be on-grade, elevated or tunneled in truly "Greenfield" areas completely outside the highway corridor, including areas to the east outside the I-25 highway right-of-way and outside the freight railroad rights-of-way. This is the most unconstrained rail alignment designed to minimize grade changes and maximize curve radii and still reach the critical Front Range passenger markets.
# RMRA Route - Definitions

<table>
<thead>
<tr>
<th></th>
<th>Existing Rail without R2C2</th>
<th>Existing Rail with R2C2</th>
<th>I-70 Highway ROW Alignment</th>
<th>I-70 Highway Corridor Alignment</th>
<th>Unconstrained Alignment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I-70 East-West Alignments</strong></td>
<td>Not Applicable, No rail infrastructure</td>
<td>Not Applicable, No rail infrastructure</td>
<td>Mostly elevated rail alignment within the current highway right-of-way. The elevated sections of the rail alignment can vary between above the right-of-way adjacent to the roadway, above the highway shoulders, above the highway lanes or above the highway median in order to minimize grade changes and maximize curve radii. The ROW alignment may include on-grade sections in areas where there is enough space in the median or adjacent to the actual highway (allowing room for snow storage) and on-grade in tunnels parallel to the current highway tunnels.</td>
<td>Rail alignment capable of being in the highway right-of-way as described above can also be on-grade, elevated, or tunnelled in areas outside the actual highway right-of-way in order to make use of the corridor valley and hillsides to minimize grade changes and maximize curve radius. A highway corridor rail alignment will remain within the primary I-70 highway corridor and does not include adjacent highway corridor rights-of-way such as US-6, US-40, US-24 or SH-91 or any freight railroad rights-of-way.</td>
<td>Rail alignment capable of being within the highway corridor and highway ROW alignments as defined above, but can also be on-grade, elevated or tunnelled in areas completely outside the highway corridor including adjacent highway rights-of-way and adjacent railroad rights-of-way. This is the most unconstrained rail alignment designed to minimize grade changes and maximize curve radii and still reach the critical mountain corridor passenger markets.</td>
</tr>
</tbody>
</table>
4.7 Summary

By a careful review of potential station locations, technologies, and potential routes, a set of preliminary alternatives were defined.

The alternatives were integrated to provide two types of route options:

- Constrained alignment, with up to 7 percent grade in I-70, and using greenfield routes in I-25. This option can only be used by the most powerful trains (220-mph steel wheel and maglev).
- Unconstrained alignment with up to 4 percent grades in I-70, and use of existing rail corridors in I-25. Electric trains can use this alignment, but diesel trains are confined to the I-25 corridor.

Six types of high-speed train technology with maximum performance speeds were considered:

- 79-mph Diesel
- 110-mph Diesel
- 125-mph Maglev
- 150-mph Electric
- 220-mph Electric
- 300-mph Maglev

These alternatives would serve up to 18 major stations and 20 secondary stations, depending on the particular route combination and technology, as shown in Exhibit 4-18 and 4-19. All the stations shown in these Exhibits have been included in the demand forecasts for each scenario. Stations were selected based on the locations of cities, towns, resorts and attractions along the route and were situated not only for the convenience of tourists, but also for the use of local residents. However, it was assumed that only half of the trains stop at the Secondary stations. The demand forecast did not assume any specific site for any station, but only assumed a certain level of modal connectivity and access time from surrounding zones. As such the station selection is generally consistent with that developed by the I-70 Coalition but perhaps allows more flexibility than the Coalition’s work. Specific station sites could not be assumed for the current study because the assumed route alignments are still very preliminary, so some flexibility must still be retained to adjust the alignments due to local constraints and along with them, the proposed station sites.