8 Capital Costs

8.1 Introduction

The study team conducted an engineering assessment of infrastructure needed in cooperation with the RMRA, freight railroads, Colorado DOT and in coordination with both the FasTracks and Colorado Freight Rail Relocation (R2C2) studies. Towards the end of this chapter, vehicle costs are estimated based on the Operating Plan developed in Chapter 5 to develop the total Capital cost of the project.

The engineering assessment provides an evaluation of the current condition of the proposed highway, greenfield, and railroad right-of-way alignments; identifies improvements to existing rail lines needed to support the 79/110/150-mph passenger service scenarios; and develops estimates for new greenfield alignments for the 220-mph and 300-mph options. The engineering assessment is presented in Chapter 3 of this report.

In addition to the engineering assessment, the capital costing methodology identifies rolling stock (equipment) costs and land costs. Land costs are presented separately, as a placeholder for access to railroad rights-of-way and for procurement of additional privately owned property where required to construct new passenger rail infrastructure.

The engineering assessment and its findings and recommendations are preliminary and have not been discussed in detail with the railroads. As discussed earlier, the Study is at a feasibility level, the project is un-funded and formal negotiations with the railroads have not been initiated. Future Engineering Assessments require considerably more discussion to ensure railroad concurrence. Final design concepts and recommended capital plans depend on detailed operations and capacity analyses, design coordination and in-depth discussions with the freight railroads. As the project moves beyond the feasibility phase, railroad involvement and coordination become increasingly important.

The engineering assessment was conducted at a feasibility level of detail and accuracy. Exhibit 8-1 highlights the levels of accuracy associated with typical phases of project development and engineering design. A low level of accuracy is associated with the evaluation of project feasibility; while the highest level of accuracy is achieved during final design and production of construction documents. The RMRA Feasibility Study is only the first step in the project development process. As shown in Exhibit 8-1, the level of accuracy typically associated with a Feasibility Study is +/- 30 percent. It had been suggested that a 30 percent contingency be added to these costs to reflect a worst-case scenario. However, the error range already covers this contingency. The cost estimate is intended to be a mid-range projection with equal probability of the actual cost moving up or down.

Exhibit 8-1: Engineering Project Development Phases and Levels of Accuracy Development

Development Phases	Approximate Engineering Design Level*	Approximate Level of Accuracy**
Feasibility Study	0%	+/- 30% or worse
Project Definition/Advanced Planning	1-2%	+/- 25%
Conceptual Engineering	10%	+/- 20%
Preliminary Engineering	30%	+/- 15%
Pre-Final Engineering	65%	+/- 15%
Final Design/Construction Documents	100%	+/- 10% or better

*Percent of *Final Design*. **Percent of actual costs to construct.
Table prepared by Quandel Consultants, LLC

8.2 Engineering Assessment

The first step in the Engineering Assessment is to divide each corridor into segments. Route segments for existing railroad rights-of-way generally begin and end at major railroad control points or rail stations. For greenfield alignments, segments begin and end at station points. Typical corridors are divided into three to five route segments. Field inspections of the corridors have been conducted. Chapter 3 and the *Existing Conditions Report* highlight the findings of the field inspections.

A systematic engineering planning process was used to conduct the engineering assessment using the five basic costing elements that were defined in Chapter 3:

- Guideway and Track Elements
- Structures – Approaches, Flyovers, Bridges and Tunnels
- Systems
- Crossings
- Stations and Maintenance Facilities

Three auxiliary costing elements have been defined in the chapter as follow:

- Right-of-Way and Land
- Vehicles
- Professional Services & Contingencies

The engineering assessment was based on these eight costing elements. In addition to the field inspections and extensive work with GIS and railroad track charts, the assessment included a thorough review of the alignment studies and estimated costs presented in the I-70 Mountain Corridor Programmatic Environmental Impact Study. Sato Associates, the prime consultant for the

Mountain Study, was extremely helpful in understanding the details concerning the PEIS alignment for the rail alternative and the estimated infrastructure costs associated with the rail alternative. Although the PEIS alignment was used in segments of the I-70 corridor, the capital costs were estimated as part of this Feasibility Study. The PEIS capital cost estimates were within a reasonable range of the Feasibility Study estimates when adjusted for inflation.

8.3 Development of Unit Construction Capital Costs

8.3.1 Base Set of Unit Costs

The study team developed unit costs in 2008 dollars for the design and construction of high-speed passenger rail and maglev infrastructure on a series of previous planning projects. Initially the unit costs were applied to planned construction in the Midwest to implement the Midwest Regional Rail Initiative. Later the costs were applied to capital cost estimates for high-speed rail in Florida, Ohio, Minnesota and California.

The base set of unit costs addresses typical passenger rail infrastructure construction elements including: roadbed and trackwork, systems, facilities, structures, and grade crossings.

The unit costs have been evaluated by peer panels, freight railroads and contractors. The values have been found to be reasonable for developing the capital costs under normal contractor bidding procedures and under railroad force account agreements for construction. It should be noted that in two cases the costs have not been sufficient, specifically:

- DBOM procurement, where the contractor takes on large future operating risks and seeks to front load the risk in the initial construction.
- Rail alignments constructed in narrow highway medians under congested urban traffic.

The unit costs were developed and evaluated in the period between January 2000 and June 2002. Two questions must be considered in applying these costs to high-speed rail planning in Colorado:

1. Relative Costs: Are the costs reasonable for rail construction in Colorado considering local costs of materials and labor?
2. Cost Escalation: How should the costs be escalated from the nominal June 2002 values to current values considering the historical changes in construction costs?

A variety of indices are employed to monitor construction costs throughout the United States. However, no publicly available index exists for rail construction. In addition, relatively few recent examples of completed intercity passenger rail construction are found. This is especially true for high-speed applications.

8.3.2 Relative Costs

The *Engineering News Record* tracks a Building Cost Index (BCI) and a more general Construction Cost Index (CCI) in major cities and averages the values to produce national indices. It is reasonable to assume that the CCI is a better indicator of regional cost differences for a transportation project than the BCI. The CCI is calculated as the sum of 200 hours of local (union) common labor including fringes plus the local cost of 1.128 tons of Portland cement plus the national average price of 25cwt of fabricated structural steel. The CCI's from 1990 to 2008 indicate that construction costs in Denver have typically been 20-30 percent lower than national construction costs, and 25-40 percent lower than the average of costs in the Midwest. There is however, considerable variability in the Midwest costs between cities: for example, Kansas City has had an even lower CCI than Denver over the period.

To some extent, the construction cost of relatively specialized products and systems is independent of local regional costs. In the case of railroad construction, the costs of key materials such as rail, concrete ties and signal equipment are relatively uniform throughout the country. Similarly, the cost of skilled labor and mechanized track laying systems will be similar in all locations. These factors tend to diminish the regional construction cost differences.

8.3.3 Cost Escalation

Many State DOTs prepare periodic highway construction cost indices based on the tabulated bid prices of earthwork, asphalt pavement, concrete pavement, structural concrete, reinforcing steel and structural steel to assemble a composite index tied to base year costs in 1987. The State of Washington publishes the indices for the states of Washington, California, Colorado, Oregon, South Dakota, Utah and an FHWA composite. (The FHWA discontinued preparing the composite index in 2006). This data cannot be used to compare the absolute costs of highway construction among states, but may be used to compare the price trends. Comparing the indices over the 6 year period from 2002 to 2008, the Colorado index has outpaced the others, increasing by a factor of 2.21 compared to an average of 1.91 for the six states.

The Bureau of Labor Statistics prepares a variety of monthly, national Producer Price Indices, which are often used for escalation cost adjustments in construction projects. Two such indices may be suitable for our application, the Highway and Street Construction Index (PCUBHWY) and the Other Heavy Construction Index (PCUBHVY). A computation of escalation from June 2002 to January 2009 using either index yields similar results (HWY=51%, HVY=44%), but as the highway index is heavily influenced by the costs of petroleum products such as asphalt, it is reasonable to assume that the Other Heavy Construction Index is more suitable for our purpose.

8.3.4 Unit Price Adjustment

Based on the available data, it is reasonable to believe that the June 2002 unit costs developed for the Midwest can be adjusted downward for use in Colorado during the same time period. Considering the regional CCI difference and the relative uniformity of railroad material prices, an adjustment factor of 0.85 is reasonable.

While the BLS PPI suggests a national escalation factor of 1.44 for the period, the coincident Colorado DOT highway cost escalation factor of 2.21 is significant and suggests that construction cost escalation in Colorado exceeds that represented in the BLS value. The State of Colorado DOT has attributed much of the highway cost escalation to a regional shortage of Portland cement and high worldwide demand for asphalt, petroleum products and steel.

While the cost of rail construction is energy intensive due to the requirement for extensive grading to achieve desirable grades and curves, it is less so than highway construction, which uses petroleum products such as asphalt as a construction material. While a precise methodology for discounting the observed Colorado highway cost inflation does not exist, it is reasonable to believe that the regional escalation factor for rail construction over the period lies somewhere between the BLS PPI value of 1.44 and the CDOT value of 2.21. An average of the two values yields 1.825. The *Unit Price Regional and Escalation Analysis* is included in Appendix F.

Therefore the unit cost adjustment value considering regional cost differences and inflation from June 2002 to December 2008 is computed as follows:

Colorado Unit Cost (2008) = MWRRI Unit Cost (2002) x 0.85 x 1.825

8.3.5 Unit Capital Costs for Colorado – Steel Wheel/Steel Rail

Trackwork and Land Acquisition

The FRA requires that passenger trains operating on the general railroad system comply with stringent crashworthiness standards. Neither the FRA nor the Federal Highway Administration (FHWA) has addressed requirements for mode separation of high-speed passenger rail equipment operating in close proximity to highway traffic. Similarly, the FRA has not developed general rules for non-compliant passenger equipment operating in railway corridors adjacent to freight rail tracks. For the purposes of defining requirements necessary to proceed with the study and in order to develop planning level capital costs, it has been assumed that highway traffic and adjacent high-speed vehicles will be separated by concrete barriers. On tangent highway and track segments, there exists a small probability that automotive vehicles will leave the highway. Thus, protection against highway traffic incursions into the high-speed rail median would be provided using NCHRP Report 350 Level 5 highway concrete barrier walls. In curved median segments, where accidents are more likely, we have planned for NCHRP Level 6. It is anticipated that high-speed rail systems in the freight rail corridors will be separated by at least 25 ft between track centers, minimizing any need for physical protection. Chain link fencing will be provided throughout the system in all corridors to prevent the intrusion of trespassers and animals. These planning assumptions may be subject to modification as a result of federal or state rule making.

Land acquisition costs for right-of-way owned and controlled by the railroad industry is always an issue when attempting to introduce new passenger rail service. Since its inception, Amtrak has had the statutory right to operate passenger trains over freight railroad tracks and rights-of-way. When using freight tracks, Amtrak is required to pay only avoidable costs for track maintenance along with some out-of-pocket costs for dispatching[1].

Amtrak's payments do not include any access fee for the use of a railroad's tracks or its rights-of-way. Amtrak's federal statutory right-of-access has never required such a payment, and therefore, Amtrak avoids paying a fee or "rent" for occupying space on privately held land and facilities.

In the case of the RMRA high-speed rail routes, Colorado Department of Transportation has already begun a discussion with the freight railroads on the development of a bypass for Denver, Colorado Springs, and as far south as Pueblo and Trinidad. (See the *CDOT Rail Relocation Implementation Study, Jan. 2009*). While these discussions are still embryonic, there is clearly a case for providing a negotiated swap of right-of-way with one or perhaps both of the freight railroads.

While the RMRA may choose a different course, the final determination of what a Colorado passenger rail system will pay host freight railroads for use of their tracks and rights-of-way will ultimately be accomplished through negotiations.

This study assumes that a cost for access based on estimated across-the-fence land values would be included as part of the up-front capital expense, and would be used to purchase the rights to use the underlying railroad rights-of-way for the passenger service. It is assumed that railroads would receive this compensation in cases where the construction of a dedicated high-speed passenger track is on their property. If new track cannot be constructed within the existing railroad rights-of-way, then this cost would fund the possible acquisition of adjacent property.

Elsewhere land will need to be purchased directly from land owners. Where highway rights-of-way were used, the study assumed that right of way or air rights access would be granted by Colorado Department of Transportation at no cost to the rail system.

The outright purchase of land is not the only method whereby railroads could receive compensation for access to railroad rights-of-way. Commuter rail development provides examples of various types of payments for access rights. Some of these projects involved the purchase of the railroad rights-of-way while others provide up-front capital improvements in return for access to a railroad's tracks. The actual methods of payment remain to be determined during negotiation, and may depend on the importance of the track to the freight railroad as well as the level of capital to be invested by the passenger rail authority.

[1] However, these payments do not cover all of the freight railroads' incremental costs associated with dispatching Amtrak's passenger trains. Railroad costs increase due to delays caused by Amtrak's tightly scheduled trains. Track capacity constraints and bottlenecks create unreliable conditions where train delays often become unavoidable. While federal regulations give passenger trains dispatch priority, railroad dispatchers often encounter congestion where it becomes difficult to control traffic and adhere to Amtrak's timetables. In some cases, Amtrak will offer the railroads a payment to provide on-time passenger train performance. On heavily used line segments, however, these incentive payments only partially compensate a railroad for the costs of increased delay, and some railroads simply refuse to accept incentive payments. On lightly used lines, the economic rationale for making these payments is questionable since passenger trains cause very little delay on such tracks.

One area of possible concern is the freight railroads' ability to retain operating control over their rights-of-way. Whenever transit systems have paid full price to acquire a freight rail line, as on some commuter rail projects, the transit agencies have assumed operating control over the property. However, this study has assumed that the freight railroads would retain dispatching control over these rights-of-way. The railroads would have the right to use the increased capacity provided by the passenger system for its high-speed freight services.

For budgetary purposes, this study assumes an over-the-fence methodology for appraising the maximum value of railroad rights-of-way. To estimate land values, two land uses alongside each corridor are identified:

- Rural (e.g., farmland),
- Urban (e.g., high density residential, commercial, and industrial areas)

The value of a 50-foot wide right-of-way was established for each land use and the total land cost of the railroad corridor was estimated. Urban land rates were used in mountain resort areas such as Vail and Avon that have very high real estate prices. In the case of Vail no additional land cost needed to be assumed because the proposed rail alignment would be elevated over the existing I-70 highway alignment, thus was assumed to be granted to the project in that specific location.

Right-of-way cost was developed for the greenfield alternatives using the conceptual alignments and general land use designations. A 100 foot right-of-way was assumed. Where the alignment falls within an existing publicly-owned right-of-way, such as a highway or street alignment, no cost to the project for that particular right-of-way has been assumed. Where the geometric requirements take the alignment outside of the public right-of-way, impacted parcels were evaluated and a square foot quantity calculated. A unit cost per acre was developed in conjunction with other studies.

Exhibit 8-2 shows the unit cost for track work and land acquisition in 2008 dollars by project element.

Exhibit 8-2: Unit Capital Costs, Track work and Land Acquisition, in $2008

Item No.	Description	Unit	Unit Cost (Thousands of $2008)
1.1	HSR on Existing Roadbed (Single Track)	per mile	$1,174.90
1.2	HSR on Existing Roadbed (Double Track)	per mile	$2,350.00
1.3	HSR on New Roadbed & New Embankment (Single Track)	per mile	$1,765.30
1.4	HSR on New Roadbed & New Embankment (Double Track)	per mile	$3,163.90
1.5	HSR Double Track on 15' Retained Earth Fill	per mile	$16,711.30
1.6	Timber & Surface w/ 33% Tie replacement	per mile	$262.70
1.7	Timber & Surface w/ 66% Tie Replacement	per mile	$391.60
1.8	Relay Track w/ 136# CWR	per mile	$418.90
1.9	Freight Siding	per mile	$1,079.10
1.10	Passenger Siding	per mile	$1,628.10
1.11	NCHRP Class 6 Barrier (on curves)	lineal ft	$1.30
1.12	NCHRP Class 5 Barrier (on tangent)	lineal ft	$0.20
1.13	Fencing, 4 ft Woven Wire (both sides)	per mile	$60.30
1.14	Fencing, 6 ft Chain Link (both sides)	per mile	$181.00
1.15	Fencing, 10 ft Chain Link (both sides)	per mile	$207.10
1.16	Decorative Fencing (both sides)	per mile	$466.20
1.17	Drainage Improvements (cross country)	per mile	$78.10
1.18	Drainage Improvements in Median or along highway	per mile	$624.70
1.19	Land Acquisition Urban and Resort (100' of ROW)	per mile	$386.90
1.20	Land Acquisition Rural (100' of ROW)	per mile	$129.00
1.21	#33 High-Speed Turnout	each	$672.00
1.22	#24 High-Speed Turnout	each	$532.40
1.23	#20 Turnout Timber	each	$146.70
1.24	#10 Turnout Timber	each	$81.60
1.25	#20 Turnout Concrete	each	$294.60
1.26	#10 Turnout Concrete	each	$139.60
1.27	#33 Crossover	each	$1,344.10
1.28	#20 Crossover	each	$590.00
1.29	Elevate & Surface Curves	per mile	$68.60
1.30	Curvature Reduction	per mile	$465.00
1.31	Elastic Fasteners	per mile	$97.00

Structures: Approaches, Flyovers, Bridges, and Tunnels

A complete inventory of bridges has been developed for each existing rail route from existing track charts. For estimating the cost of new bridges on either green field alignments or along existing rail beds, conceptual engineering plans were used for a bridge to carry either single or double tracks over highways, streams, valleys, and rivers. Some bridges require rehabilitation on the abutments and superstructure. This type of work includes pointing of stone abutment walls, painting of bridges, and replacement of bearings. Many of the major bridge cost estimates will be estimated only as placeholders, which will be subject to more detailed engineering analysis in the future.

Rail route alternatives through the Rocky Mountains require a significant amount of tunneling to maintain operable grades, avoid areas prone to rock falls and avalanches, and to provide the shortest routes. Several tunnel configurations were considered. For this study, a two bore tunnel with cross passages is used for long and deep tunnels, whereas a single bore tunnel is used where the length is 1000 feet or less. Tunneling costs lie within the $20-73 thousand per linear foot range cited in Appendix G, where the higher cost was from the long undersea English Channel tunnel; but the estimates in Exhibit 8-3 are considered more appropriate benchmarks for the probable cost of Colorado tunnels. Exhibit 8-3 details the unit costs in 2008 dollars.

Exhibit 8-3: Unit Capital Costs, Structures in $2008

Item No.	Description (Bridges-under)	Unit	Unit Cost (Thousands of $2008)
2.1	Four Lane Urban Expressway (Rail over Highway)	each	$5,720.80
2.2	Four Lane Rural Expressway (Rail over Highway)	each	$4,762.40
2.3	Two Lane Highway (Rail over Highway)	each	$3,613.50
2.4	Rail (New Rail over Existing Rail)	each	$3,613.50
2.5	Minor river	each	$958.40
2.6	Major River	each	$9,581.60
2.7	Double Track High (50') Level Bridge	per LF	$14.40
2.8	Rehab for 110	per LF	$16.60
2.9	Convert open deck bridge to ballast deck (single track)	per LF	$5.50
2.10	Convert open deck bridge to ballast deck (double track)	per LF	$11.10
2.11	Single Track on Flyover/Elevated Structure	per LF	$5.00
2.12	Single Track on Approach Embankment w/ Retaining Wall	per LF	$3.50
2.13	Double Track on Flyover/Elevated Structure	per LF	$8.00
2.14	Double Track on Approach Embankment w/ Retaining Wall	per LF	$6.50
2.15	Ballasted Concrete Deck Replacement Bridge	per LF	$2.50
2.16	Land Bridges	per LF	$3.10
2.17	Four Lane Urban Expressway (Highway over Rail)	each	$2,469.40
2.18	Four Lane Rural Expressway (Highway over Rail)	each	$3,465.60
2.19	Two Lane Highway (Highway over Rail)	each	$2,251.60
2.20	Rail (Existing Rail over New Rail)	each	$7,229.40
2.21	Two Bore Long Tunnel	route ft	$44.00
2.22	Single Bore Short Tunnel	lineal ft	$25.00

Systems

The capital cost estimates for this study include costs to upgrade the train control and signal systems. Unit costs for system elements are shown in Exhibit 8-4. Under the 79-mph scenario, capital costs include the installation of Centralized Train Control (CTC) with interlockings and electric locks on industry turnouts and a PTC overlay 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 signal system.

Most U.S. railroads that allow or provide passenger and freight service operate under manual control with wayside signals. Centralized traffic control or CTC signaling is provided on busy corridors including Amtrak's Northeast Corridor. FRA requires that passenger service exceeding 79 mph operate with cab signaling/automatic train protection or automatic train stop to provide protection against operator errors. In addition, FRA is currently sponsoring demonstration projects to develop a universal communications based train control system, known as positive train control or PTC. New high-speed passenger service will include sophisticated signal systems to comply with FRA mandates and provide safe, reliable operations. Such signal systems include train borne components and wayside equipment such as track circuits, switch operators, and wayside detectors for protection against intrusion, high water, hot bearings and dragging equipment.

Modern signal systems rely on digital communication systems for data transmission using radio, fiber optic cables or a combination or the two. In addition, the communication system provides radio for operations, supervisory control and data acquisition for power systems, passenger station public address, etc. Wayside space must be provided for ducts and enclosures to house signal and communication components.

Electrified high-speed rail options require traction power substations and distribution facilities. It is assumed that the existing Colorado electrical grid and generating facilities contain sufficient capacity to support an electrified rail system. Similarly, the electric utility is expected to provide substations, transmission equipment and connections to the utility network with such costs covered in the utilization charges. As such, it is assumed that the electric utility would amortize the costs for bringing power to the substations, so the costs of modifications to the utility's grid are not included in the electrification cost estimate. Neither has the potential benefit from the electric utilities' potential ability to use the rail or maglev right-of-way for power transmission been assessed. (Such joint development could largely offset the utility's cost for connecting the rail or maglev system into the power supply.) Typical requirements for electrification include substations at 25 mile intervals and distribution conductors. In the case of electrified rail systems, overhead catenary conductors provide power to the train pantograph and the rails serve as return conductors. The catenary conductors are supported by poles and cross arms spaced at roughly 100-150 foot intervals. The catenary system contact wire is generally located 17.5 to 23 ft above the top of the rail. Additional electrical clearance or high voltage insulation is required to overhead bridge structures.

Exhibit 8-4: Unit Capital Costs, Systems, in $2008

Item No.	Description	Unit	Unit Cost (Thousands of $2008)
3.1	Signals for Siding w/ High-Speed Turnout	each	$1,500.30
3.2	Install CTC System (Single Track)	per mile	$216.50
3.3	Install CTC System (Double Track)	per mile	$355.00
3.4	Install PTC System	per mile	$171.00
3.5	Electric Lock for Industry Turnout	each	$121.90
3.6	Signals for Crossover	each	$828.20
3.7	Signals for Turnout	each	$473.30
3.8	Signals, Communications & Dispatch	per mile	$1,539.70
3.9	Electrification (Double Track)	per mile	$3,079.50
3.10	Electrification (Single Track)	per mile	$1,539.70

Crossings

The treatment of grade crossings to accommodate 110-mph operations on existing rail is a major challenge to planning a high-speed rail system. Highway/railroad crossing safety plays a critical role in future project development phases. A variety of devices were considered to improve safety including roadway geometric improvements, median barriers, barrier gates, traffic channelization devices, wayside horns, fencing and the potential closure of crossings. Greenfield routes were developed with grade separations at street and roadway crossings. Exhibit 8-5 details the unit costs for highway and railroad grade crossings. Chapter 4 contains additional information concerning the crossing costs.

Exhibit 8-5: Unit Capital Costs, Crossings, in $2008

Item No.	Description	Unit	Unit Cost (Thousands of $2008)
4.1	Private Closure	each	$98.20
4.2	Four Quadrant Gates w/ Trapped Vehicle Detector	each	$582.10
4.3	Four Quadrant Gates	each	$340.80
4.4	Convert Dual Gates to Quad Gates	each	$177.50
4.5	Conventional Gates single mainline track	each	$196.40
4.6	Conventional Gates double mainline track	each	$242.60
4.7	Convert Flashers Only to Dual Gate	each	$59.20
4.8	Single Gate with Median Barrier	each	$213.00
4.9	Convert Single Gate to Extended Arm	each	$17.70
4.10	Precast Panels without Roadway Improvements	each	$94.70
4.11	Precast Panels with Roadway Improvements	each	$177.50

Station/Maintenance Facilities

Passenger stations include platforms, escalators/elevators and other circulation elements, passenger ticketing and waiting facilities, lighting security, and station administration facilities.

The terminal stations may require four tracks for passenger boarding, train layover and light maintenance.

A maintenance facility with sufficient capacity to service the fleet is required. The facility must provide space and equipment to service the rolling stock and maintain the track structure and systems. Storage tracks can be expanded as the fleet grows. Sophisticated component repair may be subbed out to contract shops. It is anticipated that the maintenance facility for a non-electrified system will be less sophisticated than that of an electrified rail system. Exhibit 8-6 shows the unit costs for types of stations, terminals, and maintenance facilities

Exhibit 8-6: Unit Capital Costs, Railroad Station/Maintenance Facilities, in $2008

Item No.	Description	Unit	Unit Cost (Thousands of $2008)
5.1	Full Service - New - Low Volume - 500 Surface Park	each	$5,000.00
5.2	Full Service - Renovated - Low Volume- 500 Surface Park	each	$4,000.00
5.3	Terminal - New - Low Volume - 500 Surface Park	each	$7,500.00
5.4	Terminal - Renovated - Low Volume - 500 Surface Park	each	$6,000.00
5.5	Full Service - New- High Volume - Dual Platform - 1000 Surface Park	each	$10,000.00
5.6	Terminal - New- High Volume - Dual Platform - 1000 Surface Park	each	$15,000.00
5.7	Maintenance Facility (non-electrified track)	each	$80,000.00
5.8	Maintenance Facility (electrified track)	each	$100,000.00
5.9	Layover Facility	lump sum	$10,000.00

8.3.6 Unit Costs for Colorado – Maglev

Magnetic Levitation Technology Systems

Capital costs were developed for two types of magnetic levitation technologies as follows:

- High-speed magnetic levitation (LSM) technology, represented by the German TransRapid system with speeds from 250 to 300 mph. The system will be constructed in new, fully grade separated corridors and will not share right-of-way with the freight railroads.
- Urban magnetic levitation (LIM) technology, represented by Japanese CHHST, with speeds up to 125 mph. The system will be constructed in new; fully grade separated corridors and will not share right-of-way with the freight railroads.

For the purposes of this study, the only difference in unit costs between the two types is the systems unit costs as further detailed below.

Right-of-Way Costs

Maglev right-of-way costs were developed for each alternative using the conceptual routes. A 100-foot-wide right-of-way was assumed. Where the route fell within an existing public right-of-way, such as highway, street, or rail, no cost to the project for that particular right-of-way is assumed. Where the geometric requirements for Maglev take the route of the public right-of-way, the costs were determined for either rural or urban area. Units costs are based on a per mile basis using average values of $10,750 per acre for rural and $32,000 per acre for urban land acquisition. The unit costs on a per mile basis are shown in Exhibit 8-7. This unit cost estimate is based only on the current conceptual routes and will change as the project development progresses.

Exhibit 8-7: Unit Capital Costs, Right-of-Way, in $2008

Description	Unit	Unit Cost (Thousands of $2008)
Land Acquisition Rural	Mile	$129.0
Land Acquisition Urban	Mile	$ 387.0

Guideway and Track Elements

Maglev guideway costs were developed for at-grade, aerial and bridge structures and tunnels. The guideway system is comprised of a concrete and/or steel guideway to support the vehicles, stator packs, power rails, low-speed switches and high-speed switches. The types of guideways and tunnel sections used in this estimate are detailed Chapter 4 of this report. All civil engineering costs associated with the construction of the guideways are included in the unit costs

A unit cost of $3,400 per lineal foot is used for at-grade guideways. A unit cost of $6,600 per lineal foot is used for Type A aerial structures. A unit cost of $8,800 per lineal foot is used for the Type B aerial structure. Type B is a straddle-bent aerial structure needed to carry the guideway over public roadways and other obstacles encountered on the alignment. The unit cost for these guideways includes an allowance of 15 percent for special guideways required for project elements such as crossovers between guideways and tail structures at end stations for storage of train sets in off-peak hours.

A unit cost of $25,800 per lineal foot is used for the bridge structure required to carry the guideway over deep valleys and major rivers.

A unit cost of $33,600 per lineal foot is used for a Type A tunnel section consisting of two tunnels for the guideway. A unit cost of $44,800 per lineal foot is used for a Type B tunnel section consisting of two tunnels and a service/relief tunnel. Appendix G is a technical memorandum, *Rail Tunnel*

Evaluation that was prepared as a guide for this study. Exhibit 8-8 summarizes the unit costs for guideway and track elements.

Exhibit 8-8: Unit Capital Costs, Maglev Guideway & Track, in $2008

Description	Unit	Unit Cost (Thousands of $2008)
At Grade Guideway	LF	$3.4
Aerial Guideway Type A (Low)	LF	$6.6
Aerial Guideway Type B (High)	LF	$8.8
Bridge	LF	$25.8
Tunnel Type A (Single Bore)	LF	$33.6
Tunnel Type B (Dual Bore)	LF	$44.8

Systems

Propulsion, control and communication systems include 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. A unit cost of $18,368,000 per mile, as shown in Exhibit 8-9, is used to estimate the cost of the very high-speed maglev.

Exhibit 8-9: Unit Capital Costs, Maglev Systems, in $2008

Description	Unit	Unit Cost (Thousands of $2008)
Propulsion, Command & Control Systems	Mile	$18,368
Power Distribution	Mile	$1,389

Power distribution unit costs were determined by a review of similar costs for the FRA demonstration projects. The unit cost used for this project is $1,389,000 per mile for very high-speed systems.

The sum of the Propulsion, Command & Control Systems and the power unit costs is approximately $19.7 Million per mile for very high-speed systems using liner synchronous motor (LSM) technology. The systems costs for the urban maglev is approximately $7.7 Million per mile based on information provided by Sandia National Laboratories during the development of the I-70 Mountain Programmatic Environmental Study.

Maintenance Facilities

Maintenance facilities and storage yards include the construction and all equipment necessary to properly maintain the fleet of vehicles. The size of the maintenance facility is related to the size of the maglev fleet needed for this program. The unit cost of $3,080,000 per section (or car) of a maglev train set for this study is determined by averaging the cost of the maintenance facilities for Baltimore- Washington and the Pittsburgh projects adjusted to year 2008 dollars.

Exhibit 8-10: Unit Capital Costs, Maglev Maintenance Facilities in $2008

Description	Unit	Unit Cost (Thousands of $2008)
Maintenance Facilities	Sections	$3,080

Stations and Parking

Stations and Parking Facilities include platforms, circulation, lighting, security measures and all auxiliary spaces. Space is provided for ticket sales, passenger information, station administration, baggage handling and commercial space. Exhibit 8-11 provides unit costs for various station types.

Exhibit 8-11: Unit Capital Costs, Stations & Parking in $2008

Description	Unit	Unit Cost (Thousands of $2008)
Full Service - New - Low Volume - 500 Surface Park	each	$5,000
Full Service - Renovated - Low Volume- 500 Surface Park	each	$4,000
Terminal - New - Low Volume - 500 Surface Park	each	$7,500
Terminal - Renovated - Low Volume - 500 Surface Park	each	$6,000
Full Service - New- High Volume - Dual Platform - 1000 Surface Park	each	$10,000
Terminal - New- High Volume - Dual Platform - 1000 Surface Park	each	$15,000

8.4 Other Costs

8.4.1 Contingency

Contingency costs were added as an overall percentage of the total construction cost. Contingencies are an allowance added to the estimate of costs to account for items and conditions that cannot be realistically anticipated. The contingency is expected to be needed as the project develops. The contingency is estimated at 30 percent of the construction cost elements. This contingency included 15%+ for design contingency and 15%+ for construction contingency.

8.4.2 Professional Services and Environmental

The project elements included in the Professional Services category are design engineering, program management, construction management and inspection, engineering during construction, and integrated testing and commissioning. For a project of this size, an overall program manager with several section designers is needed to provide conceptual engineering, preliminary engineering, environmental studies, geotechnical engineering, final engineering and engineering during construction. Field and construction management services and integrated testing services and commissioning of various project elements also are required. Professional services and other soft costs required to develop the RMRA project have been estimated as a percentage of the estimated construction cost and are included in the overall cost estimates as a separate line item. These costs include, as a percentage of construction cost:

- Design engineering and related studies 10%
- Insurance and Bonding 2%
- Program Management 4%
- Construction management and inspection 6%
- Engineering services during construction 2%
- Integrated Testing and Commissioning 2%
- Erosion Control and Water Quality Mgt 2%

8.4.3 Placeholders

The capital costs include allocation for special elements (placeholders) as conservative estimates for large and/or complex engineering projects that have not been estimated on the basis of unit costs and quantities. Placeholders provide lump sum budget approximations based on expert opinion rather than on an engineering estimate and are shown in the unit costs as lump sum items. Placeholders are used where detailed engineering requirements are not fully known. These costs will require special attention during the project development phase. The following list highlights some of the key placeholder costs that are assumed in this analysis. Cost details are shown on the detailed sheets in Appendix E:

- Costs for new stations in densely built-up urban areas, including Denver Union Station improvements
- Major tunnel improvements
- Rail capacity expansion
- Maintenance and layover facilities

8.5 Infrastructure Capital Costs

As route segments were examined in the field, general concepts were developed and assumptions made regarding the capacity and operational improvements needed to accommodate future passenger operations. The primary objective was to conceptualize infrastructure improvements that would improve fluidity and enhance the reliability of both passenger and freight rail operations.

In order to account for the interactive analysis needed to optimize the trade-off of capital costs with operational consideration, the study corridors were further segmented to allow for a mix and match scenario that was driven by technology consideration. Civil engineering quantities were developed for each segment using the results of the field inspections combined with data derived from GIS and railroad track charts. Infrastructure capital cost estimates by segment were prepared for each study corridor for steel wheel/steel rail, very high-speed maglev and urban maglev. Segments were identified for existing rail routes and constrained and unconstrained greeenfield routes. The following summarizes the key results of the initial screening of alternatives. The full screening process is described in Chapter 9. For the purpose of this screening, a set of capital costs were developed for each route/alignment option, or Representative Route as described in Chapter 4. The detailed cost estimates by segment are in Appendix E.

Infrastructure costs, shown in Exhibit 8-12, were developed for upgrading the existing rail lines in the I-25 corridor to 79-mph and 110-mph standards. Infrastructure costs for either 79 mph or 110 mph were thought to be practically identical, due to the need for heavy freight capacity mitigation in the I-25 corridor which requires extensive use of dedicated passenger infrastructure, regardless of speed. The only real difference is in vehicles, which have a lower cost in the 79-mph option, due primarily to the lower level of service offered and corresponding fewer number of vehicles that would need to be purchased.

Exhibit 8-12: Incremental Rail in I-25 Upgrade Costs

Capital Costs by Route and Technology (Billions $2008)

Existing Rail I-25	79 mph	110 mph
Infrastructure	$3.57	$3.57
Vehicle	$0.18	$0.28
Total	$3.75	$3.85

Capital Cost per Mile (Millions $2008)

Existing Rail I-25	79 mph	110 mph
Miles	347.50	347.50
Capital Cost per Mile	$10.78	$11.08

Infrastructure costs, shown in Exhibit 8-13, were developed for both electric rail options (150 mph and 220 mph) and for maglev options (125 mph and 300 mph.) All of these costs were developed for the full RMRA network including service to Grand Junction, Aspen, Craig and Black Hawk in the west, and to Cheyenne and Trinidad in the north and south. It can be seen that development of either of the two Maglev options would cost substantially more than would the rail options. As shown in Exhibit 8-13, a maglev system would cost two to three times that of a comparable rail system for only a few minutes difference in running time performance. This is because curves and the relatively short distances between stations fundamentally limit train performance, and maglev systems guideway structures are much more expensive than railroad guideway structures.

Exhibit 8-13: High-Speed Rail in Both I-25 and I-70 Upgrade Costs

Capital Costs by Route and Technology (Billions $2008)

Constrained I-70 7% Route/ Greenfield I-25	125 mph	150 mph	220 mph	300 mph
Infrastructure	$66.94	N/A	$35.59	$75.93
Vehicle	$1.92	N/A	$1.02	$2.44
Total	$68.86	N/A	$36.61	$78.37
Unconstrained I-70 4% Route/ Existing Rail I-25	**125 mph**	**150 mph**	**220 mph**	**300mph**
Infrastructure	$72.86	$28.56	$28.56	$82.42
Vehicle	$1.73	$0.66	$0.66	$2.32
Total	$74.59	$29.21	$29.21	$84.73

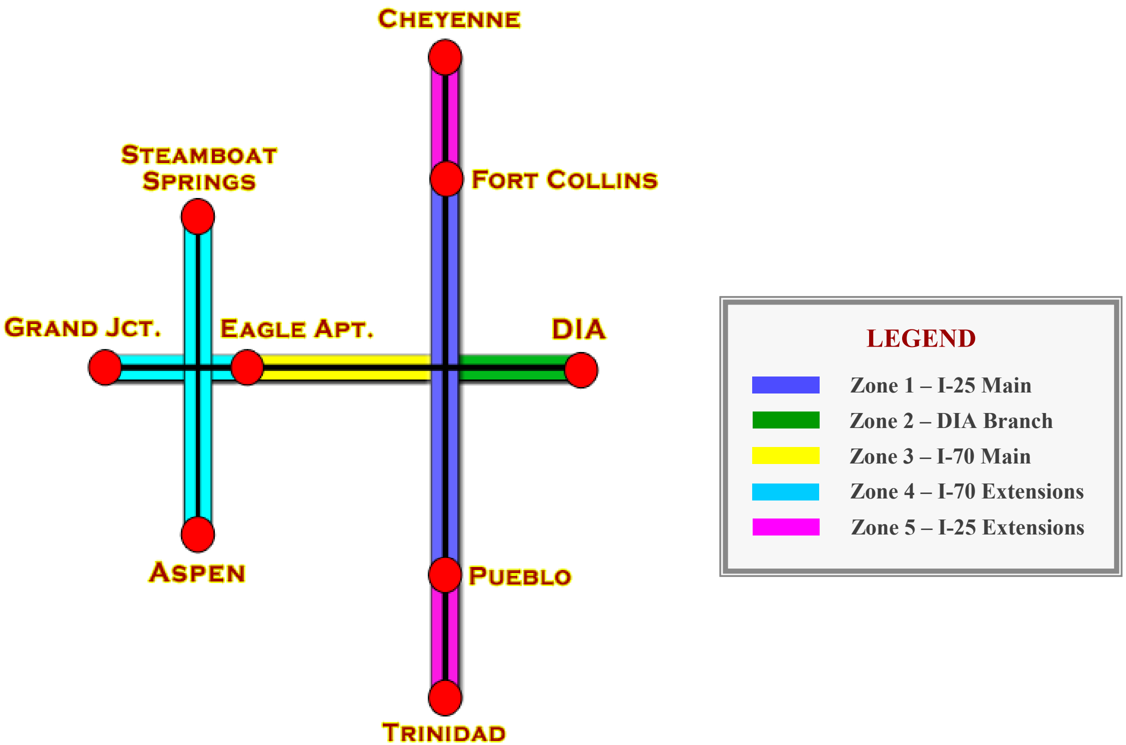
Capital Cost per Mile (Millions $2008)

Constrained I-70 7% Route/ Greenfield I-25	125 mph	150 mph	220 mph	300 mph
Miles	747.44	N/A	747.44	747.44
Capital Cost per Mile	$92.13	N/A	$48.98	$104.85
Unconstrained I-70 4% Route/ Existing Rail I-25	**125 mph**	**150 mph**	**220 mph**	**300 mph**
Miles	795.54	795.54	795.54	795.54
Capital Cost per Mile	$93.76	$36.72	$36.72	$106.51

* N/A means the train technology cannot operate over this alignment.

It should be noted that the capital costs in Exhibit 8-13 are very high, which led to difficulties with Cost Benefit ratios in the initial screening of options. See Chapter 9. Accordingly, a strategy for "truncating" or shortening the network as shown in Exhibit 8-14 was developed, for reducing the capital cost. (This schematic shows only the mainline that makes up the major costing segments, without branch lines.)

Exhibit 8-14: Major Capital Cost Segments



Costs estimates for the two network options, based on either an I-70 Right-of-Way or I-70 Unconstrained alignment, coupled with a new Greenfield alignment or Existing Rail in I-25, respectively, were developed based on the segmentation shown in Exhibit 8-14. These results are shown in Exhibits 8-15 and 8-16.

Comparing these two figures it can be seen that the I-70 Right-of-Way (or Constrained) / I-25 greenfield option in Exhibit 8-16 generates substantially more revenue, primarily because of the strength of the greenfield alignments both on I-25 and on the Western extensions. Also, the same exhibit shows that I-70 costs from Denver to Eagle Airport comprise a lower percentage of total cost, because of the very high costs of these greenfields on I-25 and in the west.

The most important thing to note is the relatively high share of revenue (93 percent and 95 percent, respectively) that is associated with a "Core" system that extends from Fort Collins to Pueblo, and from Denver International Airport (DIA) to Eagle Airport. By eliminating the high-cost extensions to Trinidad, Cheyenne and the three western destinations, the cost of the system could be dramatically reduced without losing much revenue. (Please note that these extensions were all costed as double-track electrified rail or maglev options. The possibility of providing a lower cost diesel service for these Western extensions was not evaluated by this study.)

Exhibit 8-15: Capital Cost Distribution for Unconstrained I-70/Existing Rail on I-25: 150-mph Electric

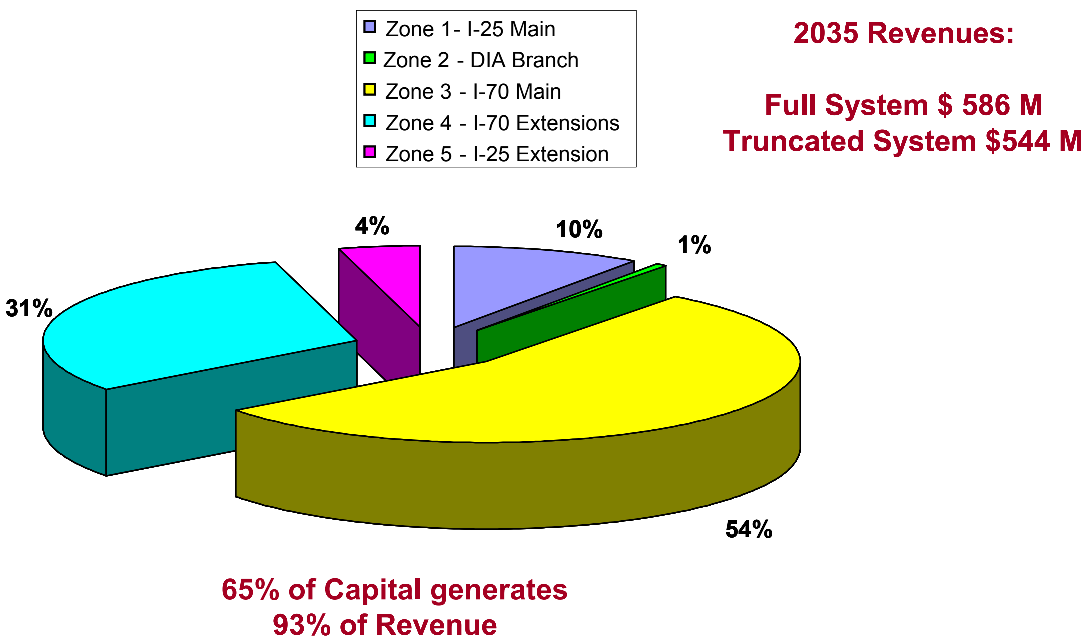
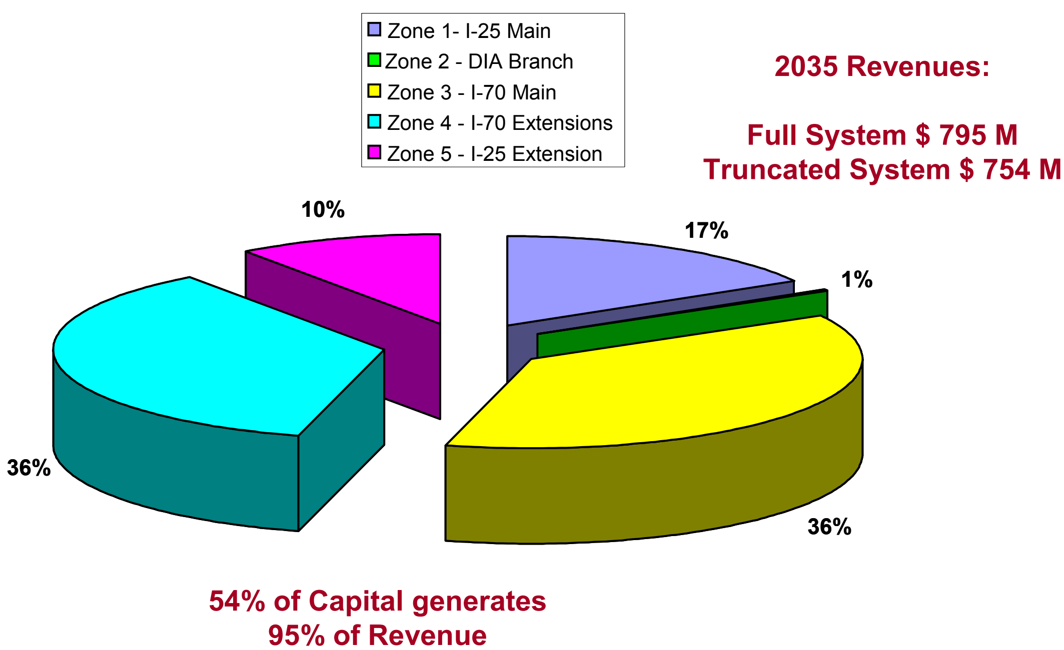


Exhibit 8-16: Capital Cost Distribution for I-70 Right-of-Way/Greenfield on I-25: 220-mph Electric Rail



8.6 Summary

This chapter has described the unit costing basis for the development of capital costs for this study.

Costs were developed initially for two main network options, a constrained route following I-70 with 7 percent grades, and an unconstrained route having only 4 percent grades. These were paired with greenfield and existing rail alignments on I-25.

These two network options have been evaluated for the full RMRA system, but it was found that a truncated system between Fort Collins and Pueblo and DIA and Eagle County Airport could still capture a very high percentage of the projected revenue and ridership, at substantial capital cost savings. Accordingly additional options will be developed for this core system.

Chapter 9 will define an “FRA Developed” option by combining segments of the original constrained and unconstrained alignments using a mix-and-match approach. After this, a four-phase implementation plan will be developed in Chapter 10.

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