



# Urban Maglev Technology Development Program COLORADO MAGLEV PROJECT FINAL REPORT

U. S. Department of  
Transportation

**Federal Transit  
Administration**

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**OFFICE OF RESEARCH, DEMONSTRATION, AND INNOVATION**

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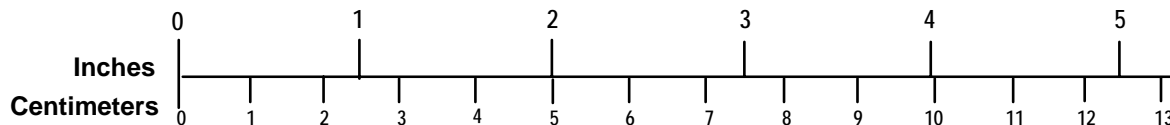
*Part 2 – Final Report*

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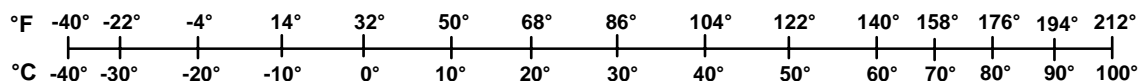
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# Abbreviations, Acronyms, & Definitions

AASHTO	American Association of State Highway and Transportation Officials
ADA	American Disability Act
ANSI	American National Standards Institute
APTA	American Public Transit Association
ASCE	American Society of Civil Engineers
ATC	Automatic Train Control
ATCS	Automatic Train Control System
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
CCCS	Command, Control and Communication System
CDOT	Colorado Department of Transportation
CMP	Colorado Maglev Project
dBA	Decibels
EDS	Electro Dynamic System
EMS	Electro Magnetic System
FTA	Federal Transit Administration
CHSST	High Speed Shuttle Transport
HVAC	Heating Ventilation and Air Conditioning
ISO	International Standardization Organization
IEEE	Institute of Electrical and Electronic Engineers
JFSA	J.F. Sato and Associates
LIM	Linear Induction Motor
LRT	Light Rail Transit
LSM	Linear Synchronous Motor
MDBF	Mean Distance Between Failure
MTBF	Mean Time Between Failure
MTTR	Mean Time to Restore
NFPA	National Fire Protection Association
O&M	Operations and Maintenance
PEIS	Programmatic Environmental Impact Statement
TSA	Transportation Security Administration
UBC	Uniform Building Code
UTM	Urban Transport Maglev



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COLORADO DEPARTMENT OF TRANSPORTATION (CDOT)  
COLORADO INTERMOUNTAIN FIXED GUIDEWAY AUTHORITY (CIFGA)

*Urban Maglev Technology Development Program*

**COLORADO MAGLEV PROJECT  
PART 2: FINAL REPORT**

*June 2004*

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## 1.0 **INTRODUCTION**

The following report documents the eighteen month effort by the Colorado Maglev Project (CMP) Team in developing the technical basis for deployment of the CHSST maglev system for use in the Colorado I-70 Corridor from Denver International Airport (DIA) to Eagle County Airport; this route is in excess of 250 kilometers (155 miles) and traverses the most challenging terrain for deployment of any type of transit system anywhere in the United States.

The full report includes three sections: the Executive Summary, which is found under separate cover, the Final Report (this document), and the Comprehensive Technical Memorandum available only in electronic format on CD.

This Final Report summarizes system requirements based on the route and ridership, the Colorado 200 maglev system specifications including required modifications and improvements to operate in the corridor, required infrastructure including guideway and stations, a Deployment Guide to create the system including the projected capital and operations costs to operate the system, an Operations Plan, and finally, an overview of a security plan necessary to operate the maglev system under the newly established Transportation Security Administration regulations.

The Comprehensive Technical Memorandum that accompanies this report provides additional detail, supporting the technical achievements and findings attained throughout this Project effort. The Comprehensive Technical Memorandum includes systems integration data, and winterization and propulsion motor trade studies conducted as part of the Project effort, as well as data on electrification and greenhouse gas emissions.

## 2.0 **TECHNOLOGY**

The system requirements are determined by a number of factors, including the route as well as the projected number of people who will use the system, and the expected patterns of their travel.

### 2.1. **ROUTE**

The CMP proposed route stretches from the DIA, through the Denver urban area, and into the Rocky Mountains ending at the Eagle County Airport, a distance of over 250 kilometers (155 miles). This corridor is clearly one of the challenging corridors under consideration worldwide. The proposed route provides an evaluation of a maglev system application in urban, semi-urban and rural environments in both winter and summer conditions with difficult mountainous terrain. Figure 1 shows a typical section of the mountainous I-70 corridor looking east from the Vail Ski resort.



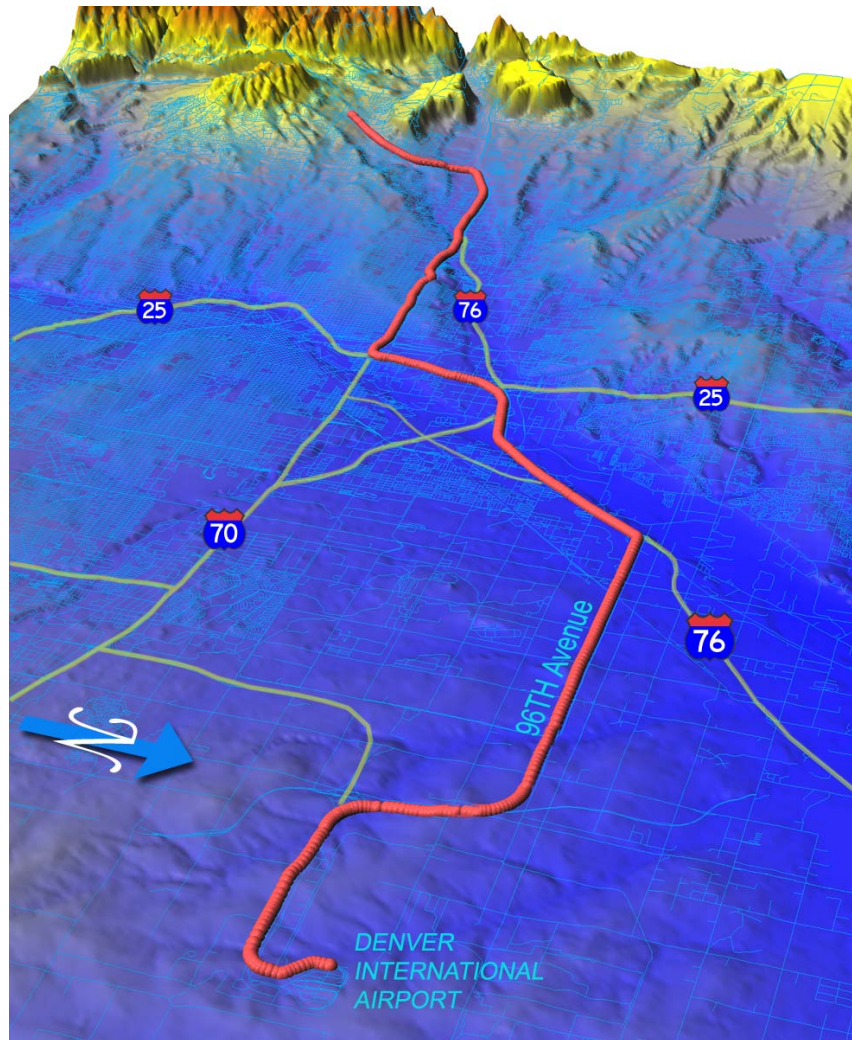
**Figure 1: I-70 at East Vail Looking Eastbound Toward Vail Pass**

Due to the significant year-round congestion occurring in the I-70 mountain corridor during weekends and on holidays, the developing commuter trips occurring in the mountain communities such as Eagle, and the limited available right-of-way along much of I-70, transit may be the only viable alternative to extremely costly highway construction beyond an already expensive proposed two-lane (one lane each westbound and eastbound) highway widening. This final report for the FTA defines a maglev system that can provide the necessary transportation capacity with the operational ability to relieve the growing congestion along the I-70 corridor.

The 250 kilometer (155-mile) CMP route has been divided into three segments for study purposes:

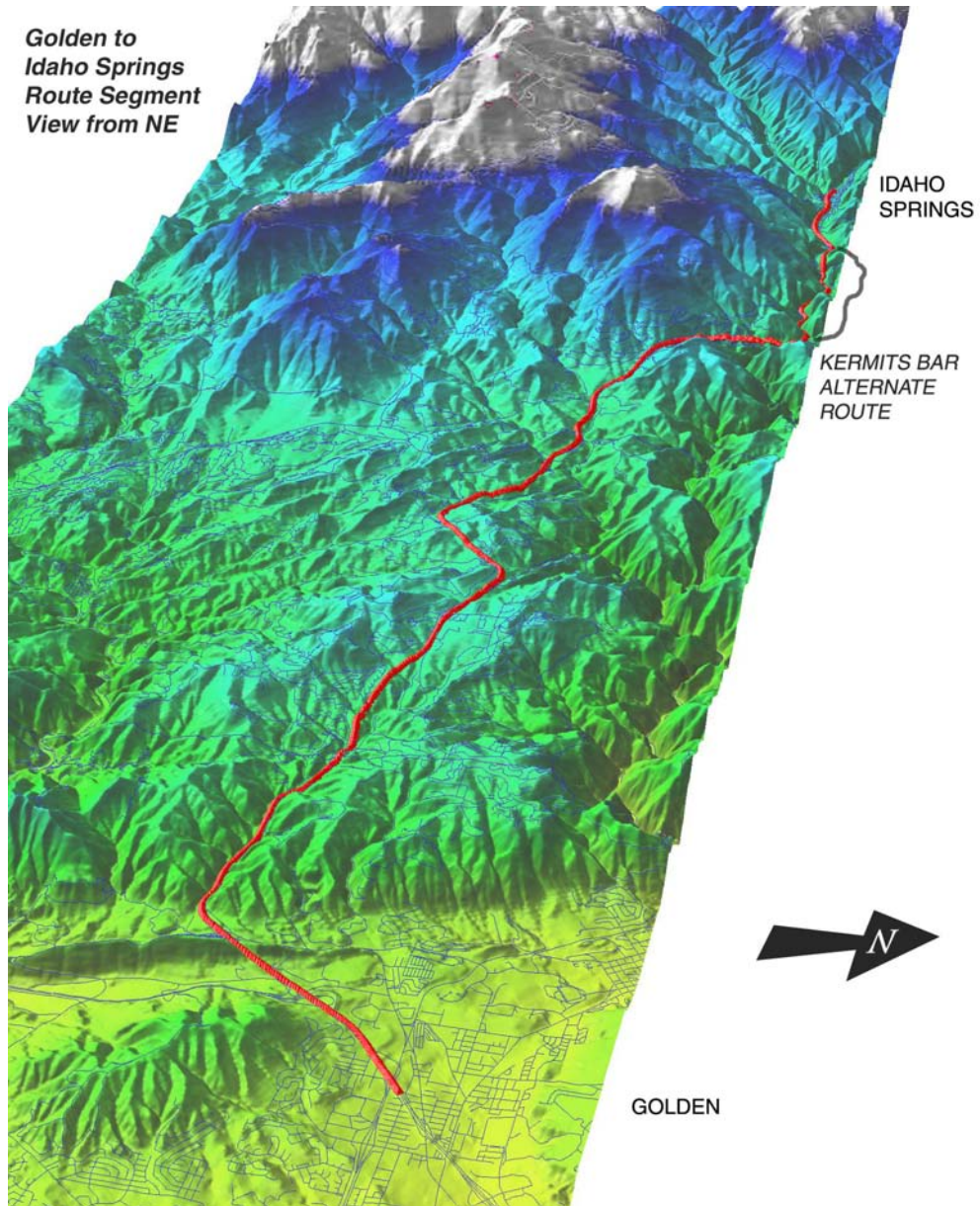
- DIA to Golden
- Golden to Idaho Springs
- Idaho Springs to Eagle County Airport (ECA)

The Denver urban area segment would generally follow the I-76 to I-70 alignment along the northern edge of the City of Denver, as shown in Figure 2. The proposed alignment will service DIA and portions of the metropolitan area.



**Figure 2: Denver Metropolitan Maglev Route**

Figure 3 illustrates a perspective of the segment from Golden to Idaho Springs and shows a possible alternative alignment avoiding the Twin Tunnels just east of Idaho Springs. A key benefit of maglev technology is its ability to traverse significant grades, potentially avoiding costly tunnel construction. The FTA emphasized during the conduct of this analysis that attributes of the technology needed to be explored and ultimately fully employed along the corridor.



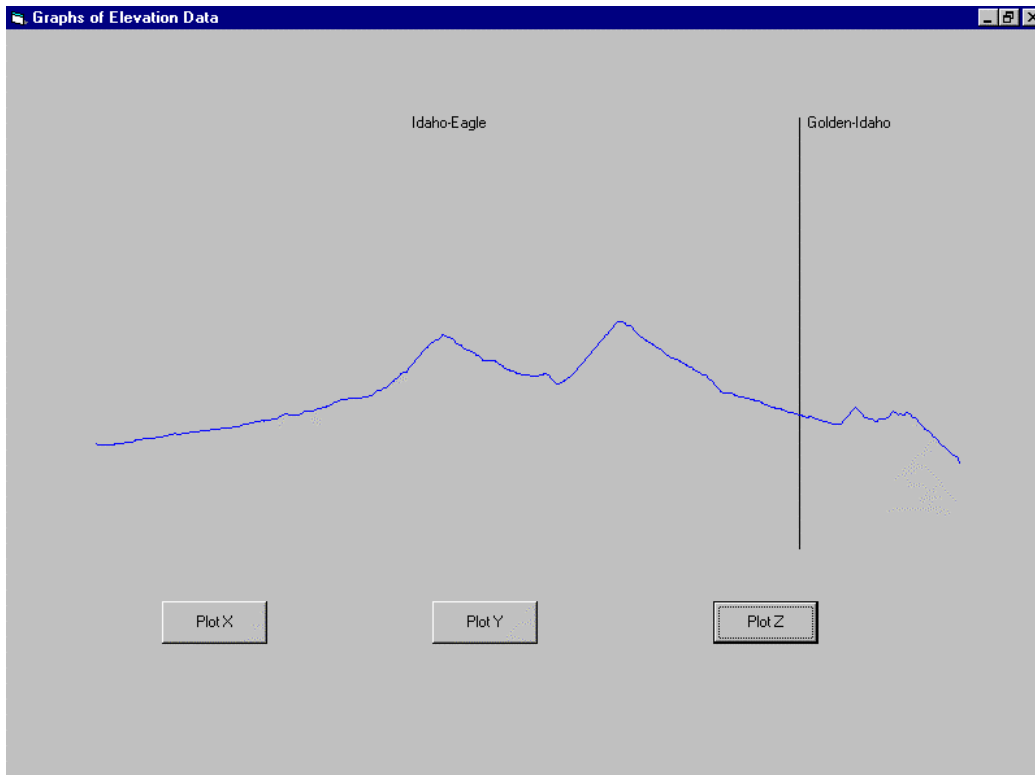
**Figure 3: Golden to Idaho Springs with Alternative Alignment**

Figure 4 is a picture of the alternative alignment to the Twin Tunnels showing the rugged terrain that the maglev system would be traversing. The picture is taken from the proposed alternative alignment, and looks westward toward Idaho Springs.



**Figure 4: Alternative Alignment Overlooking I-70 East of Idaho Springs**

Figure 5 illustrates the I-70 segment elevation profiles from Golden to Eagle. Note the extreme elevations along the entire I-70 corridor and the potential areas of difficulty conventional transit systems may encounter in operating along the corridor.

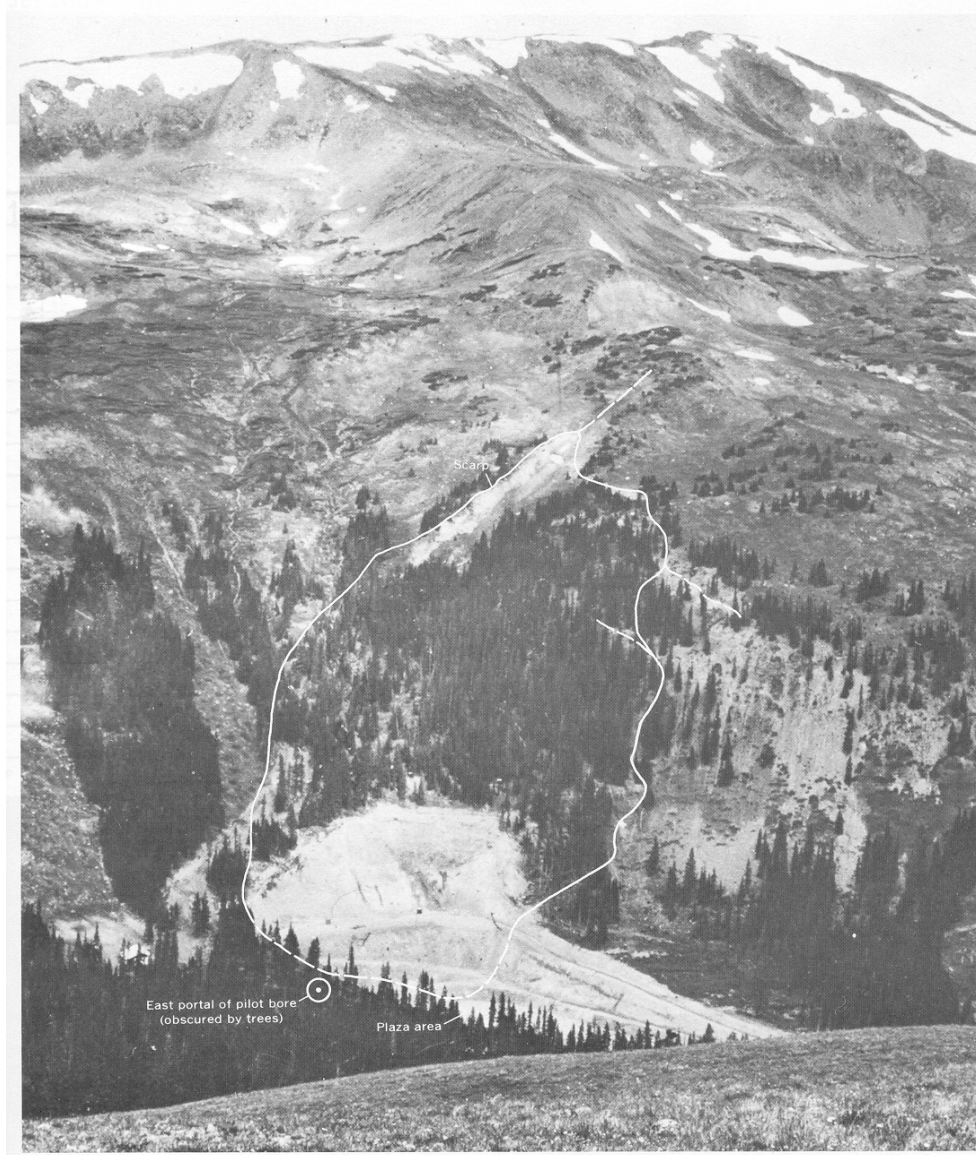


**Figure 5: Mountain Corridor Elevation Profile**

I-70 passes under the Continental Divide at the Eisenhower-Johnson Memorial Tunnel (EJMT). The EJMT area has a number of complex issues due to the history and geology of the immediate area. The Colorado Department of Highways, as the Colorado Department of Transportation was



then known, investigated possible tunnel sites through the Continental Divide between 1943 and 1960. Topographically, the ground surface above the tunnels consists of steep mountain terrain leading up to the Continental Divide forming a high mountain ridge that trends northeast-southwest across the area. As a result of the poor geological conditions, tunneling work is extremely difficult and costly. In fact, during construction of the eastern portal location for the proposed EJMT in 1963, a large slope failure, or landslide, was initiated by the removal of the toe of the slope at the current Loveland Ski Area. This slope failure became known as the East Portal Landslide with an estimated land movement encompassing 3,000,000 cubic yards. Figure 6 illustrates the landslide area in 1965 and the severity of the slopes up to the Continental Divide; the photo is looking north.

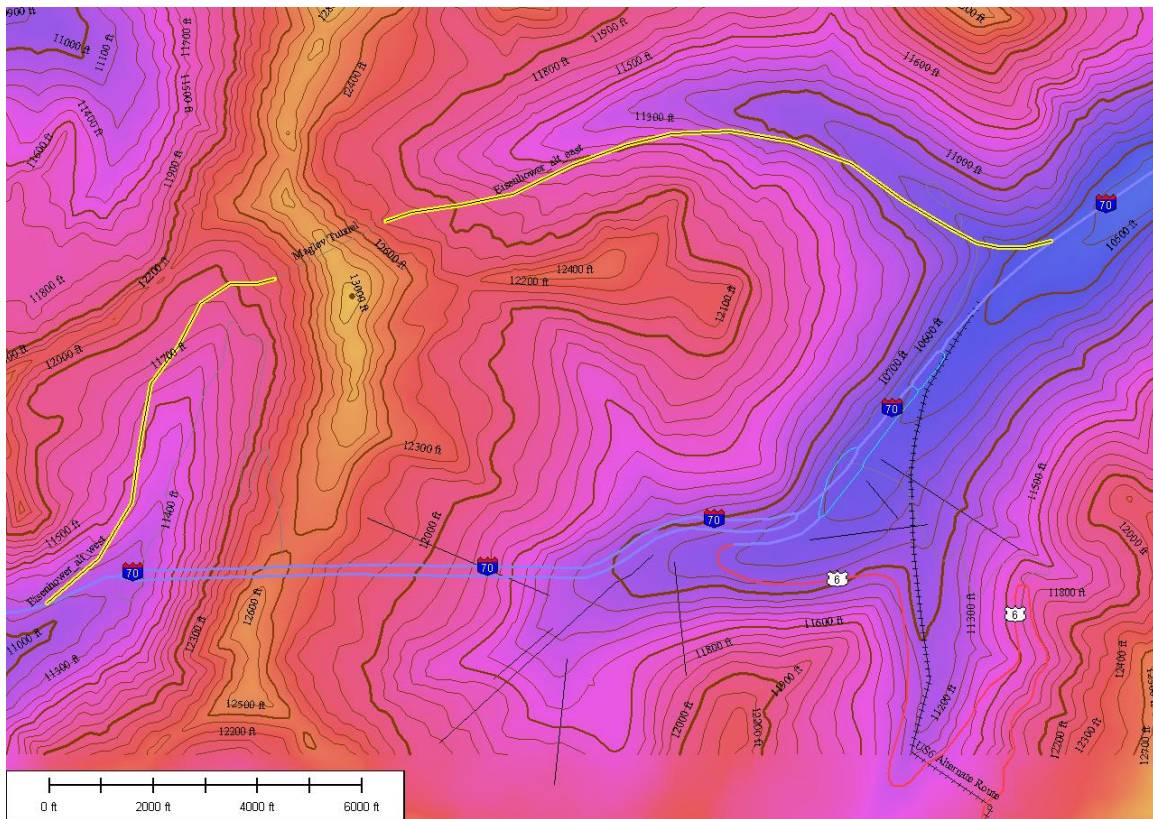


**Figure 6: Loveland Basin Landslide, 1965.**

A new transit tunnel for the proposed maglev system at the EJMT can be avoided due to the CMP's system's capability to traverse grades up to 18% with degraded train operation. The maglev system's grade climbing capability provides cost relief by reducing or completely eliminating the need for new transit system tunnel adjacent to the new proposed highway tunnel bore near the EJMT.

The cost for a new transit-only bore for a maglev system or other transit systems at the EJMT is projected by the CDOT PEIS consultant team to be approximately \$333,500,000, while the cost for a dual use tunnel is approximately \$377,500,000. During the CMP analysis of alternative alignments near the current EJMT, consideration was given to the constructability of the guideway, although environmental and permitting issues were not addressed. In areas removed from I-70, access to the construction site would be difficult, but not impossible. In addition, a short construction period due to winter conditions could complicate alternative routing. However, with the projected high costs of tunneling these factors and others deserve further scrutiny in order to provide an optimum system cost.

As part of the Project effort, significant consideration was given to alternative alignments in order to avoid costly tunnels. This evaluation resulted in an alternative to the long EJMT transit tunnel as depicted in Figure 7.



**Figure 7: EJMT Alternative Alignment, with Short Tunnel**

The least costly alignment around the EJMT, as shown by the yellow line in Figure 7, is \$165 million while the tunneling cost of a new EJMT transit tunnel is \$333.5 million. The alternative alignment is 7,328 m or 7.37 km (24,204 feet or 4.58 miles) in length and bypasses 6329 m or 6.3 km (20750 feet or 3.93 miles) in length of I-70 on its alignment through the EJMT. The added length in guideway for this alternative is 1047 m or 1 km (3432 feet or 0.65 miles) with 701 m (2300 feet) of this in a tunnel under the Continental Divide. The projected costs for the alternative alignment were derived using the CDOT PEIS estimate for tunneling costs and the FTA CMP costs for guideway. In order to establish cost optimization, the ultimate deployment of the maglev system is predicated on achieving the lowest cost to construct the transit system. The recommended alignment for the CMP FTA study traverses the alternative alignment as depicted in Figure 7. This analysis has not evaluated environmental issues or constructability issues such as rockfalls or the short construction season at this altitude. However, avalanche and rockfall can

be mitigated by snow sheds and/or fenders constructed around guideway columns for avalanche, and fenders can be specifically designed for both avalanche and rockfalls in those areas where they are known to occur. Also the alternative alignments are within the boundaries of the Arapaho National Forest and will require negotiations with the National Forest Service for use permits. The National Forest Service is at times receptive to allowing fixed transit system use over forest lands. All these factors could affect the duration of construction, and hence, the cost estimate. In subsequent phases of this project further detailed evaluation of this and other prospective alternative alignments including the EJMT alignment will need to be performed to assure conformance to design criteria as well as mitigation for rockfalls and avalanches if an alternative alignment to the EJMT transit tunnel is selected.

The capital cost estimate for the CMP incorporates the estimate for this alternative alignment as an appropriate reflection of potential cost efficiency. If this alignment later proves infeasible, then the EJMT tunnel alignment estimate would have to replace it as a component of the overall cost. The capital cost discussion references both cost estimates.

## 2.2. RIDERSHIP

Sizing the CMP was completed using the patronage demand for the system. A travel model was developed for the I-70 mountain corridor as part of the PEIS prepared by the CDOT. The PEIS travel model covers the area surrounding the I-70 corridor from the DIA to Glenwood Springs. However, the metropolitan area is only included in the I-70 PEIS travel model at a relatively coarse level for the modeling of trips between Denver and the mountain corridor.

CDOT consultants for the I-70 PEIS have completed ridership forecasts. The patronage forecasts were completed with the following guidelines:

- two day snapshot – winter Saturday and summer Saturday (with a Friday comparison east and west slope)
- 2025 peak hour transit ridership spread and annualized
- net fare definition based on O&M costs (10¢ & 25¢ per mile shown for comparisons)

The ridership projection used by the CMP team in sizing the Colorado maglev system is 40,000 daily transit passengers.

The following table summarizes the ridership estimate used for this analysis.

**Table 2.2-1 Vehicle Sizing Requirements**

**System Peak Ridership**

40,000 riders per day (weekends)<sup>1</sup>

**Patronage / Vehicle Sizing**

20,000 directional travel

3-hour peak am and pm produces 60% of total ridership – 12,000 trips<sup>2</sup>

1-hour peak hour patronage am and pm is 50% - 6,000 trips<sup>3</sup>

<sup>1</sup> The ridership projection was developed by PEIS consultants to CDOT, based on weekend ridership, the maximum ridership period.

<sup>2</sup> The peak three hour ridership will be 60 percent of the total daily directional travel

<sup>3</sup> The peak hour patronage will be 50 percent of the peak three hour ridership

In order to determine the vehicle fleet requirements, two methods were used. First, a manual schedule for express service to meet the projected demand was configured. Then, detailed operational simulations of exclusively local service were performed using stochastic passenger loads drawn from the projected passenger populations at each station. For the express service the fleet size was 65 train consists of 2 vehicles each, while the simulated exclusively local service needed a total of 75 train consists of 2 vehicles.

The local service 75 train fleet (operated with 1 minute dwell time in the simulations) does not in any way optimize fleet size through empty management and other techniques, such as dwell time adjustment (increasing the dwell time can increase the numbers of passengers on trains, thereby reducing the number of trains required). When these and other vehicle management techniques are applied, the number of trains is unlikely to exceed 65. Hence, the 65 consist fleet is considered a safe fleet size for cost estimation.

In these simulations of local service, extra trains were also assumed to be always available to meet the demand, and were introduced into the system flow as required, without attempting to optimize the use of trains. The goal of the simulations was to demonstrate:

- a) that the system could operate successfully to carry the required load
- b) verification of headway (120 seconds) and average speed (114 kph (71 mph))
- c) the maximum number of trains needed to carry the system load
- d) number of trains in the system as a function of time

These objectives were accomplished. Extensive simulation to attempt further optimization is not warranted until better system definition (particularly station locations) is available, and was beyond the scope of the present study.

### **2.3. SUMMARY AND CONCLUSIONS**

The preceding sections have discussed the route plans and profiles that would be used for the CMP. The maglev system starting at DIA in Denver would utilize a northern corridor alignment generally along the I-70 right-of-way to the Golden Intermodal Transit Station.

From Golden the maglev alignment would generally be within the I-70 right-of-way, with a potential diversion from approximately the US 6/I-70 interchange to Idaho Springs just north of I-70, eliminating the need for an additional tunnel bore at the Twin Tunnels just east of Idaho Springs.

From Idaho Springs to Eagle County Airport the maglev alignment is assumed to be in the median of I-70. Alignment alternatives were analyzed at the EJMT to allow for potential cost savings by eliminating a new, long maglev system tunnel or reducing the length of the required tunnels by utilizing the unique grade climbing capabilities of the maglev system. However, the CMP did not assess the environmental impacts of either the Idaho Springs Twin Tunnels or EJMT alternate maglev route alignments.

The route alignment for the proposed maglev system traverses challenging terrain. This terrain has mandated incremental improvements in the baseline maglev system to be deployed for the CMP incorporating some modifications to the system specifications, as discussed in subsequent sections of this report.

### 3.0 **SYSTEM SPECIFICATIONS**

The application of Urban Maglev systems technology to the Colorado I-70 corridor requires moderate speed, corridor-type service operation typified by urban-suburban-rural routes operating from one major activity center to another (in the Colorado case from DIA to Eagle County Airport) with intervening destinations of the resort areas in the Rocky Mountains.

Although the Urban Maglev Systems have common features with other Automated People Movers, maglev requirements are more stringent due to the higher expectations of the technology in the form of public acceptability (based on superior ride quality, low noise, low pollution, and low vibration), superior grade climbing capability and low maintenance and operational costs. Although low- to medium-speed technology is classified as “still emerging” with competing developmental concepts that can revolutionize future urban transportation systems, maglev technology currently exists in at least two, and perhaps three, fully deployable forms.

The CMP requirements are set down here to promote and guide system innovations for the I-70 corridor in a manner consistent with the FTA objectives of developing cost effective, safe and viable Urban Maglev Systems. The requirements are specifically tailored for maglev systems; however, they necessarily overlap with some requirements for other established transportation systems.

The deployable Urban Maglev System proposed for the I-70 corridor satisfies the functional requirements as listed for performance and safety.

#### 3.1 **TECHNOLOGY BASELINE**

The FTA mandated that the technology for the urban maglev project be a medium speed maglev, capable of safe transport at 160 kph (100 mph). However, the span of the Colorado system also required that the technology be capable of operating in mixed urban and rural environments on flat land and in mountainous terrain.

A comprehensive review of worldwide maglev technology quickly established the following facts:

- Systems employing electromagnetic (attractive) suspension are well developed to be fully deployable in the time frame of need for Colorado. Electrodynamic (repulsive) suspension systems, while potentially offering many advantages in operation, are still in the developmental stage although TransRapid has a nearly 20-mile system undergoing pre-operational testing in China.
- A fully deployable low- to medium-speed maglev technology has been developed in Japan by Chubu CHSST (CHSST) over a thirty-year development period, building from the original German technology base that produced the TransRapid high-speed system. The TransRapid system is not suitable for the Colorado application as it is essentially designed for a high-speed intercity application and the Colorado system does not require such a speed.
- Japanese maglev technology requires modifications and optimization to meet the demands of climate and grade that are unique to this particular Colorado application.
- Because the CHSST system is presently undergoing its first revenue deployment in Japan, the probable system cost of a United States deployment has been estimated specifically for the Colorado project using detailed cost and price estimation techniques. The system cost is unarguably a major factor in system deployment, given that the technology has been fully demonstrated over many years and is currently being deployed.

The research effort by the CMP team has fully resolved a number of deployment issues by defining the technical modifications and optimization of the CHSST maglev technology necessary to achieve a successful deployment in Colorado within reasonable costs.

### 3.1.1. **Capacity**

The CMP is capable of satisfying moderate to heavy passenger throughput for peak hour period service. The CMP throughput performance (capacity) goal is a minimum of 6,000 passengers per hour per direction. In meeting these performance goals, and in order to offer frequent passenger service, the corresponding headway for peak periods is a two-minute (120 second) minimum.

To provide compliance with the required capacity, a particular vehicle based on the Chubu CHSST Model 200 has been identified as capable of meeting this specific requirement. This vehicle, designated as the Colorado 200, has a capacity of 206 passengers in a married pair two-car train configuration, is capable of operation at the required two minute headway with advanced automatic train control, and is in full conformance with applicable acceleration, deceleration and velocity specifications. A maximum fleet of 65 of these consists has been shown to meet the forecasted demand at the capacity requirement level quoted above. The Colorado vehicle is pictured in Figure 8.



**Figure 8: The Colorado 200 Vehicle**

### 3.1.2. **Operable Weather Conditions**

Weather-related specifications for the deployed Chubu CHSST systems are currently:

Temperature - 10°C to 40°C (14°F to 104°F)

Relative Humidity - 0% to 95%, without dew condensation for electric equipment

The Colorado system deployment has been designed to endure the weather conditions experienced in Colorado, with all weather operation required under precipitation and temperature conditions consistent with historical data.

The technology is capable of full operation in snow and freezing rain, as documented in the Winterization Trade Study. This Study is found in its entirety in the Comprehensive Technical Memorandum provided to the FTA.

Solar thermal loads to the vehicles are compensated by HVAC, while guideway thermal excursions are accommodated by a system of rail expansion joints.

Flood zones will be safely traversed by the elevated guideway designed to safely accommodate applicable flood thresholds. Guideway displacement sensors will be strategically mounted to provide monitoring of guideway condition in avalanche, rockfalls, seismic, and flood situations.

Both electromagnetic background and electromagnetic interference testing have been conducted for the CHSST system with no adverse results as stated in the FTA's Chubu CHSST Maglev System Evaluation and Adaptability to US/FTA Standards, Final Report, September 2003.

Operation in a polluted environment is not expected to be a concern, since the elevated nature of the guideway insures that the operational structure will not be subjected to road level salt spray, or fuel and oil residue in the same concentrations as highway traffic. The guideway is constructed of durable, corrosion-resistant materials (basically reinforced concrete and weathering steel) so that atmospheric pollutants such as ozone and smog will not cause significant damage over the system design lifetime. Blowing sand and dust will represent a common occurrence and will have to be accommodated by design. Lack of moving parts on the vehicle will preclude wear issues from this source, so long as accumulation of debris on the guideway is controlled.

#### **3.1.2.1. Wind**

The Chubu CHSST maglev technology used as the baseline system and modified to the Colorado 200 for the Colorado Project is presently designed to operate normally at wind speeds up to 72 kph. Operations with degraded speed continue beyond 72 kph to 90 kph, the wind shutdown threshold. Structural integrity is designed to withstand winds up to 180 kph. Transient performance under wind loads is discussed in Section 3.4.1, Vehicle Dynamics and Stability.

#### **3.1.2.2. Lightning**

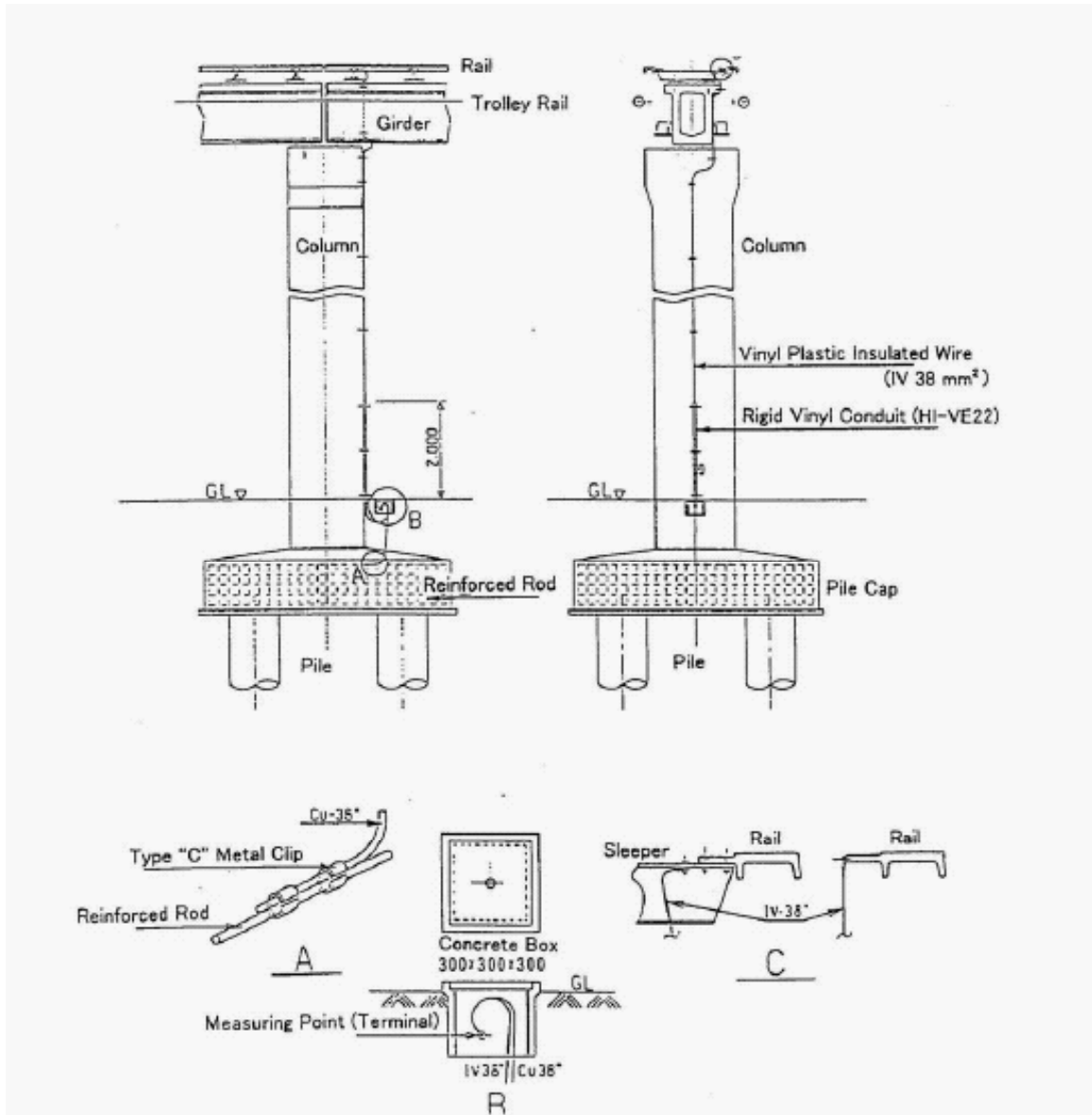
The CMP is capable of operating safely in the lightning environments described by the isokeraunic maps listed in such industry standards as IEEE 1100.

Lightning compliance in the Chubu CHSST system is achieved by a combination of electrical safety elements:

1. The vehicle is grounded at all times to the primary system ground through a positive contact electrical connection.
2. The guideway is grounded at periodic intervals by approved grounding methods.
3. The electrical substations are each grounded by approved grounding methods.

The vehicle ground is carried by a continuous contact to a dedicated ground rail.

The guideway ground is depicted in Figure 9 (FTA-MD-26-7029-03).



**Figure 9: Guideway Grounding**

Electrical substation grounding methods are called out in the appropriate standards, including Compliance with Installation Requirements for Lightning Protection Systems, UL96A, 10<sup>th</sup> edition, 1994.

### 3.1.3. Facilities

The CMP would have well defined stations and associated facilities with proper architectural treatment consistent with the practices of the buildings in the area of its operation.

The CMP assumes the following fourteen stations:

1. **DIA** (DIA, km 0/mile 0): This station represents one terminus of the entire system, serving the Denver Airport.
2. **Rolla** (96th Street & I-76, km 26.7/mile 16.6): This station serves the developing north Denver area, potentially connecting with other transit presently under development.



3. **Downtown Denver** (I-70 & I-25, km 40.3/mile 25.0): This station is located at a major transportation interchange, and will capture a large portion of riders coming from the northern Front Range cities, including Boulder and Fort Collins.
4. **Golden** (I-70/Colfax Avenue & US 40, km 60.0/mile 37.0): This station would serve as the collector for riders coming from South Denver, Pueblo, and Colorado Springs.
5. **Evergreen** (Bergen Park/Route 74, km 76.3/mile 47.4): This station would provide access to Evergreen Park recreation area, and also serve numerous small, urbanized areas along Route 74 to the south.
6. **Idaho Springs** (km 95.0/mile 59.0): This station would provide access to this historic mining town, and also serve local population in the town and in the surrounding canyons.
7. **Georgetown** (km 113.8/mile 70.7): This station would serve the three communities of Empire, Georgetown and Silver Plume.
8. **Loveland Pass** (km 132.7/mile 82.4): This station would provide access to the Loveland Ski Area just east of the Continental Divide.
9. **Silverthorne** (Dillon, km 148.0/mile 91.9): This station would serve the local communities of Silverthorne and Dillon. There are areas of scattered residential development all along Route 9 and US 6. These routes also provide access to Keystone Resort, Arapaho Basin, and Breckenridge Ski areas.
10. **Frisco** (km 157.6/mile 97.9): This station would serve the town of Frisco and the Breckenridge Ski Area
11. **Copper Mountain** (Wheeler Flats, km 166.3/mile 103.3): This station would provide access to Copper Mountain Ski Resort, and serve residential development along Route 91 as far south as Leadville.
12. **Vail** (mile 122.5): This station would serve communities of Bighorn, Vail, and West Vail, Vail Ski Resort, and residential development south along US 24.
13. **Avon** (km 212.4/mile 131.9): This station would serve Eagle Valley, Avon, Beaver Creek Ski Area and Edwards.
14. **Eagle Airport** (km 251.6/mile 156.3): This would be the terminal station that would serve Eagle and Wolcott; also both Beaver Creek Ski and Vail Ski Areas and residential areas along Route 131 to the north.

Station layouts and facilities have been defined in general terms, based on the projected passenger volumes at each location. These definitions provide full compliance with applicable ingress, egress, public accommodations, and safety requirements for such structures. Architectural, structural, and siting features of these stations are beyond the scope of the current effort, although they would be developed further in compliance with all applicable codes and regulations, including environmental and seismic regulations.

#### 3.1.4. **ADA**

The CMP meets the requirements of the Americans with Disabilities Act (Public Law 101-336) and will be useable by the handicapped.

User access to the system is confined to stations and vehicles. Station layouts provide for full conceptual compliance with access requirements of the Americans with Disabilities Act (Public Law 101-336). However, detailed design of these facilities is necessary to guarantee complete compliance.

The vehicle compliance with the Americans with Disabilities Act (Public Law 101-336) is demonstrated in Figure 13 showing ingress and egress, wheelchair restraint, and lavatory facilities. This conceptual design assures full handicapped and disabled access to and use of the public accommodations of the train.

Implementation of the vehicle body for previously deployed Chubu CHSST vehicles has fully supported handicapped and disabled access in accordance with Japan's "Barrier-free Transportation Law". The vehicle body optimization for the Colorado 200 car requirements will follow all guidelines required to provide full ADA compliance as appropriate.

### 3.2. COMPONENT LEVEL SPECIFICATIONS

#### 3.2.1. **Guideway**

The CMP concept guideway designs, which are preliminary to detailed guideway design, have been conducted in accordance with all applicable US standards. Previous deployments of Chubu CHSST maglev technology have been designed in accordance with applicable Japanese standards, documented in a recent FTA report (FTA-MD-26-7029-03). The guideway, where applicable, meets the general requirements of Chapter 11 of ASCE 21-00.

The CMP guideway is designed to meet all applicable specifications. Superelevation beyond 8° is not required in the guideway system as presently constituted. Final siting decisions are not expected to materially alter the guideway configuration in a way that increases superelevation.

##### 3.2.1.1. **Guideway Girder**

The main guideway girder and all primary structural hardware have a 75 year service life and are designed to withstand loads due to vehicle static and dynamic action, diurnal temperature variations, snow, wind, and seismic loads, and resist corrosive conditions from acid and other compounds normally found in the environment. Means are also provided to adjust the girder alignment and profile from time to time for assurance of ride quality. The guideway geometry is characterized by its profile, alignment, gage, and twist throughout the maglev system route. The tolerances of these characteristics at the time of guideway construction and thereafter during its service life are definable and consistent with standard or achievable construction and maintenance practices.

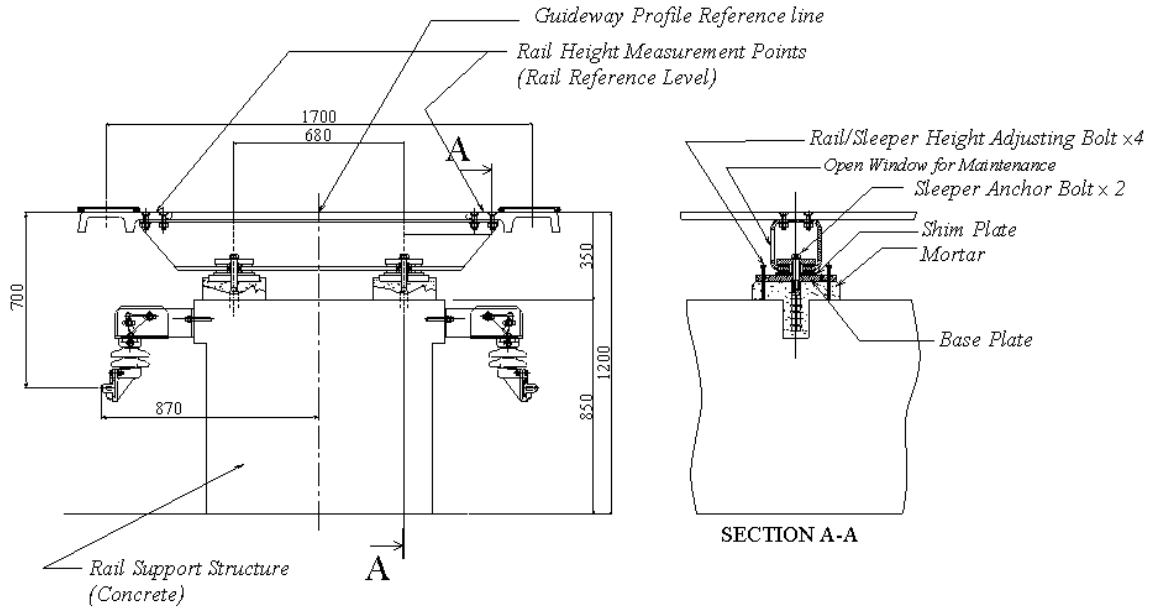
Design loads for the guideway structure are shown in the following table:

**Vehicle Live Loading:**

Maximum Vehicle Live Loading:	1,150 kgf/m per rail; 2,300 kgf/m per guideway
Live Load Impact:	24% (Steel Girders); 16% (Prestressed Conc. Gird.)
Live Load Deflection:	$L / 1,750$ (L = Bridge Span)

Girders of reinforced concrete or steel carry levitation rails of appropriate cross section on sleepers, similar to the structure of a typical railway track. However, the rails are non-contact devices that must be maintained in precise alignment as shown below.

Additionally, adjustment of the sleeper mounts following installation is a feasible and flexible method of maintaining rail alignment in use. Accordingly, an adjustable sleeper mount, Figure 10 below, has been developed and may be readjusted if necessary during the system lifetime.



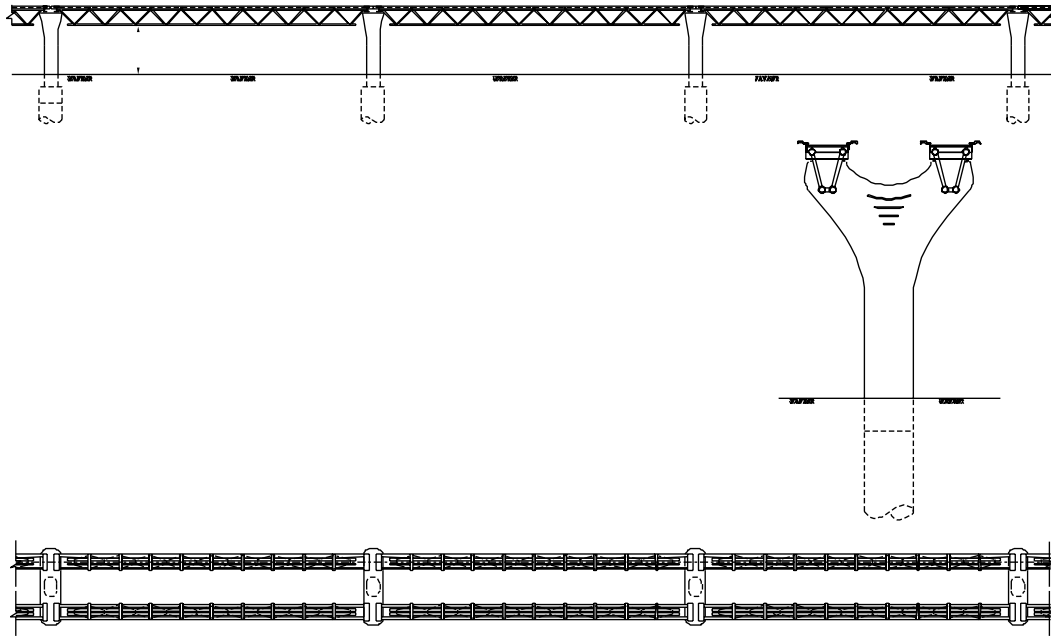
**Figure 10: Adjustable Sleeper Mounting**

### 3.2.1.2. Columns (Piers)

The columns or piers supporting elevated portions of the guideway are designed to last for 75 years under the loads and conditions as listed in Subsection 3.2.1.1 above, in addition to loads due to the guideway girders. The columns are designed to withstand collisions from other vehicle traffic, if any, under the elevated guideway.

Guideway columns are generally made exclusively of reinforced structural concrete. In subsequent designs some columns may need to be armored as required to maintain column integrity in seismic, avalanche, rockfalls, or collision events including security enhancements. The structural design of particular columns will be tailored to site conditions as well as to the necessary bearing load. Generally, columns have been configured to carry two complete sets of levitation girders, together with an inspection (emergency) walkway. Column design for the Colorado system conforms to all applicable specifications.

Two girders configured on a conceptual guideway column are shown in Figure 11.



**Figure 11: Guideway Column Carrying Two Girders**

### 3.2.1.3. Pier Foundations

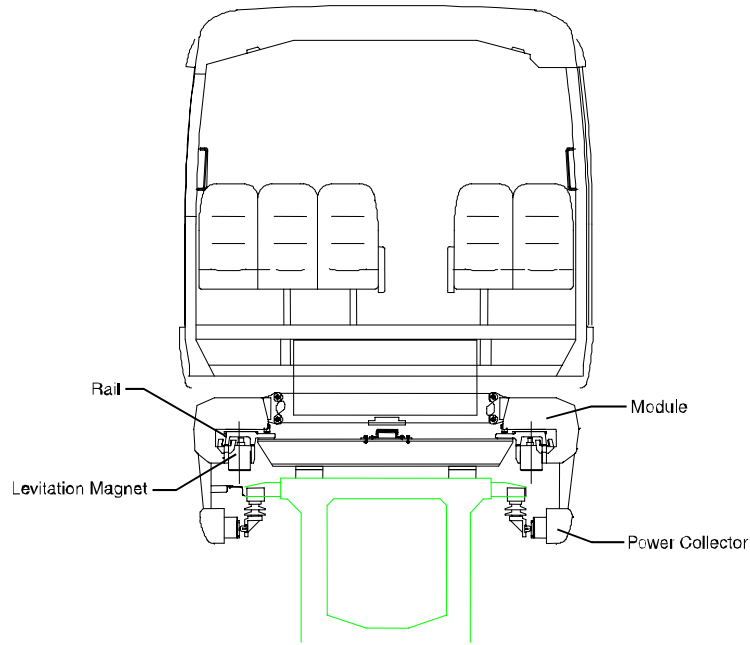
The foundation for the columns referenced in the Columns subsection above, will in subsequent designs be sufficiently deep in the soil so as to last without serious permanent settlement for 75 years. Any permanent settlement will not be more than the allowable adjustment range of guideway irregularity. The foundation will be designed to withstand seismic loads, potential liquefaction of soil, if any, and underground water flows from rain and floods, avalanche and rockfalls, etc.

The range of the girder mounting adjustment mechanism dictates the maximum permissible settlement for column foundations. This information, together with soil conditions at a particular column, will determine the nature of the column footing. The 75-year design life requirement, together with the seismic requirement, will then dictate the foundation structure. It is likely that some piers in the Colorado system will necessarily rest on bedrock, which has been taken into account in the foundation conceptual designs advanced for the system.

### 3.2.1.4. Superstructure or Equipment Mounted on the Guideway Girder

The CMP requires no auxiliary interface structure between the vehicle and the levitation rails carried on the guideway girder. Additional structures for emergency egress and potentially the power distribution have been designed to share the guideway piers with the primary maglev system structures.

The vehicle guideway interface is depicted in Figure 12. This figure clearly shows that no auxiliary structure exists between vehicle and rails, with the vehicle supported only by magnetic force.



**Figure 12: Vehicle Guideway Interface**

Emergency egress in the Colorado system is achieved by disembarking passengers directly to an emergency/inspection walkway. The emergency/inspection walkway is carried on the guideway piers and is located midway between the two travel directions so that it can be reached from vehicles on either track.

#### 3.2.1.5. Switches

Guideway switches will be required to change the vehicle direction en-route at selected locations (including terminals), to reverse direction, and also in maintenance depots. Two switch configurations, one high speed, one low speed, are suitable for use in the Colorado system. The high-speed switch is a pivoting design, well proven in practice, wherein a number of guideway segments are pivoted to interconnect one guideway segment with another. These switches operate in a time frame of 15 to 25 seconds and must be suitably protected from environmental conditions.

The low-speed docking switch requires the vehicle to be stopped for switching. This switch, developed in the 1970's and since proven in use in the rail industry, physically moves the vehicle laterally to another track segment or to a station platform. The vehicle is carried on a track segment for the movement, and the removed track segment can be replaced by another segment in the same motion to avoid disruption of normal traffic flow. The operating times for this mechanism are comparable to the pivoting switch operating times. The mechanisms are robust, although they should generally be protected from adverse weather. This makes them likely candidates for installation at each station, where they can facilitate vehicle docking, switching, and maintenance.

The conceptual design of the Colorado system employs docking switches in each station. These switches are described in the Guideway/Switches Final report, provided to the FTA.

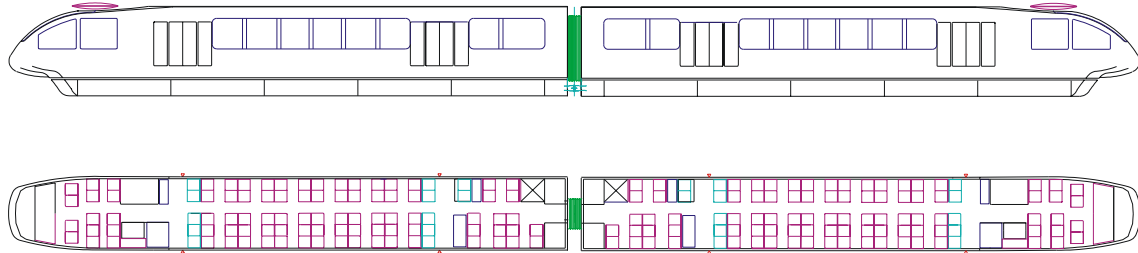
#### 3.2.2. Electrical Power Supply

The Colorado system is electrified by wayside substations located at 9.6 to 11.2-kilometer (6 to 7-mile) intervals, interfaced to a reliable source of utility power. The substations employ standard

commercial electrical distribution components including transformers, circuit breakers, and rectifiers. The Deployment Plan chapter of this report contains a detailed discussion related to existing power availability.

### 3.2.3. Vehicle

The Colorado 200 has been configured to meet the ASCE 21-00 requirements. The interior layout of this vehicle is shown in Figure 13. The vehicle is configured to accommodate 206 passengers in the 2-car, married pair configuration.



**Figure 13: Colorado 200 Vehicle Interior Layout**

The Colorado 200 maglev vehicle body is designed to last at least 30 years, which is a more stringent requirement than the one referred to in ASCE 21-00. Due to the maximum system speed, standees are not permitted in the Colorado vehicle; all passengers should have seats in the car. The Colorado 200 also has public toilet facilities since the average express trip time is likely to be on the order of one hour.

#### 3.2.3.1. Vehicle Speed

Computation of the kinematic velocity profile of the Colorado system guideway has shown that speeds up to 200 kph are generally possible within the mountain alignment portions while maximum speeds up to 250 kph are generally possible on flat land. However, energy efficiency considerations make it attractive to limit the maximum speed to 160 kph. Station spacing in the system is such that vehicles can exceed the minimum speed on any guideway segment. A specific type of service, such as express service between widely separated stations, will ultimately determine the required maximum practical speed capability requirement of the CMP.

#### 3.2.3.2. Vehicle Acceleration/Deceleration

The steady-state and rate of change of accelerations experienced by passengers resulting from both guideway geometry and vehicle speed changes will not exceed the values listed in Tables 7-1 and 7-2 of ASCE 21-98. The maximum accel/decel rates are also conditioned by the vehicle propulsion system. Results from the Propulsion Trade Study completed by Sandia National Laboratories have shown that the fully loaded vehicle will meet the required specifications over the speed range. The full Propulsion Trade Study can be found in the Comprehensive Technical Memorandum provided to the FTA.

#### 3.2.3.3. Grade Climbing

In order to exploit the superior grade climbing capability of the maglev system, a goal of the CMP was to seek full performance operation on a gradient up to and including seven percent. For steeper gradients the vehicle was designed to be capable of negotiating a grade of up to 10 percent for a minimum distance of 460 m. Grade climbing is conditioned by the vehicle propulsion system. Results from the Propulsion Trade Study have shown that the fully loaded vehicle can meet the grade climbing specifications for both normal and degraded conditions. In addition, the maximum grade capability of the Colorado 200 vehicle as configured is 18% under degraded operational conditions.

#### **3.2.3.4. Curve Negotiation**

Access to maintenance areas for the Colorado system is governed by maintenance area siting. The maintenance areas have not been sited. At present, it is unlikely that maintenance access would require turns, and would instead be accomplished by transfer tables employing docking switch mechanisms.

The Colorado 200 vehicle bogie configuration is geometrically capable of negotiating 150 m horizontal curves. The maximum speed of negotiation will be determined by the degree of curve superelevation.

The crest and sag vertical radii of 1000 m are standard radii for all Chubu CHSST vehicles.

As an urban/suburban/rural corridor system, the CMP presently does not incorporate dense urban curves.

#### **3.2.3.5. Propulsion**

The Colorado 200 vehicle employs a linear induction motor as its primary motive force. This propulsion system is controlled by a variable voltage variable frequency inverter system on board the car. The motor and electronics are designed for a 30-year life. Propulsion is achieved by a combination of the active electromagnetic motor on the car interacting with a passive aluminum reaction rail integrated into the guideway. This system can provide dynamic braking, with accompanying regeneration of electric power into a wayside accumulator during the braking process.

A relatively complete propulsion motor design has been accomplished during the development of the CMP concept. This design has been documented in the Propulsion Trade Study and provided in its entirety in the Comprehensive Technical Memorandum. This design provides peak efficiencies of 70-80% over large portions of the operational speed range.

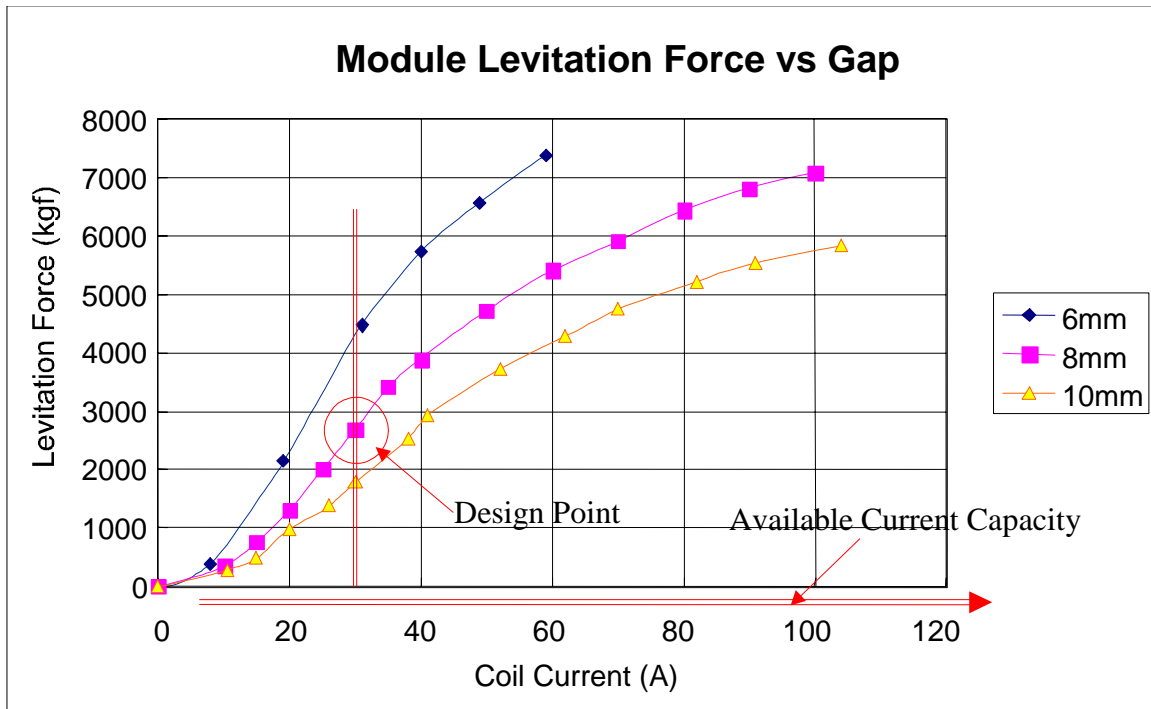
The design basis for the guideway reaction rail was examined and thoroughly documented in this Study. Tradeoffs were made for alternate motor/reaction rail combinations, including an evaluation of both aluminum and copper reaction rails and motor windings. The analysis included all relevant performance characteristics and the motor construction was optimized to reflect the required tradeoffs. The guideway and inverter power was characterized, and sources for motor control technology were identified. The completed propulsion motor design meets all design objectives and can be implemented with confidence for the Colorado system.

#### **3.2.3.6. Levitation**

Once placed into service, no vehicle delevitates thenceforth, except in emergency or maintenance situations. The nominal physical levitation gap is 8mm. Levitation is achieved by electromagnetic suspension (EMS) with active electromagnets in the vehicle bogie attracting the passive guideway levitation rail. While the proven and deployed EMS is entirely active electromagnets, future improvements to the technology could employ permanent magnets to provide a portion of the lift force.

The levitation subsystem for the Colorado 200 vehicle has been optimized and further improvements will be made during the detailed design phase of system implementation. The levitation design is based on the successful Chubu CHSST levitation technology developed since 1972 in both Germany and Japan. This technology operates successfully with a standard 8mm gap, and test measurements are available for gap fluctuation during normal operation of deployed vehicles.

Lift characteristics of the current technology are shown in Figure 14.

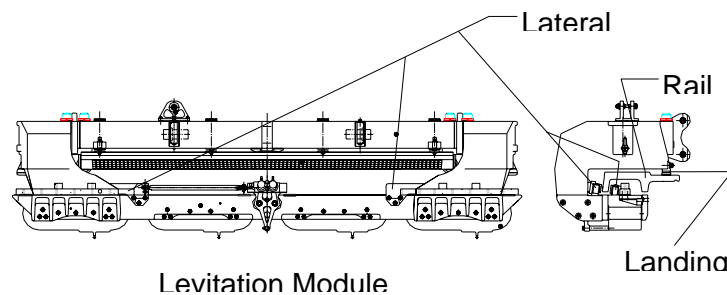


**Figure 14: Magnet Lift Force versus Gap**

These curves show not only the design rationale for the levitation gap, but the prospective lifting force margin available as the levitation current is increased, considerably larger than the 2.5 margin requirement.

**3.2.3.7. Guidance**

Lateral guidance is provided by the configuration of the vehicle-guideway interface and by the levitation electromagnets. This arrangement is shown in Figure 15. The “horseshoe” configurations of the electromagnet and levitation rails provide strong lateral restoring forces when perturbed from equilibrium. The magnitude of these forces amounts to approximately twenty percent of the lifting force at any value in its range. This value is sufficient, as shown in dynamical simulations, to maintain the vehicle centered on the rails under side forces amounting to the maximum specified wind loads for normal operations.



**Figure 15: Vehicle/Guideway Interface**

Vehicle guidance for the Chubu CHSST technology has been thoroughly evaluated over a long period of time using all available tools, including computational analysis and field-testing. The result of this effort is a stable guidance scheme.



**3.2.3.8. Braking**

The Colorado 200 vehicle carries three redundant braking systems. Primary service braking is provided, with regeneration, by the propulsion LIM. Additionally a hydraulic/mechanical brake is provided for low speed application, or for locking of the vehicle in a stopped position on slopes or in stations. Although normally applied only at low speeds, this brake can be activated at any speed if commanded by the safety system. Additionally, a fail-safe mechanical brake is provided in the form of skid pads on the underside of the vehicle. In case of the full loss of electric power or propulsion over-speed malfunction, delevitation of the vehicle can apply this brake in a reproducible manner to bring the vehicle safely to a stop.

**3.3. RIDE QUALITY SPECIFICATIONS**

**3.3.1. Passenger Acceleration**

Currently deployed Chubu CHSST technology is fully compliant with the ISO Standard 2631-1 standards (FTA-MD-26-7029-03). The maximum allowable accelerations and jerk rates for seated passengers are limited to the published numbers in the APM standards – Part 2. The longitudinal, lateral and vertical accelerations are limited to 0.16 g, 0.10 g, (1±0.25) g respectively. The jerk levels are limited to 0.10 g/s, 0.06 g/s and 0.04 g/s respectively. Standards compliance is achieved by precision control of the propulsion motor/brake. The Propulsion Trade Study has shown that the Colorado 200 LIM can be safely controlled to achieve compliance with these applicable standards.

**3.3.2. Interior Noise**

Measurements of noise levels in deployed vehicles have produced the following results:

**LINIMO (TKL train) and CHSST 100L Acoustic Noise Level Measurements**

1. Measurement: 27, 28. May 2003
2. Measurement Point: Car number: Mc2. Measurement points are the following locations above the centerline of the car.

	Driver Room	No. 3-4 door	Car Center	No. 1-2 door
Height from floor	1.6 m	1.6 m	1.2 m	1.6 m

3. Car Weight Mc1 : 20.0 tonne M : 20.0 tonne Mc2 : 17.2 tonne
4. Measurement Result with the comparison with 100L data.  
 Mean values of the maximum noise level are shown in [dBA].  
 Air conditioning was off during the measurement.

		<b>LIMINO</b>	<b>CHSST 100L</b>
		Acc =4.0 kph/sec 3-car train with IGBT inverter Weight: (20t+20t+17t)	Acc = 4.5 kph/sec 2-car train with GTO inverter Weight: (16.8t+25t) 1995.Aug. Mc2 /25t
Point	Speed [kph]		
Driver room	Acceleration 40	70.7	67.2
	Braking 40	61.7	--
	Coast 40	60.4	59.6
	Coast 70	65.4	65.7
No. 3-4 door	Acceleration 40	71.7	65.8
	Braking 40	64.3	--
	Coast 40	63.0	60.1
	Coast 70	66.4	62.2
Center	Acceleration 40	70.7	67.8
	Braking 40	63.0	--
	Coast 40	62.4	57.9
	Coast 70	66.0	60.3
No. 1-2 door	Acceleration 40	72.7	68.0
	Braking 40	63.0	--
	Coast 40	61.3	62.0
	Coast 70	66.7	63.5

These noise levels show to a general degree what can be expected of the Colorado 200 vehicle. In fact, during the design and implementation of the Colorado 200, emphasis would be placed on additional interior noise reduction. The Colorado 200 should be fully capable of exceeding the requirement, particularly if active noise cancellation techniques are used with the IGBT inverter.

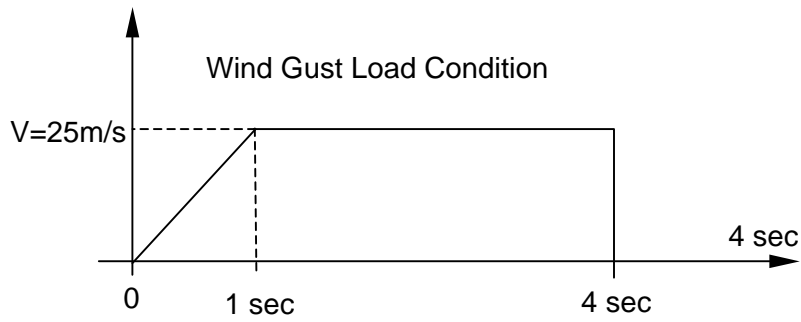
### 3.4. SAFETY SPECIFICATIONS

#### 3.4.1. Vehicle Dynamics and Stability

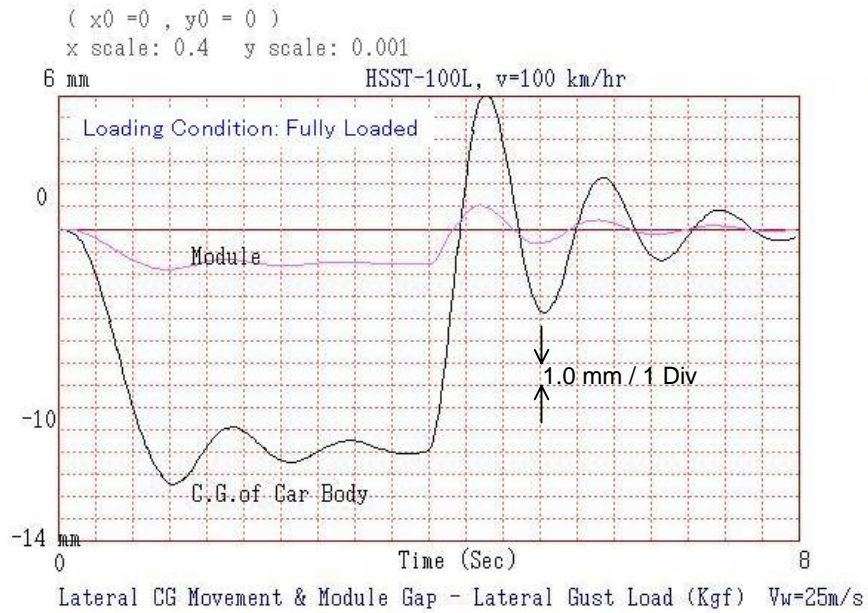
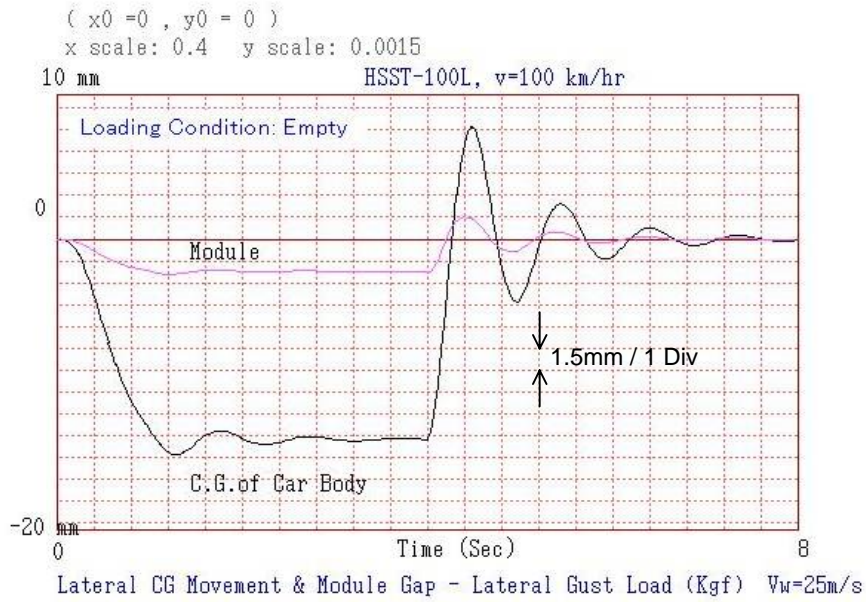
This is extremely important to maglev vehicles, since the stability may need to be actively controlled for certain types of vehicles in some directions. The EMS requires an active gap control. Lateral guidance control is crucial for all vehicles negotiating curves.

Chubu CHSST has conducted both testing and simulation to verify vehicle dynamic stability. The following are results from dynamical simulation for two different vehicles, the Model 100L low speed car and the CHSST-05, the prototype for the Colorado 200, illustrating the dynamical response of the levitation system to a wind gust.

The first two figures are for the 100L vehicle both empty and fully loaded. The assumed wind gust profile is as follows.



The vehicle response to this gust is shown by its rapid return to equilibrium:



The CHSST-05 vehicle (prototype of 200 series, with specified loading) responds similarly.

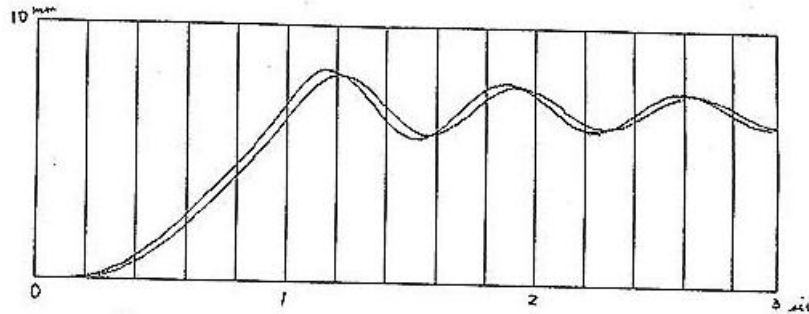


図3A モジュールの横変位

Lateral Displacement of Module

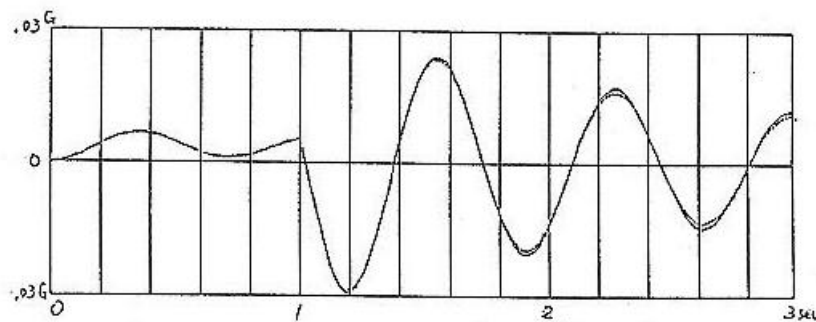


図3B 車体の加速度(横方向)

Vehicle Body Lateral Acceleration

Module Lateral Displacement from rail and Vehicle Body Acceleration under the Wind Gust of 0 to 25 m/sec in 1 sec.

Module movement in the above figures is only lateral movement. As for the levitation stability due to lateral and vertical coupled movement, CHSST states that the vertical levitation gap is stable and unaffected by lateral displacement of up to 15 mm. This is because the lateral frequencies observed in the above figures are around 1 Hz and the motion is easily controlled since the vertical levitation control cutoff frequency is around 6 Hz. (It should also be further noted that lateral displacement is limited mechanically to  $\pm 15$  mm by lateral guide shoes.) The behavior of the Colorado 200 vehicle will be evaluated through tests prior to deployment in the United States.

### 3.4.2. Magnetic Fields

Measurements on the deployed CHSST 100L vehicle have produced the following data (FTA-MD-26-7029-03), and are compliant to the specifications requirements.

**Static Magnetic Field** – At the vehicle floor level, the static magnetic field ranges between 5.7 G above the Linear Induction Motor, to 9.6 G above the DC filter reactor. At 55 cm (22 in) above the floor, static magnetic field is below 5 Gauss. Outside the passenger compartment, a maximum static field of 2.58 Gauss was measured 1 m to the side of the Levitation Module.

**AC Magnetic Field** – This field was measured at 0.233 Gauss at the floor, and 25.6 milli-Gauss at 55 cm above the floor, with a peak value at 60 Hz.

**AC Electric Field** – There has been no need to measure AC electric field because the vehicle system has no AC high voltage. Maximum voltage in the system is 1500VDC. The Colorado 200 vehicle will carry 3000 VDC

In addition, measurements show that occupational hazard field thresholds for maintenance personnel will not be exceeded.

The Colorado 200 vehicle is also expected to fully comply with all static and dynamic magnetic and electric field specifications, although additional shielding may be required.

### **3.4.3. Electromagnetic Radiation**

No electromagnetic radiation emanations have been measured from deployed vehicles. It is unlikely that the Colorado 200 vehicle will exhibit noncompliance. Unwanted electromagnetic radiation can be suppressed by appropriate and well-understood shielding techniques, if necessary.

### **3.4.4. Crashworthiness**

The concept of crashworthiness is approached differently in Japan than in the U.S. Because of advanced automatic train control (ATC), collisions are considered to be an extremely remote possibility. Therefore, vehicle designs are not presently required to include such certifications. However, the Chubu CHSST 100L vehicle does include a compression capability of 34 tons, indicating an extremely robust structure. Opportunities exist to include a crumple zone in the Colorado 200 vehicle design to meet US crashworthiness standards. Recent advances in honeycomb structural capabilities can save weight while potentially meeting this requirement.

### **3.4.5. Fire and Smoke Safety**

Similar standards to the US National Fire Protection Association (NFPA) are in force in Japan and the Chubu CHSST technology complies with all Japanese fire protection requirements. Flammability requirements of the presently deployed CHSST-100L vehicle are based on the ministerial ordinance of flammability requirements, known as "A-A Standard", issued by Japanese Ministry of Transport. The contents of the A-A standard apply to the Japanese regulations of railroad transportation.

All materials used in CHSST 100L are evaluated and certified by Classification & Test Method of the A-A Standard.

For the US application of the CHSST technology in the Colorado 200 vehicle, US standards will be implemented. There is considerable experience with these materials in the US transit industry. The Colorado 200 design will specify only compliant materials for vehicle construction.

### **3.4.6. Egress and Recovery**

Emergency egress will be provided by evacuation of passengers to an emergency/inspection walkway integrally mounted on the guideway piers between the two primary guideway girders. The inspection walkway will be provided with destination ladders that will conduct passengers to safety on the ground. Alternatively, passengers on the walkway can conveniently board another vehicle on the opposite guideway, if one is available. Instructions and assistance from central control operators will be provided in the case of emergencies requiring egress. Additionally all stations will have limited maintenance capability with personnel assigned to the stations to complete specified work. These maintenance personnel could also be used to attend to disabled vehicles located on the guideway between stations.

Failed vehicles can be towed by another train or service vehicle using the retractable steel landing rollers provided underneath each vehicle with appropriate couplers. If a tow is not available, currently deployed Chubu CHSST maglev vehicles can move under their own motive power at reduced speed on these rollers, assuming that the failure mode which created the need for towing has not disabled the propulsion motor.

**3.4.7. Exterior Environment**

Measurements taken with a deployed CHSST 100L train with an IGBT (insulated gate bipolar transistor) inverter operating on an elevated guideway measured noise less than 65 dBA at train speeds from 10 to 50 kph, with noise measured at 10m from track centerline and 1.2 m above ground level. At a distance of 2.5 m and height 1.2 m above ground level, frequency response for the IGBT inverter shows noise under 65 dBA for most of the frequency range of 0- 10kHz, with a spike to 74 dBA at 2 kHz. System-induced vibrations will not be perceptible at or within surrounding buildings.

The Colorado 200 vehicle is expected to exhibit similar environmental performance.

**3.4.8. Security**

As currently conceptualized, station layouts conform to commuter rail security standards and TSA regulations. In addition, guideway access will be fully restricted. See 9.6.11 for detailed Security discussion.

**3.5. COMMUNICATIONS AND CONTROL SPECIFICATION**

The CMP concept incorporates full advanced automatic train control (AATC) as developed and fully safety certified by Bay Area Rapid Transit (BART). This subsystem complies with all applicable US standards, as cited, including ATP, ATO, ATS, and AD, using moving block principles to achieve the required headway. The AATC is capable of safe operation at headways down to 90 seconds in a greenfield setting providing considerable system capacity expansion potential, if required, in the future.

**3.6. RELIABILITY, AVAILABILITY AND MAINTAINABILITY**

Design of the CMP will adhere as closely as practical to the definitions set forth in ASCE 21-96, as described below.

**3.6.1. Reliability**

ASCE 21-96 defines Service Reliability as the mean time between system or system subset failure (MTBFs).

$$MTBFs = \frac{\text{Operating Hours}}{\text{Number of Failures}} = \frac{OHs}{NFs}$$

where:

OHs = Total number of hours of scheduled operation over which the service reliability is being determined; the Period of Operating Hours;

NFs = Number of failures, malfunctions and operating disruptions classified as service interruptions during the Period of Operating Hours (OHs)

**SERVICE INTERRUPTIONS**

Service interruptions are those events or failures that prevent passenger use of the system as intended. The following types of service interruptions are included:

1. Unscheduled stoppage of one or more trains
2. Rerouting of trains due to equipment malfunction
3. Door malfunctions that prevent passengers from entering or exiting trains at stations.  
 Note: the manual operation of doors by station personnel is not included as a service interruption.
4. Malfunctions that result in potentially hazardous operations

5. Until the system is a mature, well functioning system, erroneous operator actions will not be included in service interruptions. After a six-month break-in period, erroneous operator actions will be included as service interruptions.

### SYSTEM RELIABILITY ASSUMPTIONS

System parameters may vary slightly as system operation is refined by the completion of further system simulations. However, since the MTBFs and their allocation to subsystems are estimates, the changes in system parameters are not expected to change significantly. The following system parameters are used in the estimate:

1. Total one-way trip length	250 km (155 miles)
2. Total number of miles/year/vehicle	+125,000
3. Total time for one-way trip	2.5 hours
4. Total annual travel per vehicle	2500 hours
5. Total number of married-pair trains	65

The major assumption is that only two (2) service interruptions of sixty (60) minutes or more will be allowed per annum. It is recognized that this requirement will place a difficult design constraint on the system, although over-rides for each major service interruption have been provided; i.e., for a control system failure, a central control operator "get-home" low-speed control has been provided. An availability value of 0.9999 is the vehicle goal.

The major reliability subsystems considered in this approximation of the MTBFs are all vehicle subsystems, as the station and guideway elements are not deemed central to the expected failure scenarios\*:

1. PROPULSION -- Because the propulsion system design is inherently redundant, it is expected to be a robust reliability subsystem. It will require a test track evaluation to determine how many LIM's can fail before system operation is totally compromised.
2. LEVITATION -- This subsystem is also inherently redundant and the electro-magnets are expected to be robust. However, it is expected that the gap sensors will need to be triple redundant.
3. CC&C -- This subsystem is presently envisioned as triple redundant, with a backup that allows central control to bring home a failed vehicle and further has a portable control console to manually drive the vehicle from on-board, if required.
4. POWER CONDITIONING -- Envisioned to be redundant with a single frequency back up.
5. POWER PICK-UP -- This subsystem will have to be redundant. Power-ups require special attention and inspection to maintain their reliability and integrity because failures generally result from environmental hazards such as dirt, dust, salt, ice, snow, water, etc.
6. DOORS -- There is an abundance of data on operational parameters for automatic doors. However, current doors are not necessarily designed to operate in the extreme environment imposed by the I-70 corridor. Therefore, in extreme conditions only, manual operation of the doors may supplement automatic operation. This may cause some service delays.

\* Station and guideway subsystems are unlikely to have any frequent failure mechanisms that can result in service interruptions. A potential exception to this is the wayside power subsystem. Although redundant, its reliability, potential failure modes and effects will have to be documented in a future trade study.

**TOTAL SYSTEM MTBFs ESTIMATION:**

$$\text{MTBFs} = \frac{\text{OHs}}{\text{NFs}}$$

where:

$$\begin{aligned} \text{OHs} &= 2500 \text{ hours/vehicle} \times 65 \text{ vehicles} = 162,500 \text{ operating hours} \\ \text{NFs} &= 2 \end{aligned}$$

$$\text{MTBFs} = \mathbf{81,250 \text{ Operating Hours between failures}}$$

**Note:** As a comparison value, an MTBF of 100,000 hours was projected for the PRT system designed by Dr. Ed Anderson.

**3.6.2. Availability**

Chubu CHSST has maintained failure histories since its first systems were implemented. On this basis, in cooperation with component manufacturers, it is possible to predict required critical component inventory per car per year.

**AVAILABILITY CALCULATION**

The conceptual design for the CMP has established a desired vehicle availability in excess of 0.9999, which equates to a vehicle MTBF of approximately 7500 hours; i.e.,

$$A_v = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

WHERE: MTTR is the mean time to restore service.

The availability calculations assume a one-hour MTTR because of the maintenance philosophy proposed for this system. The philosophy proposes only to diagnose a failure in a subsystem, replace that subsystem, and return it to a repair facility for repair. While this may require more spare subsystem assemblies, it allows for shorter MTTRs, smaller maintenance facilities, and fewer highly skilled technicians.

All critical parts are incorporated in major reliability subsystems identified above. Except for catastrophic failures, the Colorado system conceptual design is such that any vehicle subsystem (or part of a subsystem, in case of the propulsion subsystem and levitation subsystem) can be exchanged by a skilled technician in less than one hour.

To achieve a vehicle MTBF of 7500 hours requires that the major subsystems have MTBFs of 45,000 hours. At first glance, the subsystem MTBFs may seem excessive, but with extensive use of redundancy, regular care (oil, clean, etc), preemptive wear-out failures, frequent inspections and high tech diagnostic systems to locate failed redundant parts, this MTBF is obtainable.

Good operational policies in the industry seem to indicate that a spare ratio of 10% should be maintained until evaluations conducted during system operations disclose that sparing levels require adjustment.

**3.6.3. Maintainability**

ASCE 21-96 defines service maintainability as the mean time to restore service (MTTRs) following a system service interruption.



Therefore,  
MTTRs = 
$$\frac{\text{Sum Total of Time to Restore Service}}{\text{Total Number of Failures}}$$

The total number of system failures predicted per annum = 2  
The sum total of time to restore service = 1 hour each failure

MTTRs = 
$$\frac{2 \text{ hours}}{2 \text{ failures}} = 1 \text{ hour to restore service}$$

#### **MAINTAINABILITY PHILOSOPHY**

The CMP requires a different approach to maintainability that should reduce the initial construction cost, improve system operations, improve reliability, reduce maintenance skilled techs and make system recovery time much less. Basically, the approach is:

1. Dispersed storage of vehicles at stations along the route.
2. Spare vehicles dispersed at stations along route.
3. Spare major subsystems at every other station.
4. Extensive electronic evaluation of each vehicle daily.
5. Daily functionality test of all major subsystems.
6. Daily visual inspections of each vehicle searching for damage that may affect the vehicle structural integrity.
7. Daily drive-by or other visual inspection along each section of guideway looking for damage that may affect the structural integrity of the guideway, or other suspicious conditions including foreign materials or attempted intrusion.
8. A maintenance facility large enough to maintain four vehicles at once with a double track spur for vehicle storage.

In keeping with this maintenance philosophy, the conceptual design for the CMP also incorporates two primary maintenance facilities. The location of these facilities is not established, although they could be sited at DIA and Eagle County Airport or at intermediate locations, such as Golden or Frisco. A wide variety of factors must be considered in locating these facilities, including mean predicted towing distances, land availability, vehicle MTTR, operational costs, and others. The identified system maintenance philosophy also dictates that critical subsystems replacement can occur at the Least Replaceable Unit level in the stations, where the extra vehicle storage position in each direction serves as a maintenance access point. With this maintenance approach, acceptable service availability can be maintained in spite of the considerable geographic extent of the system, without requiring more extensive service facilities.

## 4.0 VEHICLE

The previous section discussed the system specifications for the CMP while this section describes the CHSST vehicle technology for use on the Colorado I-70 corridor from DIA to the Eagle County Airport. The basis for the selection of the CHSST technology and a number of key technical issues related to the CHSST vehicle are discussed. In addition, this section establishes the requirements to provide an improved propulsion motor as a result of the corridor requirements and the vehicle sizing requirements dictated by the patronage demand.

### 4.1. BASIS FOR THE COLORADO MAGLEV VEHICLE CONFIGURATION

The I-70 maglev corridor encounters all the challenges that make transit deployment difficult: temperature extremes, steep grades, narrow canyons, snow and ice, heavy rains, restricted right-of-way, small radius curves and densely populated areas. In order to produce a workable system design, a primary project objective for the CMP was to identify an existing maglev system vehicle that could be deployed in the I-70 corridor with minimum modification.

#### 4.1.1. I-70 Corridor and Ridership Demand Requirements for Vehicle Configuration

The topography and weather conditions of the I-70 corridor from DIA to Eagle County Airport dictate the maglev system requirements. In addition to the physical requirements of the corridor, the ridership demands dictate the vehicle sizing.

#### 4.1.2. Vehicle Sizing

The maglev system vehicle capacity, speed and power requirements were determined from the topography and the ridership estimate for the I-70 mountain corridor that was projected as 40,000 transit passengers per weekend day. This sizing requirement establishes the dimensions of the vehicle, the seating capacity, the requirements for thrust and the requirements of the remaining vehicle subsystems. The following sections discuss the various subsystems and related requirements from the vehicle sizing needs.

### 4.2. COLORADO 200 VEHICLE PARAMETERS

Based on the above discussions related to the propulsion motor requirements for the Colorado corridor, the levitation gap, the track rail installation and the patronage demand forecasts, the following vehicle parameters have been developed for the proposed Colorado 200 vehicle:

#### VEHICLE

Length (each car)	24.3 m (80')
Width	3.2 m (10'6")
Height	3.65m (11'6")
Passengers per car	103 seated
Train set	2 cars per set
Weight of single vehicle	44 Tonnes (approx. 97,000lbs)
Levitation and Guidance	Attractive Electromagnets
Propulsion	10 LIMs per car
Propulsion Control	VVVF Inverter
	2 each 2000kVA, 1300A max per car
	Freq. 0-120Hz
Bogie System	5 modules under each side of each car
Electrical System	3000VDC
Environmental Control	Heat pump
Operator	Automatic Train Control

**PERFORMANCE**

Max. Speed	200 km/hr
Max. Acceleration	5.76 kph/sec
Min. curve radius	50 meters
Max. Grade	7 % without degradation, 10% with some degradation, 18% over small track lengths with significant degradation

**LONGITUDINAL CONTROL**

Automatic Train Control	Inductively Coupled Radio Freq. Between T/GW
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**SAFETY SYSTEM**

Fail-safe	Moving Block, vital components
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**POWER SOURCE**

Collected from Wayside	3,000VDC
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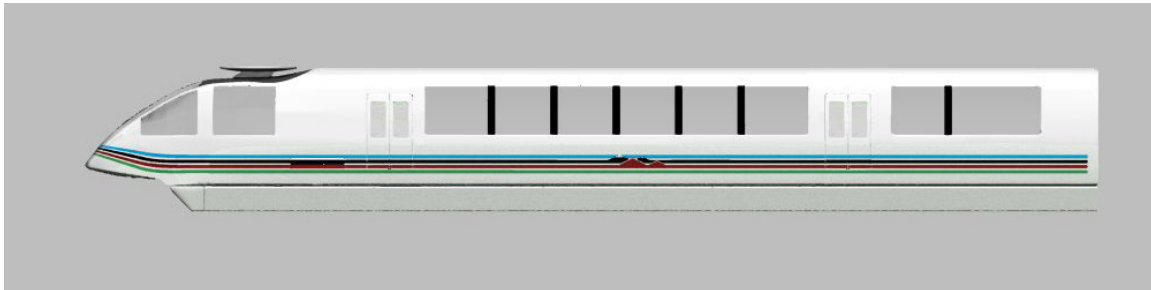
**4.3. FINAL VEHICLE CONFIGURATION**

**4.3.1. Vehicle Description**

The modified version of the original CHSST-200 design has been designated as the Colorado 200 Vehicle. In addition to the increased power as described in the previous section, modifications made to the design include:

- 1) addition of luggage and ski equipment carrying capability
- 2) addition of lavatory
- 3) modify nose cap to eliminate driver and add seats

A schematic of the Colorado 200 Vehicle is shown in Figure 16.



**Figure 16: Colorado 200 Vehicle**

The Colorado maglev train consists of two Colorado 200 vehicles in a permanent, married-pair configuration. The two cars are identical in every respect except for their seating patterns and have the same levitation, motors, and electronic controls. The vehicles are exclusively electric, taking power from local utilities at 3000 V DC through a compliant current collector running along power rails mounted on the side of the guideway. Due to the use of fully automatic controls, the train consist may travel in either direction with equal facility.

Each vehicle carries two sets of bi-parting doors on each side through which passengers embark and disembark. These doors are pneumatically operated and include pressure sensitive switches causing the door to reopen if any object greater than an inch in diameter obstructs the door.

Each vehicle is fully fenestrated with large window areas on both sides, and in front. The forward facing windows are made of a heat absorbing safety glass, and the side windows, including the windows in each passenger door, are tempered safety glass.

The interior of a single car offers eighty-nine lightweight seats, and positions for two wheelchairs, one close to each doorway pair. Additionally, twelve folding seat positions are available, for a total per vehicle passenger capacity of one hundred three. The seating configuration is shown previously in Figure 13. Because of the likelihood of substantial express service between high volume destinations such as Golden, Frisco and Vail, provision has been made for each vehicle in the consist to carry an aircraft-type lavatory. Also provided are areas for vertical storage of skis, and several general areas of bulk storage, where luggage and other items may be safely secured for the duration of a trip.

#### 4.3.2. **Structure**

The vehicle structure is divisible into two sections: car body (upper portion) and a series of levitation modules, or bogies (lower portion). Fully loaded vehicle weight, including modules, is estimated to be 44 tonnes (~97,000 lbs). Each vehicle is 24.38 meters (80') long, 3.2 meters (10'-6") wide and 3.5 meters (11'-6") high.

The car body structure is principally aluminum alloy with use of fiber-reinforced plastic and a thin aluminum plate, of semi-monocoque construction, consisting of frames, stringers and skin panels. Structural loads imposed on the vehicle are borne primarily by the floor base frame, the structural element that connects the body and bogies. It resists the axial load transferred through the coupler, and also transmits the payload and superstructure loads to the levitation modules by way of sliding tables and secondary air suspensions. The floors carried on this frame consist of aluminum honeycomb panels.

Each Colorado 200 vehicle body is attached to ten levitation modules (five under each side of the car), which provide the levitation and propulsion for a single car. Each module is a complex assembly, carrying levitation electro-magnets and gap sensors, linear induction motors, hydraulic brakes, emergency rollers and landing skids.

#### 4.3.3. **Levitation**

The levitation subsystem provides both vertical and lateral support and guidance for the vehicle. A series of electromagnets attached to the modules of the vehicle are fed by control currents in order to create a magnetic flux which has a path linking the ferromagnetic portion of the vehicle born magnets with the track rails of the guideway. The ferromagnetic material of the magnets is thereby attracted to the track rails of the guideway. It is this mutual attraction force that provides the levitation and guidance for the vehicle.

The track rails are individually connected to the guideway sleepers in the Japanese CHSST design. Both the electromagnets on the car and the track rails are U-shaped so that both vertical and lateral forces can be created between them. Two air gap sensors are mounted per module and are used to indicate the separation of the module from the individual rail. Appropriate amounts of current are fed into the electromagnets in order to increase or decrease the magnetic field and hence, the force between the components.

The standard magnetic gap is 8 mm (0.315"), while its mechanical air gap from the magnet shoe to the bottom of the levitation rail flanges is set to 6 mm (0.236"). Design magnetic attractive force is 1,040 kgf/m (699 lbs/ft) per rail or 2,600 kg-f/module (5,732 lbs/module).

To mitigate component damage from any accidental physical contact between magnets and levitation rail, induced by failure of a critical control component, by earthquake, or other cause, each magnet core is capped with copper alloy shoes. Such contact cannot occur during normal operation and is considered to be extremely unlikely due to the conservative design approach

taken in the levitation system. Nevertheless, this provides a concrete example of the consideration for safety that has gone into the vehicle design.

The magnets are carried in the levitation modules. Four individual levitation magnets are housed in each module. The magnet coils are connected pairwise in series to realize two complete magnet systems per module. Levitation current in the magnets is maintained by servo-controlled magnet driver units (MDU) and sensors, supplied from a 275 V DC source created by the vehicle's power electronics. The power supply to each MDU is designed to be independent so that problems in any particular unit will be localized and isolated in that unit. The sensors provide the module levitation status variables to the MDU. The MDU is installed in the vehicle side section above the module it supplies. The gap sensor is installed on the top of the magnet in close proximity to an accelerometer.

The MDU controls the voltage of electrical power fed to the levitation magnets based on acceleration signals from the sensors installed on the module and calculates the proper voltage to be supplied to the magnet. Further, it sends levitation status information to and from the vehicle control system and provides gap signals for the other guidance calculations. Finally, it provides current levitation status (floating or landing) and current system activity (working or failed) to the train integrated management system (TIMS), the global control component of the entire system.

The MDU has three sections: control computer section, chopper section and monitor section:

The **Control Computer Section** receives gap and acceleration signals from the sensors installed in the module, and calculates the voltage to be supplied to the magnets. It also monitors levitation command from the vehicle control system (through the monitor section) and current signals from the chopper section. The control computer section sends the appropriate magnet voltage signal to the chopper section.

The **Chopper Section** chops the 275 V DC power according to the pulse width modulation (PWM) signal received from the control section, and supplies the chopped DC power to the magnets. One MDU has two channels of chopper. The rated current of the MDU is 45 A and the maximum allowable current is 150 A, a wide dynamic range.

The **Monitor Section** receives levitation commands and sends and receives levitation status information to and from the vehicle control system. When required, it also provides gap signals for testing.

As noted earlier, the MDU takes its power from the vehicle's power supply. Batteries are also provided to maintain vehicle levitation until the train comes to a stop if main power to the magnets is lost or interrupted.

#### 4.3.4. **Secondary Suspension**

While the primary suspension of the vehicle is provided by the levitation and guidance system, air springs and mechanical linkages provide the secondary suspension. The suspension system holds the car body so as to isolate vibrations due to track irregularities and give good ride comfort and resistance to external disturbances.

- The Air Suspension System is comprised of an air spring installed between each module end and slide table. It conveys the car weight to the module and, at the same time, buffers the module movement before it is conveyed to the car body, resulting in a comfortable ride.
- The car body is leveled at a certain height above the rail by means of an air supply system with a source of air pressure between 7 and 9 kg-f /sq cm (100 and 128 psi).
- The Air Supply System is divided into three individual systems so the car body weight is supported in a three-point suspension.

- The Lateral Mechanical Suspension System consists of slide tables installed at the front and rear of each module. They are designed to move laterally so that the vehicle can follow a curving guideway. All slide tables are connected mechanically to each other and equalize and convey lateral load to each levitation module.
- The Longitudinal Mechanical Suspensions consist of linear bearings installed on the lower surface of the vehicle body floor, slide tables and thrust rods connected to slide tables. They convey linear motor thrust and brake force.

#### 4.3.5. **Power Conditioning**

The electrical power system of the vehicle consists of an on-board power converter/inverter apparatus referred to as the power supply unit (PSU), input switch, and battery. The power supply unit transforms the high voltage direct current (3000 V DC) picked up by the onboard current collectors into the following three types of electrical power:

- Main DC Power 275 V DC for levitation, air conditioner
- AC Power 100 VAC 1 ph 60 Hz, for general housekeeping use
- DC Power 100 V DC for control and communication

The PSU consists of a high voltage inverter section (H-INV) and low voltage converter section (L-INV). The power collected by the current collector is fed to the PSU via an input disconnect switch. Since 275 V DC is essential for levitation and vehicle control, the 275 V DC power source is backed up by 2 units of on-board 237 V, 20 A-h battery. Even in case of PSU failure or loss of wayside power, the vehicle can continue to levitate by using the battery power source for approximately 30 seconds as it decelerates to a stop. The battery power source can also supply power for safety and emergency systems such as lighting and communication for approximately 30 minutes. Two PSU's are installed on a two-car train.

The propulsion motors have their own dedicated power conditioner.

#### 4.3.6. **Propulsion**

Vehicle propulsion is provided by linear induction motor (LIM). The LIM is a single-sided, axial flux design consisting of a module-mounted primary with a secondary member, the reaction rail, mounted on the guideway. One LIM is installed in each module in close proximity to the electromagnets that provide guidance and support. Due to their close proximity and their fixed position relative to the electro-magnets, the LIM primaries operate at essentially the same airgap from its reaction rail as do the electromagnets from the guideway mounted support rail. The airgap of the LIM is typically 12 to 15mm.

Each primary coil (stator) of the motor is mounted in the levitation module on the underside of the vehicle. The primary reacts with a thin aluminum reaction plate (rotor) installed along the top surface of the levitation rail, to propel the vehicle. The reaction rail comprises an aluminum top cap and a ferromagnetic back iron assembly. The reaction rail comprises the upper surface of the U-shaped levitation and guidance support rails. Japanese experience to date has indicated that there has been no need for adjustment of the linear motor reaction rail. Nonetheless, there is provision in the mounting fasteners for shimming to adjust both the angle of the bracket and its height relative to the tie member and the corresponding rail on the other side. It is expected that any adjustment required in the alignment of the rails will be due to long-term settlement of the guideway that is more readily accommodated in adjustment of the sleepers rather than the support rails.

The sensors used by the levitation system measure the relative airgap between the electromagnets and the support rail. These measurements made by two instruments on each side of each module are recorded, retained and analyzed on a periodic basis as a means for detecting any trends suggestive of relative change in rail position. The need for some remedial measures and maintenance action on the track can thus be identified and located. Thus, the

relative airgaps of the linear motor and the electromagnetic support system are inherently provided by the manufacturing tolerance of the complete steel bracket comprising both elements. This configuration minimizes the complexity of the guideway with the added benefit that if a motor fails, only the train itself is affected, not the system as a whole.

The complete assembly is manufactured directly from a heated steel ingot by rolling with a special die. This propulsion configuration is well suited to the CMP, for reasons of cost, speed capability, and efficiency.

Specifically the propulsion elements consist of one inverter and ten LIMs for every car. Each LIM is installed on the under surface of the module's main structure and is supported at multiple fixed points. Each LIM is approximately 2.9 m (9' 6") long, 0.6 m (2') wide, and 80 mm (3.2") thick.

The LIM Specifications are as follows:

- Thrust (nominal) 7000 N/LIM (1573 lbf/LIM)
- Phases /Poles: 3 phases/10 poles
- Material of Coil Aluminum
- Current (Max) 386 A
- Secondary Conductor (track) 4 mm (0.16 in.) thick aluminum plate

When supplied with current, each LIM generates horizontal and vertical thrust in a controllable manner. Current to the LIMs is provided by a variable voltage, variable frequency (VVVF) inverter, which transforms wayside DC power into an appropriate AC power on board the vehicle. Thrust is controlled by varying both the voltage and frequency of AC electric power supplied to the LIM. By this means, the propulsion system provides either the propulsion force or the electrical braking force by using the LIM to alter the direction of thrust generated.

LIMs are normally electrically connected in a series and parallel arrangement, and this configuration is currently being optimized for the Colorado 200 vehicle.

#### **4.3.7. Propulsion Trade Study Results**

A Propulsion Trade Study was conducted by Sandia National Laboratories to identify and evaluate prospective linear motor designs that could potentially meet the system performance requirements of the CMP and be applicable to other urban maglev transit corridors. The analysis involved the performance of the linear induction motor (LIM) propulsion system of the Chubu CHSST (CHSST). Potential near-term improvements to the propulsion system and the relative impact of research and development in critical areas were considered.

This section highlights the findings of the Propulsion Trade Study Final Report that is contained in its entirety in the Comprehensive Technical Memorandum of the CMP [4].

##### **4.3.7.1. Requirements and Assumptions for Analysis**

The requirements for the LIM propulsion system are based on the design of the Colorado 200 vehicle, anticipated environmental conditions, and FTA requirements.[5, 6, 7] The requirements are shown in Table 4.3.7-1.

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<sup>4</sup> FTA Urban Maglev Program, CDOT Team report "Task 14: Integration, Propulsion Trade Study, Final Report," 22dec03 in Comprehensive Technical Memorandum.

<sup>5</sup> FTA Urban Maglev Program, CDOT Team report "Task 3, Transit System Performance Requirements," Final Report 1.1, 17oct02.

<sup>6</sup> FTA Urban Maglev Program, CDOT Team report "Task 10, Vehicle Design, Technical Memo 4.1, Vehicle Interior Configuration" 6Jun03.

<sup>7</sup> FTA Urban Maglev Program, CDOT Team Quarterly Review Meeting, Washington, D.C., 9Jul03.

Table 4.3.7-1. Parameters and system requirements for analysis of required thrust and power.

Vehicle mass, loaded	44 tonne COL-200a
Vehicle length	24.3 m
Vehicle width	3.2 m
Vehicle height	3.5m
Vehicle drag	Drag force for COL-200a modified to
Number of LIMs per car	10
Number of cars per train	2
Speed range	0-160 km/hr (kph)
Average Speed/Headwind	114kph / 90kph
Climb grade	Up to 10%, no degradation at 7%
Acceleration rate	0.16g's

An assessment of the thrust and mechanical output power required for the linear motor was completed to establish how closely the existing CHSST linear induction motor (LIM) met the needed requirements, and the motor's required thrust performance curve.

Constant velocity was assumed for this estimate of power demand. This analysis determined the thrust necessary to overcome contactor friction, magnetic and aerodynamic drag, and grade. The speed of 114 kph was the average speed obtained over the route from analysis that includes limitations due to lateral accelerations from route curvature. [8] A 90 kph headwind was also included to obtain an upper bound estimate of power, as this is the maximum operable wind condition for the CHSST-100 system [9]. From the required thrust, the mechanical power was derived, and the electrical power was determined from the estimated LIM motor and other efficiencies.

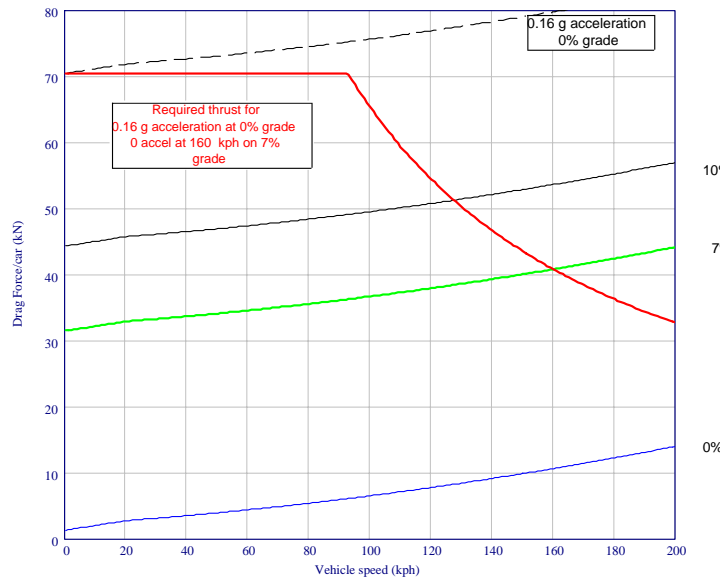


Figure 17: Drag force including grade climbing force

Colorado 200 Vehicle based on 2-car consist with a 90 kph headwind. (Red thrust curve is based on achieving 0.16 g acceleration on level grade from rest, and maintaining speed of 160 kph climbing 7% grade.)

<sup>8</sup> FTA Urban Maglev Program, CDOT Team report "Task 14, Integration, Technical Memo 4.0," 22Apr03.

<sup>9</sup> FTA Urban Maglev Program, FTA Assessment Team report "Assessment of CHSST Maglev for U.S. Urban Transportation," July 2002, pp. 6-11.

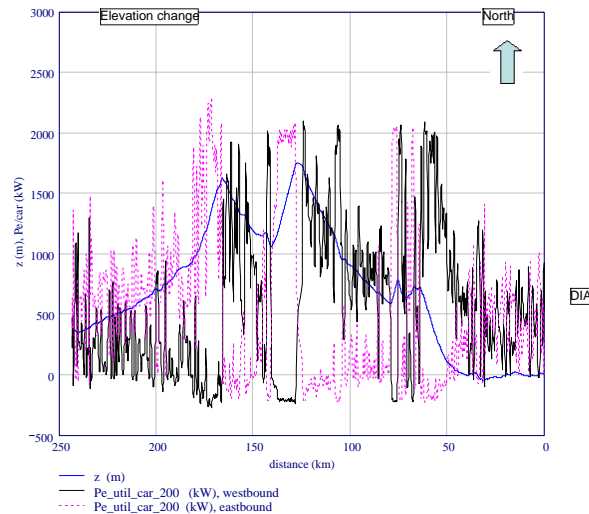


The required thrust per LIM is derived by dividing the total thrust required per car by the planned 10 levitation/propulsion modules for the Colorado 200 vehicle. The LIM proposed for this module has been extended 27% longer than the existing CHSST-200 LIM design to increase thrust.

#### 4.3.7.2. Electric Power per Car Along Route

An estimate was made of the thrust and electric power required per car to propel a 2-car consist of Colorado 200 vehicles at constant speed of 114 kph on I-70 from DIA to Eagle County Airport. The route data used was the westbound data set from the GPS survey of I-70 [10].

Figure 18 shows the electric power required per car traveling westbound or eastbound along the route with a 90 kph headwind. Of course, this condition would not occur simultaneously, but the values represent high-power conditions for each direction. The abscissa in this plot is the distance along the route from DIA, and increasing distance is the westbound direction. The electric power required per car was based on the required thrust curve (0.16 g), the estimated efficiency of the LIM, and a 90% forward rectification and transmission efficiency of the DC power to the vehicle. The negative power value represents power from regenerative braking, but a very low, conservative efficiency of 35% was assumed for the power returned to the utility in this example based on lower efficiency of bi-directional inverter/rectifiers and previous user's experience.[11] Present plans are not to return the power to the utility, but use regenerated power for on-board loads or within the station-vehicle power system.



**Figure 18: Electric utility power required per Colorado 200 Vehicle for 2-car consist westbound or eastbound at 114 kph along route, with 90 kph headwind.**

#### 4.3.7.3. LIM Performance and Modifications to CHSST-200 Baseline LIM

The baseline design of the LIM to drive the Colorado 200 vehicle is the CHSST-200 LIM (Toyo Denki model TDK6800) that was designed for the CHSST-04 and CHSST-05 vehicles. Although these vehicles were operated only at low speed due to short tracks at the 1988 Saitama Expo in 1988 and the YES'89 Yokohama Expo in 1989 respectively, the motor was designed for operation at speeds up to 200 kph. Specific parameters of the physical geometry, materials, primary electrical winding and secondary of this motor are given in Table 4.5.7-2 in the column labeled 'CHSST-200 14Jan03c' [12].

<sup>10</sup> David Munoz, "I-70 GPS Survey," Technical memorandum, October 14, 2002.

<sup>11</sup> Private communication, Prof. E. Masada, Science Univ. of Tokyo, 2003.

<sup>12</sup> Data from Chubu CHSST Corporation, Nagoya, Japan.

**Table 4.5.7-2. Parameters of CHSST-200 LIM used as baseline and two possible configurations of the LIM for Colorado 200 vehicle. Fields highlighted yellow indicate parameter was changed.**

	<i>HSST-200 14Jan03c</i>	<i>COL-200 11oct03 b</i>	<i>COL-200 19nov03 a</i>
<b>MOTOR PRIMARY PARAMETERS</b>	<b>CHSST</b>	<b>RK-SNL</b>	<b>RK-SNL</b>
Core length in x direction, (meters):	2.30	2.91	2.91
Core transverse width, (meters):	0.22	0.22	0.22
Core height in y direction, (meters):	0.085	0.088	0.088
Number of primary current phases, (integer):	3	3	3
Number of poles:	8	10	10
Pole pitch, (meters):	0.261	0.261	0.261
Total turns per phase,:	120	120	120
Primary winding conductor:	Aluminum	Aluminum	Aluminum
Primary total weight/LIM, calculated (kg)	289	379	379
<b>MOTOR SECONDARY PARAMETERS</b>			
Mechanical clearance gap, primary core to reaction rail, (mm):	15	13	13
Reaction rail material:	Al	Al	Al
Equivalent width of reaction rail, (meters):	0.33	0.33	0.33
Reaction rail thickness, (meters):	0.004	0.004	0.004
Reaction rail temperature for calculation, (deg C):	40	40	40
Thickness of spacer, (meters):	0.001	0.001	0.001
Secondary core material:	steel	steel	steel
Secondary core height in y direction, (meters):	0.010	0.010	0.010
Secondary core electrical conductivity at 20 C, (Siemens):	8.70E+06	8.70E+06	8.70E+06
Relative permeability of secondary iron:	500	100	100
<b>POWER SUPPLY PARAMETERS</b>			
Total LIMs per inverter:	6	20	5
Trolley rails voltage (V DC):	+1500 to gnd	+3000 to gnd	+1500 to gnd or gnd to -1500
Calculation Line current into LIM, (A rms):	280	386	386
Connection type, Wye(Star) or Delta:	Delta	Delta	STAR
Configuration description (series - parallel):	2s-3p	4s-5p	1s-5p
Inverter conversion efficiency:	0.91	0.91	0.91
Slip Frequency, (Hz):	12.0	11.5	11.5

**4.3.7.4. Colorado 200 LIM Propulsion Performance**

Calculated performance for the 4-series-5 parallel and 1-series-5 parallel configurations of the Colorado 200 LIM with parameters as shown for case Colorado 200 11oct03b and Colorado 200 19nov03a, respectively in Table 4.5.7-2 are listed in Table 4.5.7-3.

**Table 4.5.7-3. Summary of output values from calculations for CHSST-200 and Colorado 200 LIMs**

<b>CALCULATION Results</b>	<b>HSST-200 14Jan03c</b>	<b>COL-200 11oct03 b</b>	<b>COL-200 19nov03 a</b>
Thrust/LIM at zero speed (N)	4538	7008	7008
Attraction/LIM at zero speed (N)	1659	2765	2765
Breakpoint speed (kph)	130	125	130
Thrust/LIM at breakpoint (N)	4115	6191	6191
Attraction/LIM at breakpoint (N)	3163	4169	4483
LIM voltage at breakpoint (V rms)	479	551	571
Efficiency at breakpoint (%)	75	77	77
Thrust/LIM at 160 kph (N)	2812	3726	4007
Attraction/LIM at 160 kph (N)	2736	3265	3510
LIM current at 160 kph (A rms)	239	304	315
Efficiency at 160 kph (%)	78	80	80

The maximum attraction force has increased from 3163 N per LIM for the 33 tonne, 6-LIM CHSST-200 vehicle to 4169 N per LIM for the 44 tonne, 10-LIM Colorado 200 vehicle. Most of this increase is associated with the 26% increase in length of the LIM as expected, and the vehicle will have additional levitation magnets to support the longer, heavier vehicle. The attractive force from the six LIMs of the CHSST-200 is 19 kN which represents about 6% of the loaded vehicle mass. The attractive force from the ten LIMs of the Colorado 200 is 42 - 45 kN which represents about 10% of the loaded vehicle mass. CHSST staff has indicated that while the change is not negligible and attention must be given to the limits of the levitation control system, the problem is not critical. In addition, future advances in levitation control and magnet design will also support mitigation of the impact of the normal force. [13]

The inverters that feed the LIMs have been sized to deliver up to 10% greater current than the 386 A normal operating level. This is done to provide a margin in capability in normal operation and permit emergency braking at high acceleration. Figure 19 shows the thrust curves for the normal and maximum LIM current levels and the drag force/LIM for the 44 tonne vehicle in a 2-car married pair configuration with a 90 kph headwind. A 15% climbing grade appears to be a practical limit under normal operating conditions, while 18% may be possible at maximum current for short durations. If steady operation at the maximum current is considered, additional forced-air (or possibly liquid) cooling of the LIM will be needed.

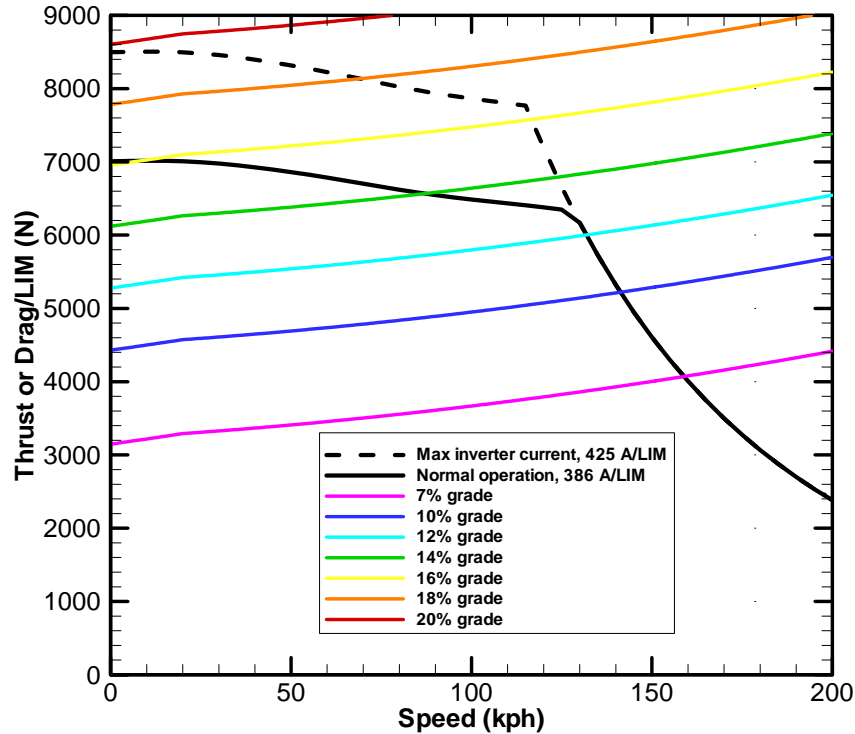
**4.3.7.5. Colorado 200 LIM Braking**

In the braking mode, the LIM is in a regeneration mode where energy from the vehicle is converted to electrical power that can be delivered back to the trolley line. The regeneration mode is used from 160 kph down to 22 kph.

**4.3.7.6. Summary**

The Propulsion Trade Study sized the LIM for the CMP. Significant effort was expended with the CHSST staff to define and optimize the existing propulsion motor. The findings of the trade study are that the LIM optimization is substantially available today with even additional improvements easily achieved in the near term. See the entire Propulsion Trade Study in the Comprehensive Technical Memorandum for additional information and detail.

<sup>13</sup> Review of Propulsion Trade Study LIM modifications and calculations, CHSST and Toyo Denki, 21oct2003.



**Figure 19: Thrust per LIM at normal operating current of 386 A and maximum inverter output.**

(Drag force/LIM curves for married pair of Colorado 200 vehicles on various grades into a 90 kph headwind at zero acceleration.)

#### 4.3.8. Variable Voltage Variable Frequency (VVVF) Inverter

The wayside DC electrical power, supplied through the high voltage input section of the VVVF inverter, is inverted to produce AC power with appropriate voltage and frequency for the LIM. Although the current control is basically determined by the thrust command calculated using the automatic train operation (ATO) command signal, the thrust command is always compensated by the vehicle weight data, which is picked up by air suspension pressure transducers.

Non-contact speed detection devices are used as a source of speed data for the inverter system. The frequency output by the inverter is also an important factor determining the speed of the vehicle. There is a predetermined slip frequency that represents the difference between the inverter output frequency and synchronous frequency, which is proportional to the vehicle speed. The frequency applied to the LIM is controlled both in acceleration and deceleration ranges, and can be altered according to an adaptive control law to achieve greatest efficiency in specific situations.

At high speed, the thrust that the motor can generate is limited by the maximum output voltage of the inverter, and by the maximum frequency that the inverter can produce.

#### 4.3.9. Braking

The brake system features two independent components: electric service braking using the LIM (providing regenerative and reverse phase braking) for normal operation, and a supplementary hydraulic brake used when the vehicle is traveling below 5 km/hr (3.1 mph) (the transition from electric brake to hydraulic occurs at approximately 5 km/h).

However, in case of an emergency, the hydraulic brake system can be used at any speed. The hydraulic brake system is designed and sized to handle full emergency braking needs and assumes no assistance will be available from the service braking system during an emergency.

The hydraulic brake actuator is a mechanical friction brake whose brake linings pinch the rail flange using hydraulic pressure, where the friction between brake lining and rail flange provides the braking force. Hydraulic units are installed on six of the ten modules.

Each car has an independent hydraulic system. The hydraulic brake system consists of the section of hydraulic power brake pressure control and brake actuators. This system operates at pressure of 210 kg-f /cm<sup>2</sup> (2,986 psi) and uses synthetic fire-resistant fluid (Quinto lubric 822 series) as the hydraulic fluid. The principal component of hydraulic power section consists of the hydraulic pump, the primary and the standby accumulator, and the pressure switch. The hydraulic pump is operated by a pressure switch located in each accumulator line.

#### **4.3.10. Landing Skids**

In case of catastrophic failure with no power of any kind available to levitate or control the vehicle, it will descend onto the landing skids, which consist essentially of brake pads mounted on the vehicle under structure. These pads will come in contact with a predetermined surface on the levitation rail and the vehicle will stop safely without damaging the modules or guideway. The weight of the vehicle provides a reproducible braking force if these skids become necessary and the stopping distance can be predicted confidently, even under adverse environmental conditions.

#### **4.3.11. Emergency Rollers**

The purpose of the emergency rollers is to support the train when the levitation has been compromised or lost. The emergency rollers and associated hydraulic actuators are installed near each landing skid at the front and rear ends of each module. When the hydraulic actuators are operated, the emergency rollers can support the total vehicle weight. Hydraulic power for the actuators is supplied by the primary hydraulic system.

The emergency roller hydraulic system consists of a solenoid-operating valve, check valve, restrictor, 10 self-sealing couplings and 40 hydraulic actuators/car. The solenoid-operating valve is installed under the floor and is operated by the emergency roller switch inside the vehicle. When the emergency rollers are in the extended position, the train can run slowly under its own LIM propulsion, or it can be towed by a service vehicle.

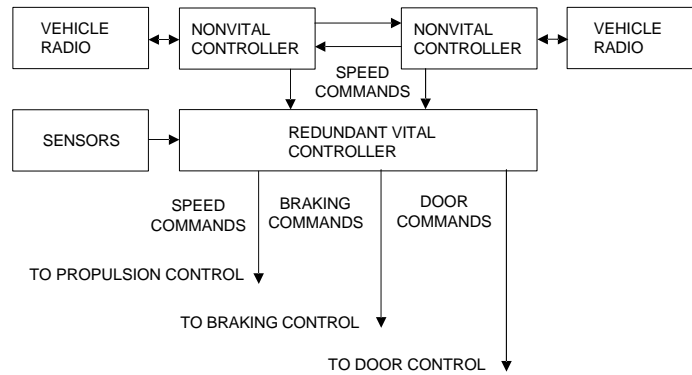
#### **4.3.12. Controls**

The levitation control element of the Colorado 200 is autonomous, responding only to the command to levitate, or delevitate. Once the command to levitate has been received and implemented, there is no need for further external control, unless the vehicle is to be taken out of service for some reason. The vehicle control will not accept a delevitation command unless the vehicle is at zero speed and the propulsion system is also inhibited. Hence, vehicle levitation need be communicated to vehicles only as they are put online or offline and is not an element of usual wayside communications, except for status reporting.

Control of propulsion, braking, and doors are the central focus of on-board vehicle controls. Commands for these three control elements can come routinely from the wayside for a variety of operational reasons, but propulsion and braking can also be actively modulated by the on-board controls in response to instantaneous local conditions, including emergency conditions.

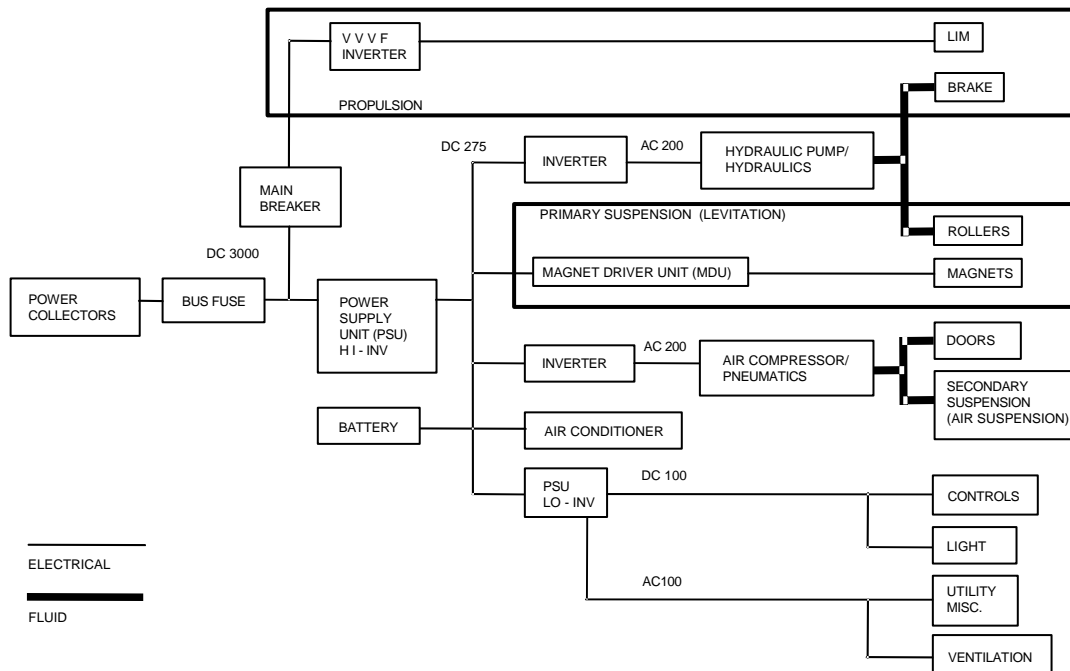
In the Colorado system design, communications with the wayside are carried by packet radio. The vehicle carries redundant packet radios on each end of the train consist. These radios supply position, velocity, and direction of motion information, along with system operational commands, to redundant non-vital controllers. These, in turn, pass commands to a fully redundant vital controller. This vital unit independently gathers vehicle status information from

sensors, and independently determines whether operational commands transmitted from the wayside will be allowed. Those commands that are allowed by the vital element are sent onward to their respective control mechanisms. The vital element, of course, can also autonomously generate its own commands, based on its assessment of the data provided to it. A simplified diagram of these elements is shown below, approximately at the level of replaceable units.



**Figure 20: On-board Control Structure-- Schematic Vehicle Diagram**

The operational elements of the vehicle described above, and their interrelationship, are shown schematically in the following diagram.



**Figure 21: Colorado 200 Major Components**

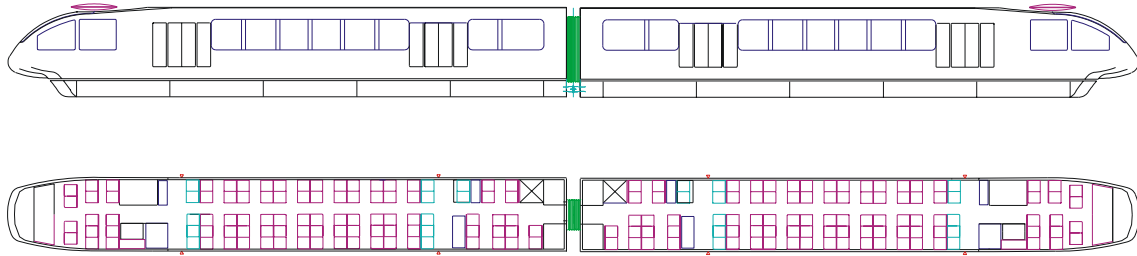
**4.3.13. Vehicle Drawings**

The following sections depict the important operational, mechanical, and electrical structures in the Colorado 200 vehicle.

**4.3.13.1. Seating Configuration**

Figure 22 shows the proposed seating configuration for the Colorado 200. The configuration provides for loading and unloading from either side of the car, a standard practice for commuter rail. This guarantees that vehicles can operate fully when traveling in any direction on the

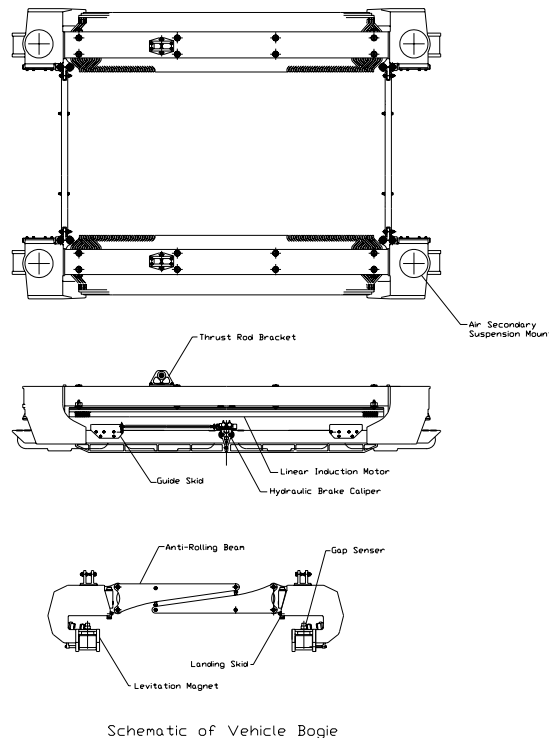
guideway, accommodating station platforms on either side of the car. The configuration provides storage space for skis and luggage, and also has lavatories for longer express trips. The vehicle is handicapped accessible, with positions for a minimum of two wheelchair positions. At least one lavatory is handicapped accessible. The configuration does not provide for standees on express trips, requiring an all-seated passenger cohort. Folding seats are combined with fixed seats to increase the seating capacity. The final seat count is 103 per vehicle, including wheelchair positions.



**Figure 22: Colorado 200 Seating Configuration**

**4.3.13.2. Bogie**

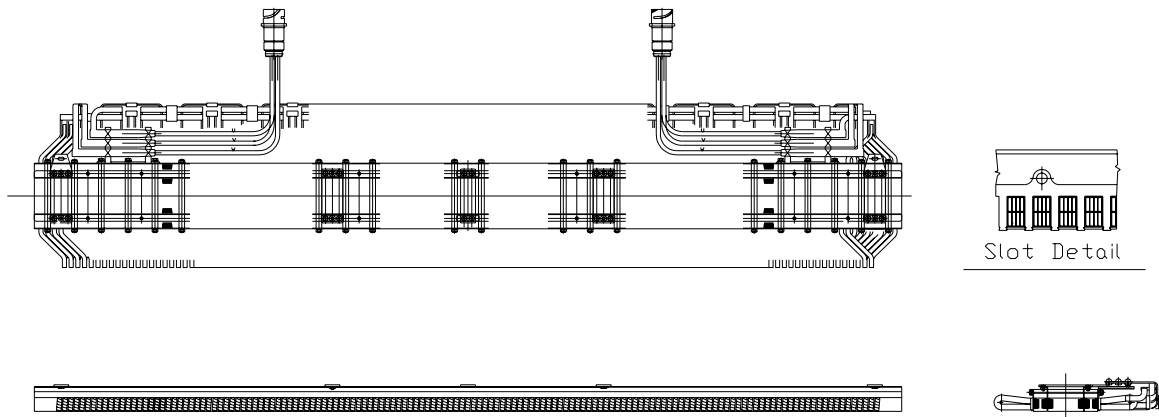
Figure 23 shows the bogie configuration for the Colorado 200. Each unit carries four magnet groups and a single LIM on each side. Forces are transmitted from the superstructure to the bogie and vice versa by way of linkages and the air suspension system. Locations of the air suspension bags can be seen at the four extreme corners of the bogie structure. The vehicle/guideway interface is largely defined by this drawing.



**Figure 23: Colorado 200 Vehicle Bogie Configuration**

#### 4.3.13.3. LIM

A modified LIM has been specified for the Colorado 200. This powerful device is capable of 7000 N peak thrust at zero speed, and will assure that the Colorado 200 can meet the performance requirements for acceleration and velocity. The LIM is shown in Figure 24.



**Figure 24: Colorado 200 Linear Induction Motor**

This LIM has been in development for some time at Toyo Denki, and the design has been modified during this project to provide the needed thrust. It is the key ingredient in meeting the Project performance requirements.

#### 4.4. CONCLUSION

During the project, an approach was developed to specify a maglev system that is deployable in the near future in the I-70 corridor in a cost effective manner. This effort has resulted in the Colorado 200 vehicle that meets or exceeds all the performance requirements developed for the I-70 corridor. Deriving the Colorado 200 vehicle from the Chubu CHSST-200 vehicle will ensure successful deployment at minimal cost.



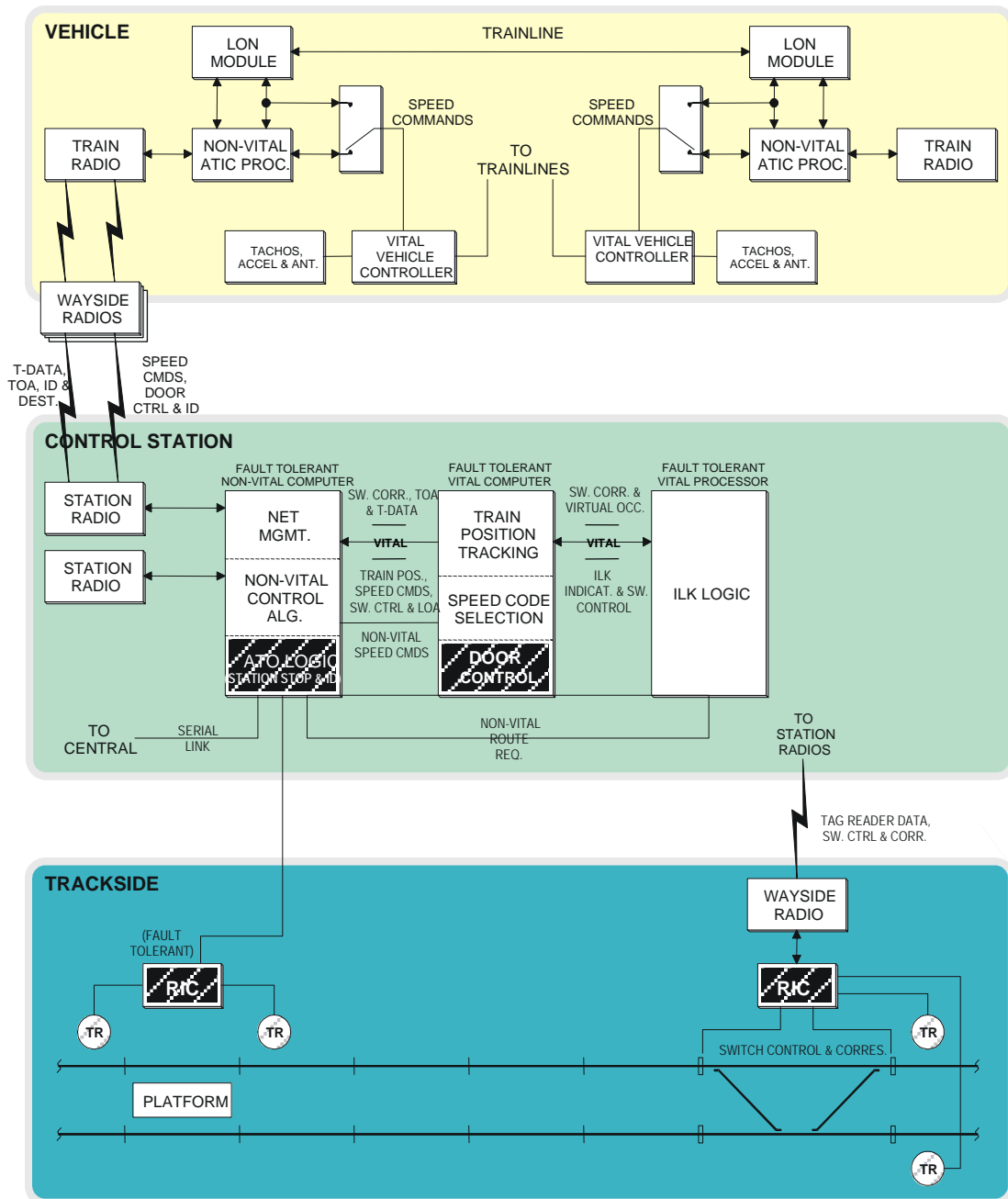
## 5.0 **COMMAND, CONTROL AND COMMUNICATIONS SUBSYSTEM (CCCS)**

The Command, Control, and Communications Subsystem (CCCS) coordinates and controls all activity in the transit system. As a new system design, the CMP should employ the most advanced, safest, CCCS available consistent with its deployment schedule and other equipment. The goals for this key subsystem include deployability, reliability, and safety. The dimensions of deployability include commercial availability, technical performance, and cost. Fortunately, there are technology candidates that fit this profile.

Fortunately, the CHSST system is control-neutral. Until this study effort, CHSST systems had always been put forward with fixed block controls and manually operated trains. CHSST has shown a willingness to embrace more modern controls made in the United States, and the vehicle control interfaces appear to be compatible with many different control approaches.

It is fortunate that moving block systems are just now coming into operation in several parts of the country. The most promising of these for the CHSST system appears to be the system in development by the Bay Area Rapid Transit District (BART), although there are others also in development. This system relies on packet radios and vital wayside computers and circuitry to achieve brickwall headways presently limited to 90 seconds, with the opportunity to safely further reduce this number in the future as technology improves. From the simulation results, it appears likely that the CMP can be operated during peak periods at 120 to 150 second headways. Given the demonstrated capability of the BART control system, it seems straightforward to meet or exceed the Colorado operational goals without stressing the controls.

The BART control system is schematically described in Figure 25.



**Figure 25: BART Moving Block Train Control**

A brief description of this control system follows.

The partition of function places the station control computer(s) at the center of the hierarchy. Based on the service schedule communicated to them by central control, each non-vital station computer manages the vehicles in its region of responsibility. A non-vital processor deals with schedule issues and speed commands to maintain service. A vital processor deals with safe train positions and speeds, and with interlocks (doors, switches, etc.) All these elements are fault

tolerant, employing primarily checked redundancy to insure continuous operation. In addition, the vital elements have had special techniques and methods applied to insure that they can only fail in a manner which places the system into a safe state.

Position and velocity information are derived from measurements taken dynamically on and from the cars using radio propagation delay techniques. A series of wayside radios along the track maintain constant communications with train radios, permitting the measurement of signal delays as the information reaches each end of the train. The times of transmission and receipt are known, and since the transmitter positions are also known precisely, the differences in these times can be used to provide precise measures of instantaneous train speed and position. The station computers use this information as their criteria for actions.

This information is also available to control equipment on the train. However, the train controls also make use of independent tachometer and accelerometer data collected directly from the train itself. This information provides a primary verification of information derived from radio propagation. If there is any indication of over-speed or other problem, the on-board control can act independently to place the train in a safe condition, i.e., apply brakes.

A control system based on the BART system is straightforward and economical to implement. Its performance capabilities are consistent with the Colorado system requirements, it is well supported commercially, and it appears to be competitive with other systems available now or currently planned. Accordingly, this CCCS represents a good choice for a baseline control system for the CMP.

Evaluation has shown that the system is compatible with Chubu CHSST's maglev technology, and should be readily interfaced to existing vehicle designs with little modification. The recommended CCCS offers technical performance exceeding the Colorado requirements, and consequently has additional expandability if further enhancement of the system were to be required in the future. Therefore, it represents a good choice for Colorado deployment.

## 5.1. COMMAND SUBSYSTEM

Commands for the operation of the CMP are produced through a hierarchical division of labor in the control subsystem. The command hierarchy can be described as follows:

- Central commands
- Regional commands
- Local commands

Central commands implement the operating philosophy of the system, beginning with service policies, and going on to dispatch and emergency commands.

Regional commands fundamentally originate with the station computers, as they carry out central commands.

Local commands are local to the vehicle control systems as they implement regional commands from the wayside.

As the commands cascade each level down to the electronic units that control vehicle motion, there is an increase in the number of decisions and of constraints on the decisions. Ultimately, as each is safely resolved and action taken, the vehicles go where they are instructed to go.

Generally, because of the complexity of these processes, discussion of the command subsystem is restricted to a discussion of central control.

Every transit system has an operational center. This center coordinates global information about the status of all active elements of the system, including vehicles, stations, guideway,

electrification, and controls. During operating hours, the center will be staffed with supervisory operations personnel who can react to unforeseen situations not handled by the automatic control systems. During non-operating hours, the center is to be staffed by security personnel. Key equipment in the control center will include a status and information display, which provides status information concerning all system elements. The default display for this information will be vehicle status, captured and displayed for all vehicles in a comprehensible manner for the operators. Status of other subsystems will be readily accessible, either through fixed status displays, or dynamically, as called up on operators' displays. The central control facility can be located anywhere within the system or located remotely. The optimum location for the central control facility will be the subject of a future trade-off analysis at a later stage of the Project.

Operators in the central control facility will be able to communicate readily with all system employees and passengers, through a variety of means. Every train will carry a direct communications channel with central control, as well as an internet connection. All service and security personnel will also be able to communicate with central control via dedicated radio channels, wi-fi, or cell phones.

## **5.2. COMMUNICATIONS SUBSYSTEM**

The communications subsystem is straightforward in its function, which is to carry messages between subsystems. Because it does this in a characteristic and predictable way by following specific protocols, it has become possible to utilize portions of the communications system as key elements of the control approach.

The best way to understand this system is to describe the architecture of a safety-certified modern moving block control system.

Neglecting the central portion of control, the system is divided into three segments, trackside, station, and vehicle.

The vehicle is controlled by information received from the station computer. This system, which has both vital and non-vital elements, is the watchdog for the entire system. It keeps continuous watch over vehicles in its area, and maintains continuous communications with each through the wayside packet radios. These radios pass station messages in "bucket brigade" fashion until they reach their intended vehicle. Messages from the vehicles are in turn relayed back along the path, and the propagation times can be used to accurately derive the motional and positional state of the car. The station computer elements can use this information to verify that the car is safely implementing commands given to it, and it can use the accurate kinematic information to manage the system operational headway.

## **5.3. CONTROL SUBSYSTEM**

The control subsystem is composed of those elements of the system that produce the actions of the cars. These controls consist of computers and electronic subsystems, such as the variable voltage variable frequency inverter, which control the motor and brakes of the cars. Generally speaking, this functional partitioning restricts the control subsystem to the wayside and vehicle controls. The inclusion of central controls leads to the combination of the command and control subsystems; automated systems are frequently described with this combined nomenclature.

To achieve the required actions, nothing can be done in an unsafe manner. Consequently, elaborate means, including checked redundant and separate monitoring and decision elements totally devoted to safety, are involved in every action. It is also common to aggregate the safety related elements of the controls into a separate subsystem, the safety subsystem. However, that level of detail is not required at this stage of definition of the Colorado system and the safety functions can be described along with the normal control functions. Requirements for system safety are spelled out in the APM Standards.

## 6.0 **ELECTRIFICATION**

Due to the prospective costs, it was necessary to evaluate the electrification of the system in detail (see the Comprehensive Technical Memorandum for the full electrification report). With the help of CHSST and Sandia National Laboratories, wayside subsystems and rectifiers were specified for costing with the designs reviewed by competent power engineers. The result of this activity was a workable design for wayside electrification, together with a cost scenario usable in the context of the total system cost. Previous review of the electric utility situation in the corridor had disclosed a shortage, or total lack, of transmission capacity along the route. Discussions with utilities and industrial electrical equipment vendors made it clear that the permitting process to add transmission facilities to the corridor would be a long and arduous process, conceivably lagging behind the construction of the maglev system. As a result, consideration was given to the potential collocation of the transmission facility with the guideway. This approach was enthusiastically accepted by the utility companies providing electricity in the corridor, since these utility companies have been seeking new transmission capacity to serve the growing population and economic activity of the I-70 corridor. All agreed that a successful effort to use the guideway route for additional electric transmission facilities would be a valuable supplemental benefit from the construction of the maglev system. Several indicated interest in financial participation in the system if this proved technically feasible.

This concept was pursued, even though it was clear that it might also face regulatory issues. It was felt that the technologies available might provide a unique way of meeting those issues.

First, it is now possible to routinely consider undergrounding 115 KV transmission facilities. Several of these undergrounding concepts have been proposed in other states, some involving considerable distances. These designs have been based on advances in electrical insulation technology, using a number of different technologies. One relies on new cable technology employing cross-linked polyethylene insulation. There is long experience with this material in Germany, for example, and it seems clear that some use could be made of this technology for solving some undergrounding problems.

However, in the I-70 corridor, full undergrounding of the electrical transmission system is probably impractical, due to a wide variety of factors, such as geologic and environmental conditions, regulatory issues, and costs. Because of these considerations, full undergrounding along the entire guideway route is not a feasible option, although it might prove useful for the solution of some specific engineering problems in limited portions of the alignment.

Second, there may be a way to carry the required transmission capability on or within the guideway structure itself. This type of approach is more speculative because the structural implications are not fully understood. But, there is the well proven technology of the gas insulated transmission line, developed and proven in Europe and the US over the last 25 years, and this technology is likely adaptable to electrical transport on the guideway structure.

These lines have remarkable safety, structural integrity, electrical capacity and characteristics, and excellent durability. They appear to be fully compatible with other guideway materials, and may even help to mitigate some of the other safety costs associated with necessary guideway functions.

Their operating principles are simple: a coaxial transmission line is constructed with the current carrying conductor configured as the central coaxial element. The central coaxial element is suspended by insulators in an outer metal pipe and then the assembly is filled with a stable insulating gas mixture of 80% nitrogen and 20% sulfur hexafluoride. The resulting assembly is mechanically rugged, thermally stable, and can safely carry huge currents at voltages ranging up to 1200 kilovolts. Because of the coaxial geometry and insulating gas characteristics, the line has

low capacitance and, unlike overhead cable transmission systems, has low degradation and sensitivity to environmental conditions over time. These characteristics make it an option for use in the CMP, although the cost may be more than other alternatives. It should be noted here that tabulation of these costs is beyond the scope of the current effort.

A second transmission technology, employing dielectric-insulated cables, is also feasible for the transmission of the needed power along the guideway. Using cross-linked polyethylene insulation, voltages up to 345 kilovolts can safely be carried in underground trenches. There is long experience with this type of insulation, also pioneered in Germany, and it is very reliable with long service life when protected from UV radiation. Carried in grounded conduit, this technology may have a cost profile better suited to the overall Project, although a comparison of electrical characteristics may become the driving consideration in selection of a transmission technology.

With either transmission technology a safe way to carry the transmission lines from auxiliary towers or suspended from auxiliary beams, would have to be found. This is routinely accomplished with bridges and some of those techniques may be applicable to the Colorado Project. However, this approach represents an engineering challenge. Conceptually, there is a way to suspend the needed transmission facility with the emergency egress girder, perhaps even taking advantage of the structural characteristics of both to achieve a stronger guideway. If this can be done, the guideway costs attributable to emergency egress can instead be partially absorbed as system infrastructure costs attributable to the primary electrical transmission system.

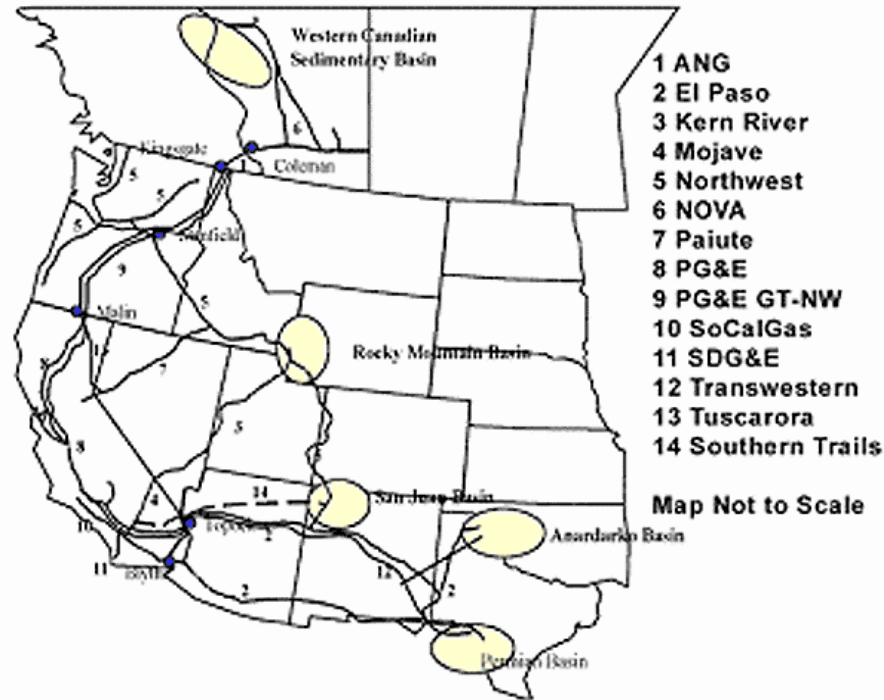
Clearly, this represents a direction for future research in guideway design. This preliminary technology identification effort has confirmed that one of these technologies can probably meet the power transmission requirements for the CMP.

The question remains as to whether existing electrical generation has the capacity to support the maglev system operation. Pending resolution of this issue through further study, it is probably sufficient to point out that gas turbine power plants located along the alignment could provide the needed power. Such plants are economical, reliable, and now with newer approaches, even offer acceptable emissions control. With correct design, this approach could provide excess generation and transmission capacity, which could be shared with the utilities for use in serving new growth in electric demand in the corridor; revenues from this source could also help to defray maglev system costs.

Generally speaking, power plants are much easier to permit than transmission lines because they are geographically confined to one place, and the environmental impact is restricted to other considerations. In particular, emissions are a critical factor in modern power plant operation and this would be particularly important at altitude. There are new processes for removal of NO<sub>x</sub> and these processes are well tested. Typically, a well-run turbine generator can now achieve 0.5 ppm NO<sub>x</sub>, and very effective heat exchangers are also available for waste heat recovery. The co-generation aspect of a local power plant would be welcome in many mountain communities in the corridor, who could also make good use of both the waste heat and the off-peak power generated.

These plants are economical to purchase and to operate. Their reliability is superb and they can run for long periods with only routine maintenance. First class installations can be procured and installed at between \$30 and \$50M each. However, there is a collection of issues which could prevent serious consideration of this alternative.

The chief problem with this alternative is the location of an adequate fuel supply. These units run from natural gas. Natural gas is not particularly plentiful in the United States, although there are strategies such as coal gasification that might be feasible in Colorado; there are plentiful supplies of coal and oil shale in Colorado. However, there are two large natural gas basins located in the adjacent states of Wyoming and New Mexico, as shown in Figure 26, taken from [http://www.energy.ca.gov/naturalgas/western\\_state\\_pipelines.html](http://www.energy.ca.gov/naturalgas/western_state_pipelines.html).



**Figure 26: Natural Gas Pipelines in the Western US**

The Rocky Mountain Basin and the San Juan Basin are in reasonable proximity to Eagle County Airport. There is a major pipeline connecting these two fields, and there is a compressor station in western Colorado, midway between the two fields. To serve power plants in the I-70 corridor, it would be necessary to construct a connecting pipeline from the compressor station to the Eagle County Airport vicinity, where the first plant would be sited. Then, the pipeline would have to be carried to the next site, say Frisco, using the guideway right-of-way. A third plant could be located in the Idaho Springs/Georgetown area.

For hypothetical purposes, this resolves the power issues for the maglev system and benefits the mountain communities by increasing the quantity and reliability of their power sources, thereby benefiting the Colorado ski economy. However, there are several practical considerations, which make this alternative less attractive.

First is the altitude. This has the effect of reducing the efficiency of the power plant, and secondarily of placing more emphasis on emissions control. Power plant engineers who have examined these scenarios have indicated that at 1980 km (6500 feet), the approximate altitude of two of the hypothetical sites, the relative efficiency loss could amount to 10%, which is a tolerable derating. However, at 2600 km (8500 feet) or more, the altitude of several potential sites, the derating climbs rapidly, requiring careful consideration from the standpoint of fuel efficiency, emissions, and cost/benefit.

Second, these plants require a significant amount of water for their operation. This water is used for cooling and is evaporated directly to the atmosphere, and is thereby lost. While wastewater can be used for this purpose, the implications for water may be the most important issue this concept faces. A new technology for secondary generation through waste heat recovery by propane cycle heat transfer may significantly influence the demand for water cooling of conventional generators.

Third, there is considerable cost associated with pipeline construction. It should be pointed out, though, that there also is cost associated with new electric power transmission lines. One way or

another, providing energy to operate the maglev system will incur cost. The issue as to how this is to be accounted is an open issue, since this increased capacity might be considered as an infrastructure improvement for the entire corridor.

Finally, there is the cost of fuel for plant operation. The price of natural gas is subject to fluctuations and is entering a period of increasing prices, due strictly to supply/demand characteristics. It is not likely that this situation will stabilize in the future, and it may in fact worsen. Strong demand from the eastern US has stimulated the gas fields to produce increasing quantities, and the long term stability of the fuel supply for gas fired plants would have to be studied carefully before it could be recommended as a viable power source for the CMP.

At this point in the research, ways to obtain the electrical power needed by the maglev system have been identified, and are doubtless feasible at some level. Regulatory and other issues would have to be studied further, along with additional study of the technical tradeoffs, before a firm recommendation as to power source could be made. Suffice it to say, there are ways to generate and deliver the needed power, although there are challenges to accomplish this in an economically secure manner. This situation mirrors the overall general situation for power consumption in the United States as a whole, wherein secure sources of electrical energy must be provided economically to support future economic growth.



## 7.0 **GUIDEWAY/SWITCHES**

Guideways and switches are important factors in the study of feasibility for a maglev transit system along the 250 km (155-mile) Colorado I-70 corridor between Denver and Eagle County. Guideways are generally considered to make up approximately 60% of the overall cost of such a system, making it the single largest cost component. One of the primary Project goals was to develop economical and aesthetically pleasing guideway design concepts with estimates of probable cost, considering the challenging environmental conditions of the I-70 corridor.

This guideway analysis includes discussion of the following subjects:

- Factors affecting guideway cost and aesthetics
- Design concepts for a standard guideway
- Maglev switching systems
- Design concepts for special guideway site locations
- Emergency egress requirements
- Guideway drainage
- Avalanche protection

Numerous factors affect the cost of transit system guideways, which are essentially bridge structures equipped to carry the vehicle technology employed. These include general market conditions and labor, material and equipment costs as well as specific site conditions affecting access and construction difficulty.

For the standard guideway, which is adaptable to the relatively unconstrained sections of the alignment within the median or alongside the I-70 highway section, the following three structural system concepts have been developed for spans in the range of 25 m (82 feet) to 30 m (98 feet):

- Precast, prestressed concrete U-girder with precast concrete deck panels
- Steel box girder with composite concrete deck slab
- Tubular steel space truss

Like any transit system technology, switching is required to satisfy the operational needs of a maglev system. A high-speed pivoting guideway switch is presented in this analysis in addition to both a low-speed and high-speed docking switch.

There are many locations along the I-70 alignment that require spans in excess of those provided by the standard guideway. At these “special site” locations, studies have been conducted for guideway structures with spans up to 90 m (300 feet). A cast-in-place, prestressed concrete box girder structure with both tracks carried on the same deck is the proposed solution where the use of falsework is feasible for construction.

Passenger safety is a major concern for any public transit system and the maglev technology proposed for use in the I-70 corridor has been developed with safety as a tenant. The ability to evacuate a disabled vehicle in an emergency, such as a fire, has been explored and several alternatives are presented. The use of an auxiliary emergency walkway beam appears to be the most reliable approach, although this walkway would need to be installed along the full length of the alignment.

In the extreme environment of the mountain corridor along I-70, drainage on the guideway was evaluated as an issue. It will be necessary to keep the levitation/reaction rails clear of ice, snow and concentrated drainage flow for proper vehicle operation. The results of this evaluation show that drainage can be adequately managed on the guideway.

Avalanche zones exist at numerous locations along the I-70 mountain corridor.<sup>14</sup> Occasionally, an avalanche will bury a section of the highway and require highway closure for removal of snow and debris. A concern is whether a maglev transit system can be adequately protected from destruction due to avalanche. Both avalanche sheds and fender systems have been considered. The avalanche sheds are typically built along the segments of highway that an avalanche run-out zone impacts.

The conclusion of this guideway analysis is that there are clear opportunities to design and construct economical and aesthetically pleasing guideway structures for a maglev system in Colorado along I-70 or elsewhere in the U.S. With proper guideway design, costs can be managed so that maglev systems can be competitive with conventional transit technologies. In addition, the necessary safety and reliability characteristics can be achieved without serious cost implications.

## 7.1. INTRODUCTION

The guideway is a fundamental element of a maglev system, interacting with the maglev vehicle to provide vertical and lateral support and rigidity for the vehicle's levitation, longitudinal propulsion and lateral guidance. Whether the vehicles operate at grade or elevated, a structural guideway is necessary to maintain strict alignment tolerances and provide a secure and reliable track way. In an elevated configuration, the guideway is essentially a bridge structure that incorporates the maglev components required for the system technology utilized.

With many of the basic technological issues of first-generation maglev transit systems essentially resolved or in the refinement stage, a remaining challenge in terms of deployment is the issue of cost. The structural guideway is widely considered to represent a majority of the overall construction cost of a maglev transit system. In addition, aesthetic design for greater public acceptance has not been a high priority for the elevated maglev guideway structures built to date for testing or initial commercial use.

Transit guideways are basically bridge structures equipped to carry the vehicle system employed. Many factors influence the cost of guideway structures and the I-70 corridor offers a host of challenging site conditions that make the type selection for the guideway very important to keeping the overall cost of the system manageable. A central goal of the studies leading to this analysis was to develop economical guideway concepts that also provide aesthetic qualities suitable for the I-70 corridor and other applications in the U.S. This analysis includes the results of guideway studies that yielded three structural design concepts for a standard guideway system considered adaptable to the majority of the I-70 corridor where the maglev system would run within the median or along the side of the highway. Cost estimates have been developed for each of the concepts based on Colorado highway costs and are found in the cost section of the Deployment Guide of this Final Report.

In addition, studies have been conducted for special sites that require spans greater than those of the standard guideway. A cost premium has been estimated for special sites with long-span guideways.

Switching is an essential operational requirement of a maglev system as with any transit technology. Because of the way the maglev vehicle wraps around the outside of the guideway, switching cannot be accomplished in the same manner as a conventional rail system. Concepts are presented in this analysis for a high-speed pivoting guideway switch as well as both a low- and high-speed "docking" switch.

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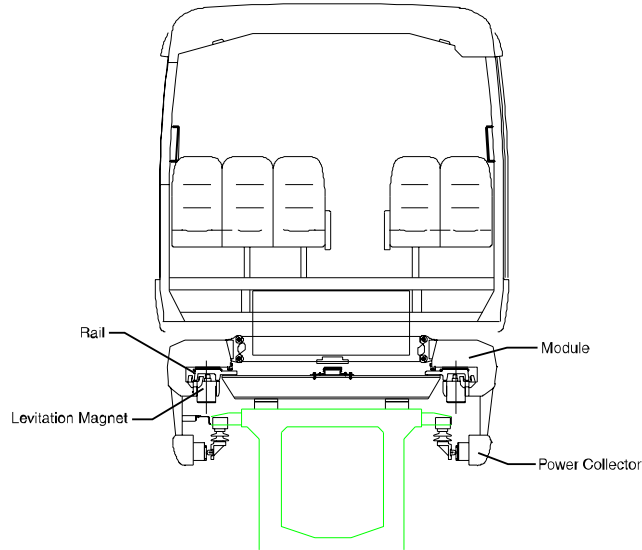
<sup>14</sup> Colorado Avalanche Information Center Data

Other issues of concern for a commercial maglev operation within the Colorado I-70 environment are also presented. These include methods for emergency egress, drainage of the guideway and avalanche protection.

## 7.2. VEHICLE/GUIDEWAY INTERFACE POINTS

The vehicle/guideway interface determines the guideway design requirements.

Figure 27 illustrates the CHSST 200 vehicle cross-section showing the rail reference level where the vehicle and guideway interface. The rail installation tolerances will be an important determinant in guideway construction costs as well as to the vehicle requirements as they relate to the guideway interface.

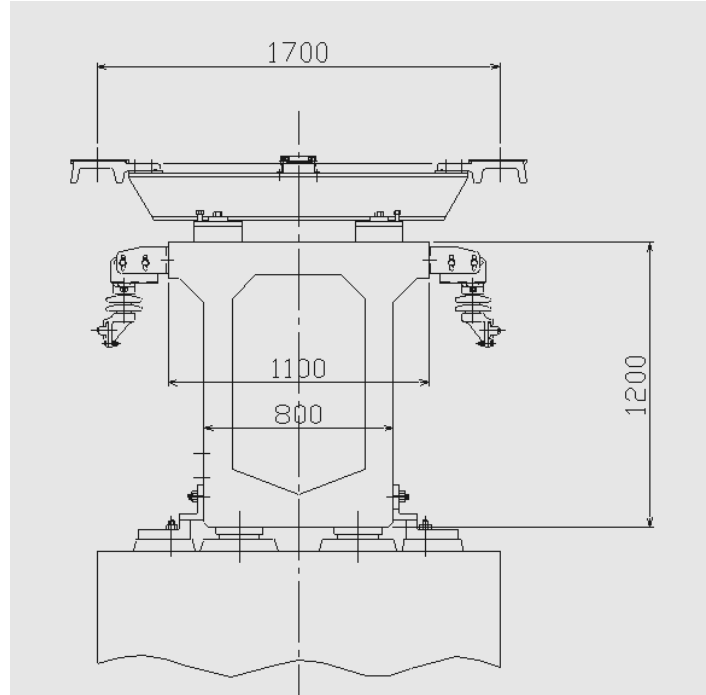


**Figure 27: CHSST 200 Vehicle Cross Section**

Figure 28 illustrates a typical girder at the CHSST test track. The standard column spacing and beam length at the CHSST test site are both 20m.

The standard column spacing for the Tobu-Kyuryo line, which is deployed in Japan, is 30m, and the standard girder type is a continuous girder beam of 3 spans (90m) in length.

The CHSST vehicle systems (either the 100L or 200 series vehicles) do not require special civil construction work in relation to construction tolerances. For example, the height tolerance of 350 mm from top of rail supporting structure to rail reference level is in the general range of standard civil works.



**Figure 28: Cross Section of Standard Girder at CHSST Test Site**

The only special requirement for the structure or equipment are those that make it difficult for the girder beam to shift laterally against the neighboring girder beam once the beam is installed on the pier tops. This requirement is the result of the lateral gap (step) at the rail end joint between adjacent rails. A large gap should be avoided to prevent damage to vehicles even under earthquake movement.

### 7.3. FACTORS AFFECTING THE CONSTRUCTION OF THE GUIDEWAY

Like all construction, the construction of guideway (bridge) structures is driven primarily by the cost of labor, overhead, materials and equipment. These costs are affected by a variety of factors related to both the characteristics of the construction site and the marketplace of the project location. Cost is often the most dominant factor in the bridge type selection process. Given the significance of guideway cost for an elevated transit system, it is important that structure type selection be conducted carefully to maximize the economic feasibility of a given corridor. Following is a discussion of the key factors that would be expected to influence guideway costs for a maglev transit project.

#### 7.3.1. Regional Contracting Environment

It is common for certain construction methods and techniques to predominate in a particular region. State Departments of Transportation, which contract for most transportation structure work, often standardize on certain structure types. This results in the standard types gaining a significant economic advantage over types that are seldom specified. The capabilities and experience of contractors likely to submit bids on a project will typically correspond to the predominant type of structure work contracted in their market area.

One of three bridge types will typically be considered the most economical (in general) for a particular state or region. These are precast concrete girders, cast-in-place concrete slabs or box girders, and steel rolled beams or plate girders. In Colorado, standard precast concrete girders are regarded as generally the least costly type for moderate span highway bridges. However, in the case of the CMP, other design approaches can potentially minimize transport, erection and

alignment costs, with resultant impact on overall system cost. Therefore, for purposes of the CMP, an intuitive response to cost issues must be avoided.

### **7.3.2. Labor Costs**

The cost of labor is a function of wages and production rates. Both rates vary between regions resulting in variability of labor cost for similar operations. Bridge types that require more labor, such as cast-in-place concrete, must have lower material costs to be competitive with other types. The variability in labor costs between regions further influences the economics of different bridge types.

### **7.3.3. Availability and Cost of Principal Construction Materials**

Closely related to the regional contracting environment issue is the availability and cost of materials. The availability and cost competitiveness of steel bridge girders varies significantly between regions. However, in regions where steel is commonly utilized and readily available, it is competitive with concrete. Federally funded projects generally require a "Buy America" provision, which often precludes the use of foreign steel for bridge girders and can significantly increase the cost.

### **7.3.4. Site Access**

Accessibility of the bridge site has a dramatic affect on construction cost and great influence over structure type selection. Following is a discussion of several accessibility issues.

*Equipment Access Space* - Modern bridge construction relies on the use of heavy equipment to minimize labor cost and facilitate economical construction operations. Large equipment that is commonly used includes cranes, pile drivers, drill rigs, concrete transit mixers, concrete pumps, excavators and tractor-trailer rigs. Bridge types for which certain pieces of equipment are essential, require adequate space for operation of that equipment. For instance, precast concrete or steel girders require space for cranes to set up adjacent to each span requiring girder erection.

*Maintaining Traffic* - Traffic conditions often influence bridge type selection due to safety considerations and space limitations. Bridge girders and falsework beams typically cannot be erected over live traffic.

*Bodies of Water* - The types of bridge superstructure and substructure construction may be limited for water crossings. Falsework required for cast-in-place concrete construction may not be feasible if the crossing is wide and deep. Precast concrete or steel girders erected from barges or segmental concrete or long span (suspension or cable-stayed) bridge construction may be required.

*High Profile* - High profile crossings (over 30m/100') would also render falsework impractical and lead to the use of a type suitable for wide and deep-water crossings as discussed above.

*Environmentally Sensitive Areas* - The use of falsework or construction access may be severely limited in sensitive habitat areas. This may lead to the use of special construction methods that minimize disturbance.

*Remote Sites* - Sites that are remote and have rugged access may preclude delivery of large prefabricated girders and may necessitate the use of portable batch plants for concrete production, or the use of alternative materials where possible.

*Cold Weather* - If construction is required during cold weather, cast-in-place concrete requires special measures to facilitate curing. This cost premium could lead to selection of a different bridge type.

### 7.3.5. **Complexity of Design Details**

Complex details in bridge construction increase labor costs through reduced productivity. It is often more cost-effective to sacrifice materials in order to simplify details. Complex details are often problematic, resulting in re-work and schedule delays.

### 7.3.6. **Construction Tolerances**

Current maglev technologies operate with small clearances at the lift and guidance points. To satisfy these tolerances, primary bridge members would require prefabrication under controlled shop conditions. This is feasible for precast concrete or steel girders at a nominal cost premium.

Cast-in-place concrete construction of primary bridge members to these tolerances, if possible, would result in substantial cost premiums. For this construction method, the primary structural members could be constructed to normal tolerances with the maglev system components mounted to precisely aligned secondary members. Alternatively, the maglev system components could be attached using adjustable mountings fine-tuned to the proper tolerance. Prefabrication of structures in controlled environments can help to control these costs.

## 7.4. **DESIGN CRITERIA AND LOADINGS**

The maglev guideway needs to be designed on the basis of loading and criteria given in Ref [Urban Maglev System Requirements in publication by the FTA]. The loads consist of dead loads, seismic loads in earthquake zones, and thermal loads due to temperature gradients across the cross section. These are discussed in a previous section.

## 7.5. **DESIGN AESTHETICS**

The focus of maglev prototype systems should be not only on technology, but also guideway aesthetics. As maglev systems are placed into actual service, particularly in urban or high-visibility environments, aesthetics will be important from an environmental standpoint and in order to maintain public acceptance.

The art of designing aesthetically pleasing bridges has evolved to a point where many successful techniques are recognized and utilized by practicing bridge engineers and bridge architects. With the need for greater attention to the aesthetics of urban transit guideways, these methods can be applied to significantly improve the appearance of the structural systems without contributing significantly to increased cost. Aesthetic considerations applicable to maglev guideways include:

**Vehicle Compatibility** – Maglev prototype vehicles are consistently of a modern, streamlined design to reduce aerodynamic drag and noise and provide a pleasing contemporary appearance. Supporting the vehicles, guideway structures should have similar clean and simple lines for compatibility.

**Member Proportions and Shapes** – Proportion is a fundamental architectural consideration. Beams and columns of guideway structures should have compatible proportions and span lengths should be proportional with respect to the height of the structure. Shaping can be used for both beams and columns. Beams can include rounded corners and sloping sides. Columns can include various cross-sectional configurations and may incorporate flares of various shapes at either end. Custom steel column forms can be fabricated economically and re-used extensively.

**Use of Light and Shadow** – Light and shadow can be used to de-emphasize a portion of the structure and reduce the apparent depth of the girders. Shadows can be created by extending the bridge deck beyond the exterior girder face. This effect can be magnified by sloping the girder face away from the edge of deck.

A parapet (barrier railing) along each side of a deck-type structure could be used to house the maglev system components while providing a reflective element in combination with shadows to accentuate the impression of structure thinness. These effects are illustrated in Figure 29.

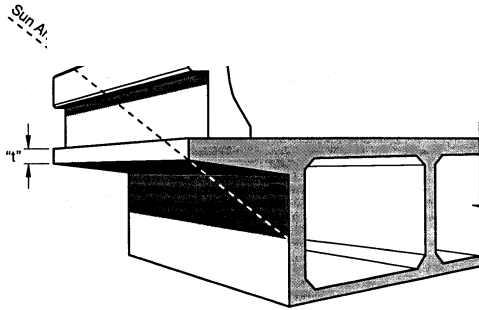


Figure 6. Concrete Box Girder with Vertical Sides

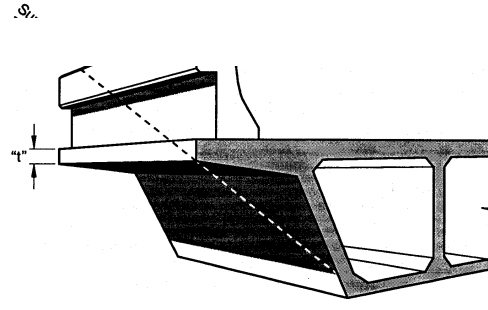


Figure 7. Concrete Box Girder with Sloping Sides

### Figure 29: Use of Shadow and Parapet

**Textures** - Contrast can be created by using concrete surface treatments consisting of form liners of various patterns and/or by use of different finishing techniques such as abrasive blasting and chipping.

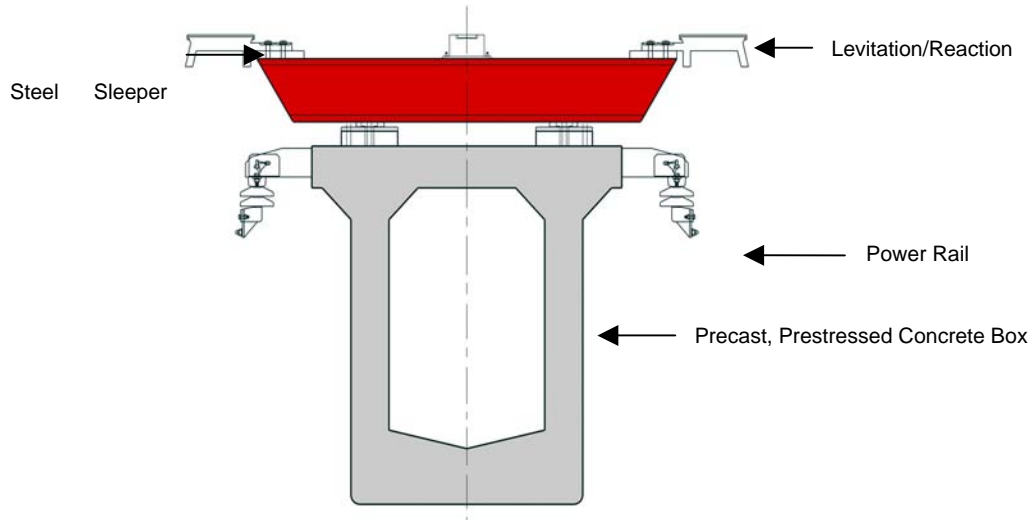
**Color** – Color can be applied to concrete structures using integral pigmentation or, at lower cost, by application of surface stains, which can also be used to combat graffiti. Color can add interest to the structure by changing the sometimes stark look of plain concrete and can help the structure blend with its surroundings.

**Concealment of Appurtenances** – Care should be taken to avoid unsightly appurtenances and joints in the structure that disturb the continuity and flow of the lines. This is especially important on rapid transit structures where power, signaling and communication systems are involved.

## 7.6. CHSST MAGLEV SYSTEM TECHNOLOGY

With a maglev vehicle selected, further studies of specific guideway structural systems and switching mechanisms were facilitated in terms of vehicle design loading, vehicle-guideway interface needs and design criteria, including deflection limitations and tolerances.

CHSST utilizes a standardized guideway structural system that is being constructed for the Tobu Kyuryo Line. The guideway superstructure consists of a single line of precast, prestressed concrete box beams for each track direction. The standard span length between supports is 20 m (65.6 ft). The two longitudinal levitation/reaction rails (secondaries for the linear induction motor) required for each track are mounted at the ends of transverse steel sleeper beams mounted to the top of the box beams that maintain rail gauge and allow for profile and superelevation adjustment.



**Figure 30: CHSST Standard Guideway**

The CHSST guideway is a good, simple design that satisfies the basic functional needs of the system. However, improvements in the design may be possible in terms of both structural efficiency and aesthetics, particularly with respect to the sleeper beam system, which incorporates a large quantity of steel while not contributing to the overall load-carrying capacity of the guideway beams.

#### 7.6.1. ***Precision Requirements for CHSST Vehicle / Guideway Interface***

The rail installation requirements are established taking the following into consideration:

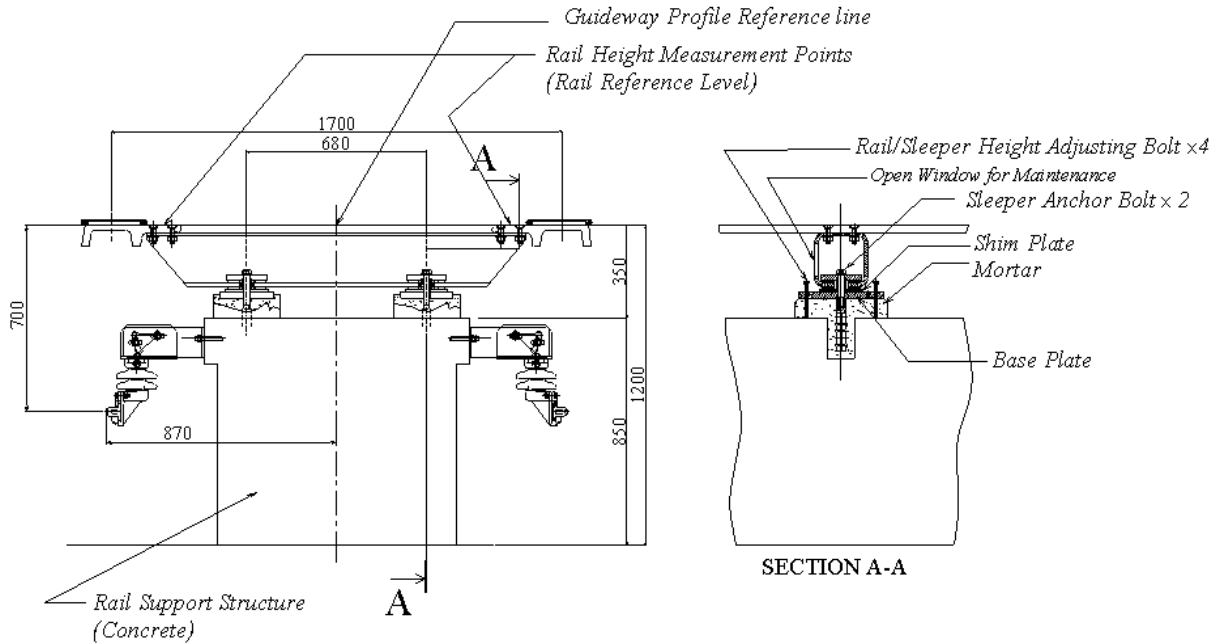
- ease of manufacturing the rail and rail components
- ease of installation
- ability to maintain the rail tolerances.

The basic design concept is to apply the same construction requirements used for road bridges, including foundations, piers and girders, while imposing requirements similar to railway installation in Japan.

Since requirements for rail installation are more precise than those required for civil works, the rail components above the sleeper beams are designed to allow for vertical and lateral adjustment during installation. Figure 31 illustrates the typical rail components and the sleepers.

The steps for installation and alignment are given below.





**Figure 31: Typical Rail/Sleeper Structure for Tobu-Kyuryo Line**

1. Rail height at end of the sleeper near the neighboring rail already set is measured and adjusted by height adjusting bolts.
2. Rail end is connected to neighboring rail end by connection fitting and plate.
3. Rail height of adjacent rails is measured and adjusted using height adjusting bolts.
4. After completing the rail adjustment, sleepers are fixed by mortar under the base plates of the sleeper.
5. All sleeper anchor bolts are fastened.
6. Continue next rail unit installation as specified above.

After completion of rail installation, accuracy is confirmed by vehicle operations. If an abnormal gap fluctuation between magnets and the rail is identified, then the relevant location is inspected and rail position corrected.

Rails are manufactured with precision in straightness as well as curvature, since rails cannot be bent for adjustment during installation due to high lateral rigidity.

The following precision requirements are easily met if the accuracy of the rail cross-section and sleepers are maintained during manufacturing:

- Rail Joint Step
- Track Gauge
- Level Difference
- Rail Inclination

Rail components and production methods are shown below.

<b>Name of Components</b>	<b>Production Methods/Materials</b>
Rail	Hot Rolled /Atmospheric Corrosion Resistant Steel
Rail Joint Plate	Forging, partially machining / Steel
Sleeper	JIS G 3466 Square Pipe / Steel

As described previously, CHSST is using sleepers to allow the rail installation to easily meet the rail precision requirements. Once rails are assembled with sleepers, the following requirements will be met without any adjustment work:

- Track Gauge
- Level Difference
- Rail Inclination

The track gauge and rail joint step (lateral and vertical) tolerance requirements can be automatically satisfied at the construction site. This results from the fact that the installation bolt holes of the rails and sleepers are machined in the factory in order to satisfy the rail gauge tolerance limit. For the rail joint, the rail shape has a groove under the surface to allow for the alignment of the two rail ends laterally and a connection plate slot to align vertically.

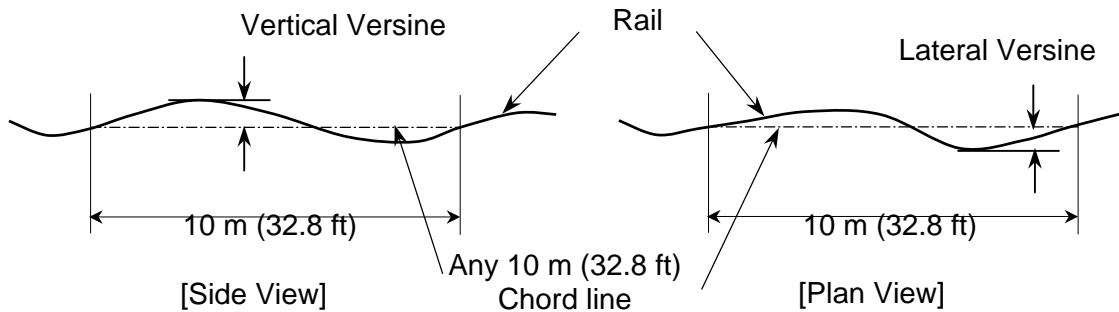
In addition, as parallel rails are fixed to sleepers, rail installation and maintenance do not affect Track Gauge, Level Difference and Rail Inclination.

Rail irregularity tolerances are set as follows.

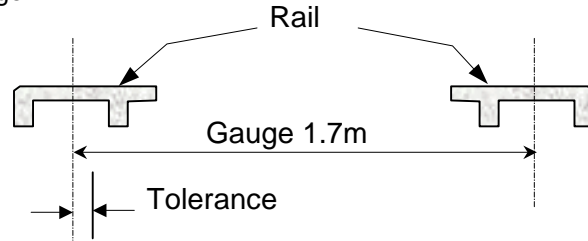
	Tolerance at construction	Tolerance at service	Remarks
A. Deviation from Alignment (Versine from 10m chord)	4 mm (0.12 in)	5 mm (0.2 in)	Lateral and vertical deviation from design alignment per every 10 m (32.8 ft) chord
B. Track Gauge (1.7 m)	4 mm (0.12 in)	5 mm (0.2 in)	Distance between right and left rail centers
C. Rail Joint Step	1 mm/1 mm (0.04 in)	1 mm/1.5mm (0.04 in/0.06 in)	Vertical / Lateral steps
D. Level Difference	4 mm (0.12 in)	5 mm (0.2 in)	Difference from designed superelevation

Each tolerance is illustrated in the following figures.

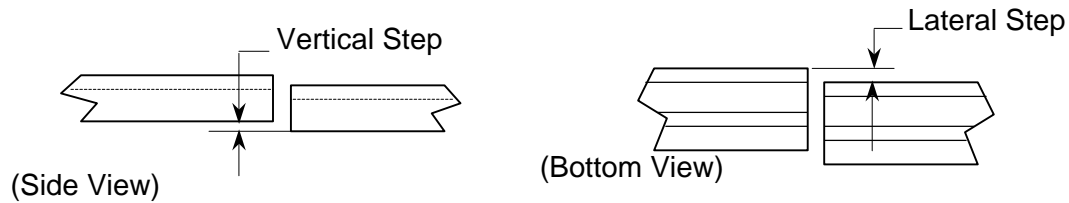
A. Deviation from Alignment



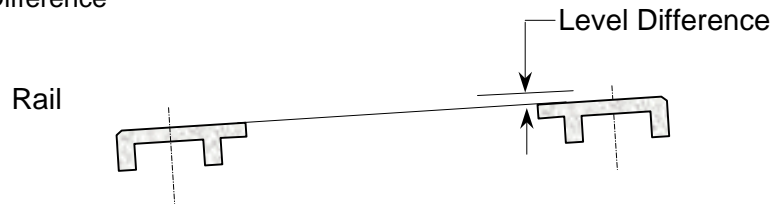
B. Track Gauge



C. Rail Joint Alignment



D. Level Difference



In the situation that the rail height requires adjustment, the rail position at relevant locations is corrected by loosening the anchor bolts and inserting or removing shims between the base plate and sleeper.

The sleeper position rarely requires lateral adjustment since the column foundation piles are sufficiently deep and the situation of column inclination due to unequal sink conditions is considered an extremely rare occurrence. In the situation where the column inclination occurs, the girder must be shifted at the girder shoes.

If there is an opportunity to relax the stringency of the rail requirements, it is important to evaluate how much a potential relaxation will contribute to a reduced guideway cost. The impact from a relaxation is discussed for the following factors:

A. Material cost

- No special requirement for production of the rail components.
- Machining processes are to be minimized or eliminated altogether.
- Fabrication procedure is already established. As a result, further cost reduction is difficult to achieve even if the requirements would be relaxed.

B. Installation cost

- The sleeper itself imposes rail accuracy.
- Vertical adjusting jack is incorporated in sleeper.
- More stringent control in adjusting rail is required only for a couple of meters at the girder ends.
- As a result, further cost reduction is difficult to achieve even if the requirements were to be relaxed.

Japanese conventional railways have similar rail precision requirements. Every system has developed its own construction and maintenance method in accordance with the specific site conditions. As for CHSST, experience has produced the current vehicle performance and rail precision requirements as well as the installation methodology. New relaxed requirements for guideway are possible, although the cost reduction potential may only be minimum.

As the above discussion has shown, the vehicle and rail requirements are such that no special civil works are necessary beyond periodic adjustment of rails at prescribed intervals. Therefore, the vehicle/guideway interface does not require special treatment and there is no added cost beyond normal rail construction techniques.

## 7.7. COLORADO MAGLEV SYSTEM GUIDEWAY DESIGN CONCEPTS

Conceptual design studies have been completed for three alternative guideway structural systems, based on the CHSST system, for a generic segment of the Colorado I-70 corridor with no unique site constraints. It is anticipated that much of the corridor will allow for repetitive construction of a single, highly economical structural system representing the “standard guideway” design.

The approach to the conceptual design studies consisted of the following tasks:

- Task 1: Establish Design Criteria
- Task 2: Development of Alternatives
- Task 3: Preliminary Structural Analysis and Design
- Task 4: Preparation of Conceptual Design Plans

### 7.7.1. Criteria for Conceptual Design

The following table summarizes the basic vehicle live loading criteria applied for conceptual guideway design.

**General:**

Baseline Maglev Technology:	Japanese CHSST
Vehicle Type:	CHSST 100 or 200
Design Speed:	160 kph
Track Gauge:	1700 mm

**Vehicle Live Loading:**

Maximum Vehicle Live Loading:	1,150 kgf/m per rail; 2,300 kgf/m per guideway
Live Load Impact:	24% (Steel Girders); 16% (Prestressed Conc. Gird.)
Live Load Deflection:	L / 1,750

For preliminary guideway design, the Service Load Design Method was used to obtain a reasonable proportioning of members and for estimating material quantities. Aside from the specific criteria listed above, the AASHTO Standard Specifications for Highway Bridges were generally followed for design with the exception that no tensile stress in prestressed concrete was allowed under full design load in accordance with the AREMA specifications.

### 7.7.2. Preliminary Structural Design

Conventional structural analysis methods were employed to determine maximum dead and live load moments and shears for preliminary design of the guideway structural sections. No detailed dynamic, vibrational or stress analysis has been performed at this stage since these factors are not expected to materially affect the basic superstructure design.

### 7.7.3. Guideway Superstructure Concepts

Three concepts were deemed to have sufficient merit to carry forward as alternatives and are as follows:

- Concept A: Precast Concrete U Girder (Figure 32)  
Concept B: Composite Steel Box Girder (Figures 33 & 34)  
Concept C: Tubular Steel Space Truss (Figures 35 & 36)

The guideway currently employed for the Japanese CHSST system consists of a precast, prestressed concrete box girder with the levitation/guidance/propulsion rails mounted on the ends of transverse steel sleeper beams spaced closely along the top of the box girder. The sleeper beams are mounted on plinths that allow for alignment adjustments. In the proposed CMP, the sleepers are omitted in preference to other concepts, which have the advantages of reduced cost, installation time, and visual impact.

#### 7.7.3.1. Precast Concrete U Girder – Concept A

This concept utilizes precast concrete U girders with a precast deck slab that can be adjusted for alignment and then made composite for live load. The technique of match-casting is envisioned for the exact matching of joints between the U girders and the precast deck slab to be sealed with epoxy after post-tensioning. The goal of this design is to improve upon the current CHSST design by combining the function of the sleeper beams and deck slab. While the sleeper beams allow for alignment adjustment, the Colorado Team feels that they can be eliminated from the design while still providing a means of rail adjustment. Further study is required to find the best means of future rail alignment for this design. One possibility is the use of conventional composite deck slabs with attached adjustable mounted rails that would allow for future, fine-tuning adjustments.

This concept takes advantage of the inherent economy of full-span precast concrete girders in an application with very high repetition and potential for great efficiencies in manufacture. There are several manufactures of precast concrete girders in the Denver area as well as in most major metropolitan areas throughout the U.S. This ensures competitive pricing for this type of construction.

The structural continuity in the precast option would reduce liveload and deadload deflections and possibly allow for higher speeds. Deformations due to creep and joint bearing costs would also reduce with the use of structural continuity. Over time, precast girders get considerable variation in cambers and early creeps, but very little time deflection after continuity and composite behavior is achieved. However, the relatively high live load to total load ratio combined with the use of the AREMA allowed tensile stresses may effect this typical situation.

The U girder is inherently simpler to fabricate than an enclosed box girder section. The U girder is also lighter for easier transportation and erection. With this system, the deck slab is made up of precast panels that would be post-tensioned longitudinally. The deck slabs are mounted on adjustable screw jacks for profile and superelevation adjustment. Horizontal curvature can be accommodated by horizontal shifting of the deck slab. Once the rails are in precise alignment, the spaces between the U girder and deck slab are grouted to provide composite action. Additional study and testing will be required to insure full composite action between the grouted connection of deck slab and U section.

A span length of 25 meters was selected for preliminary design since spans in this general range are known to produce economical results. This span length also results in a relatively small and light girder section.

The appearance of the section is clean and simple with a shallow profile and softened edges. The exterior concrete surface can be stained to provide color and better blend with the surroundings.

Maintenance of concrete structures is typically minimal with no need for such operations as re-painting, which may be problematic in environmentally sensitive areas.

#### **7.7.3.2. Steel-Concrete Composite Girder – Concept B**

This alternative guideway structure consists of a steel-concrete composite box girder. The girder has inclined webs and a bottom flange of steel plates with steel top flanges attached to a composite concrete deck. The concrete deck can be either cast-in-place or precast concrete. Generally, the basic idea of the composite structure is to optimize suitable structural material for stresses in the structure. Hence, the traditional approach of using concrete for compressive stress and steel for tensile stress is applied. The combination of these materials leads to a competitive and economical system.

Span lengths of the girders will vary depending on the alignment characteristics, although typically a standard length of 20 to 30 meters has been selected for reasons of economy and the practical consideration of transporting the steel box girder from the shop to the erection site. Conversely, longer span lengths and heavier girders could result in lower costs and fewer visual impacts. For this study, two variations were considered consisting of simply-supported spans and two-span continuous units.

One of the most important reasons for the selection of a box-girder guideway is its pleasing appearance since it hides all bracing and stiffening while minimizing exposed steel surface. It is a detail-clean structure with few visible appurtenances. The webs are inclined to further improve appearance and to provide additional space for welding.

It is well known that torsion has particular significance in curved bridges. A box section has a special advantage for a curved guideway because of its high torsional rigidity. A curved steel box girder guideway can provide longer curved spans with fewer supports than would be required for I girders, thereby creating greater cost savings in the substructure.

The box is an uncluttered, exposed surface that helps make the box girder more corrosion resistant, and easier to maintain. The steel would be protected from corrosion by the use of a modern paint. Maintenance costs of the paint were not included in the initial cost estimate of this alternative.

When the guideway cross-section is superelevated, customary geometry for the steelwork is obtained by rotating the entire flat cross section into the superelevated position.

A box girder is inherently more stable during erection, particularly when provided with lateral bracing between flanges, and may be easier to erect under different conditions or under a limited time schedule.

Modern fabrication equipment has made the welded steel box more economical and precise to fabricate. But, the small width of the bottom flange makes welding difficult, although possible. If the steel box option is studied further, consideration will be given into using a rectangular box to provide additional room for welding and inspection

Provisions for the initial and future alignment of the rails needs further study. The current concept is to use adjustable rail mounts installed in the concrete deck after the deck has been placed.

#### **7.7.3.3. Tubular Steel Space Truss – Concept C**

The key driving factors in developing the Tubular Steel Space Truss (TSST) for a maglev guideway are: (1) structural system efficiency for the optimization of material used while satisfying the required functions, (2) modular standardization for cost control in fabrication, (3) aesthetic design for social and natural environments. Specific advantages of this design concept include the following:

The TSST is one of the most efficient load-carrying systems known to engineers. For wide ranges of short to medium span bridges, the TSST is generally more efficient than T-girders, box girders, etc. Therefore, it leads to the least use of materials for a given deflection and strength demand. The proposed design uses the top chord brace also as a sleeper beam for the rails, a significant savings in material use.

The modular truss will span 30 meters with less than 30% of the weight compared to an optimized prestressed concrete box design, and less than 50% of the weight of a comparable steel/concrete composite solution. This results in savings in the substructure and in transportation as well as erection. Further, an even greater span could allow for even lower costs and fewer visual impacts by requiring fewer piers.

The standard TSST module can be fabricated with a well-tuned mass production procedure and most of the steel tubular members used in the TSST are off-the-shelf sections for maximum economy. The idea is to use steel trusses fabricated to the normal construction tolerances and then rely on adjustable rail mounts to meet the specific tolerance requirements.

With its open design, snow is unlikely to be accumulated within a TSST guideway.

The long-term deformation caused by creep and shrinkage in either a concrete or a composite solution would not be a factor for the TSST solution.

The contemporary appearance of the TSST complements the modern look of maglev vehicles.

One of the main adverse factors resulting from the TSST design is maintenance during its service life, specifically painting for corrosion protection and the cost of material. The life cycle cost of the paint was not factored in to initial costs estimates for this alternative. However, considering the relatively dry environment in and near the Denver area, this may not be a major issue. The required tube material is also slightly more expensive than the steel box and could require more difficult welding. Further assessment into the fatigue issue at the joints would be needed if further consideration were given to the truss alternative.

Provisions for the initial and future alignment of the rails would also require further study. The current concept is to use adjustable rail mounts attached to transverse beams across the top chords of the truss.

#### **7.7.4. Conceptual Substructure Design**

Although this study focuses on superstructure design at this stage, the design of the substructure is also very important and accounts for a large proportion of the overall cost of the guideway. For the purposes of this study, the same basic substructure is used for each superstructure alternative so that straightforward cost comparisons can be made.

##### **7.7.4.1. Bent**

The design shown is based on a single-column design with a two-way flared section at the top to carry both guideway tracks. The flared section functions as a deep cap beam. The design of the bent offers many opportunities for aesthetic treatment. The traverse shear keys used for support, although not yet designed, are thought to be similar to those commonly used for seismic resistance. The expansion joint filler used to form the key against the girder will also work to prevent debris from entering the joint.

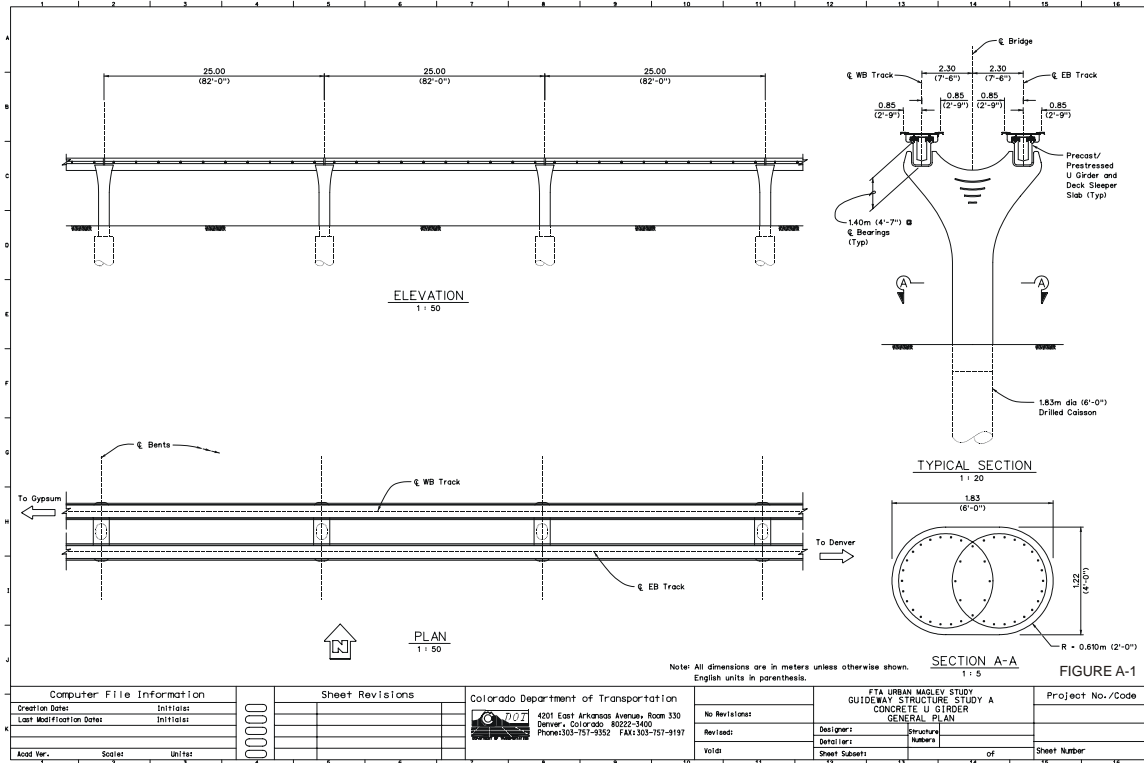


Figure 32: Alternative A-1

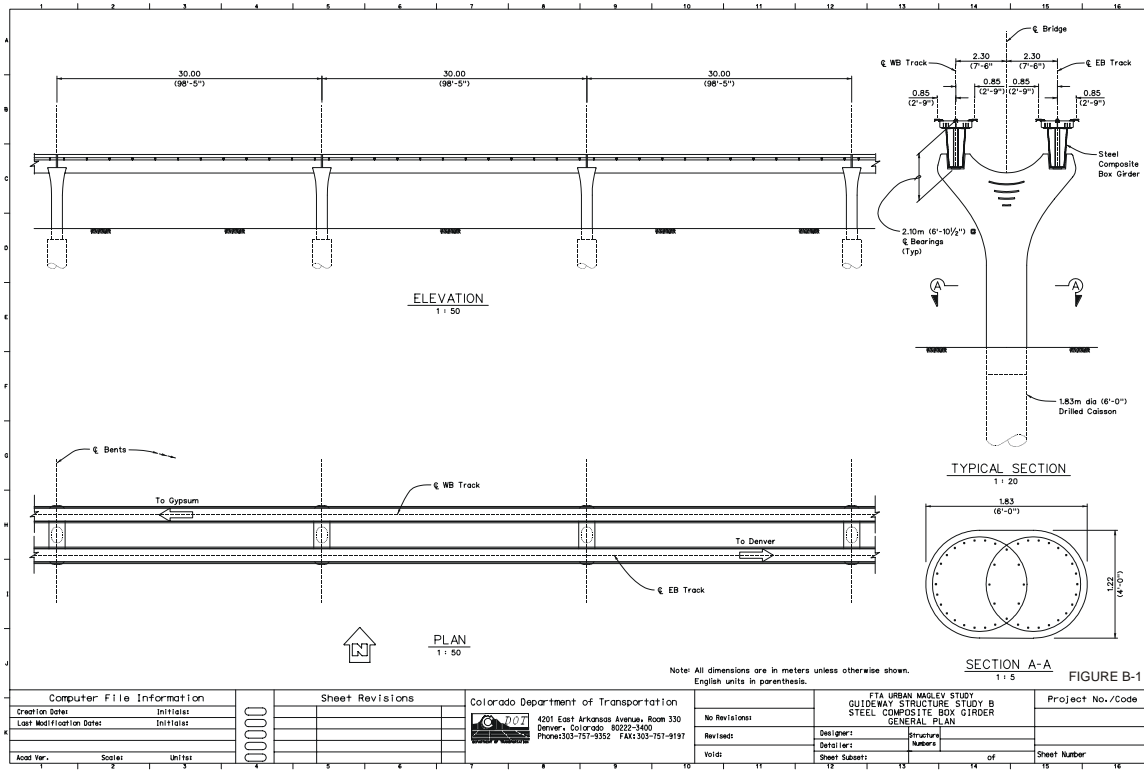


Figure 33: Alternative B-1



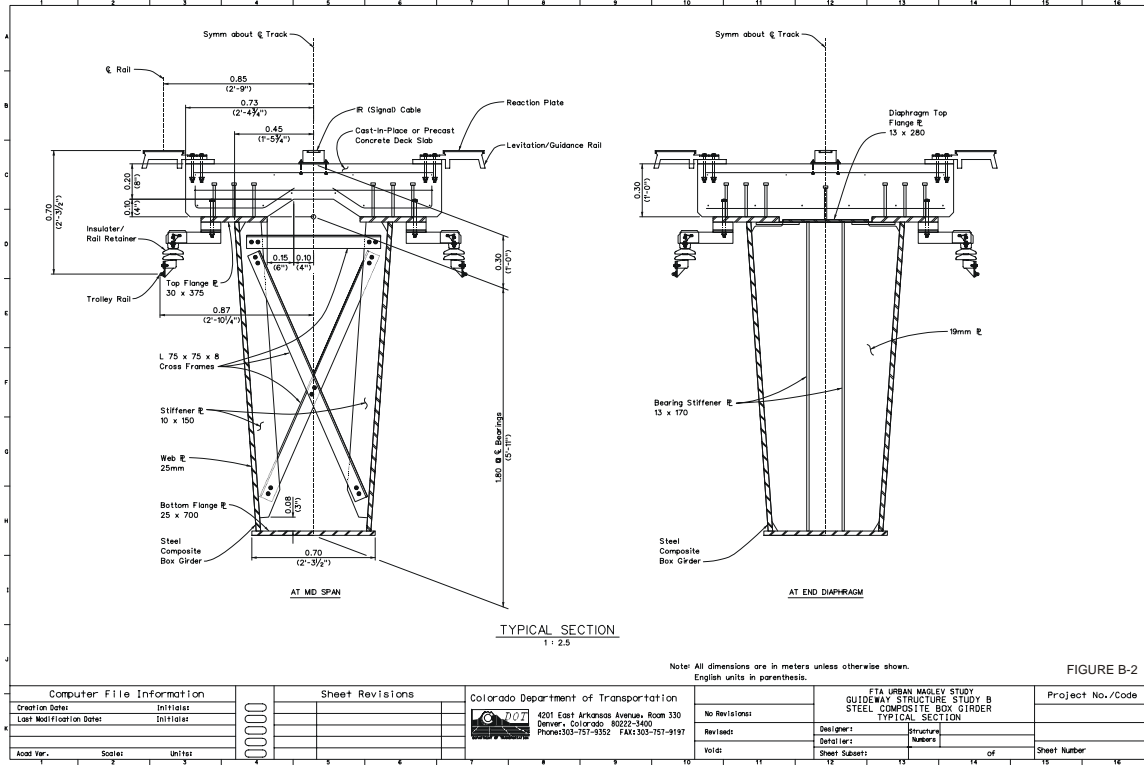


Figure 34: Alternative B-2

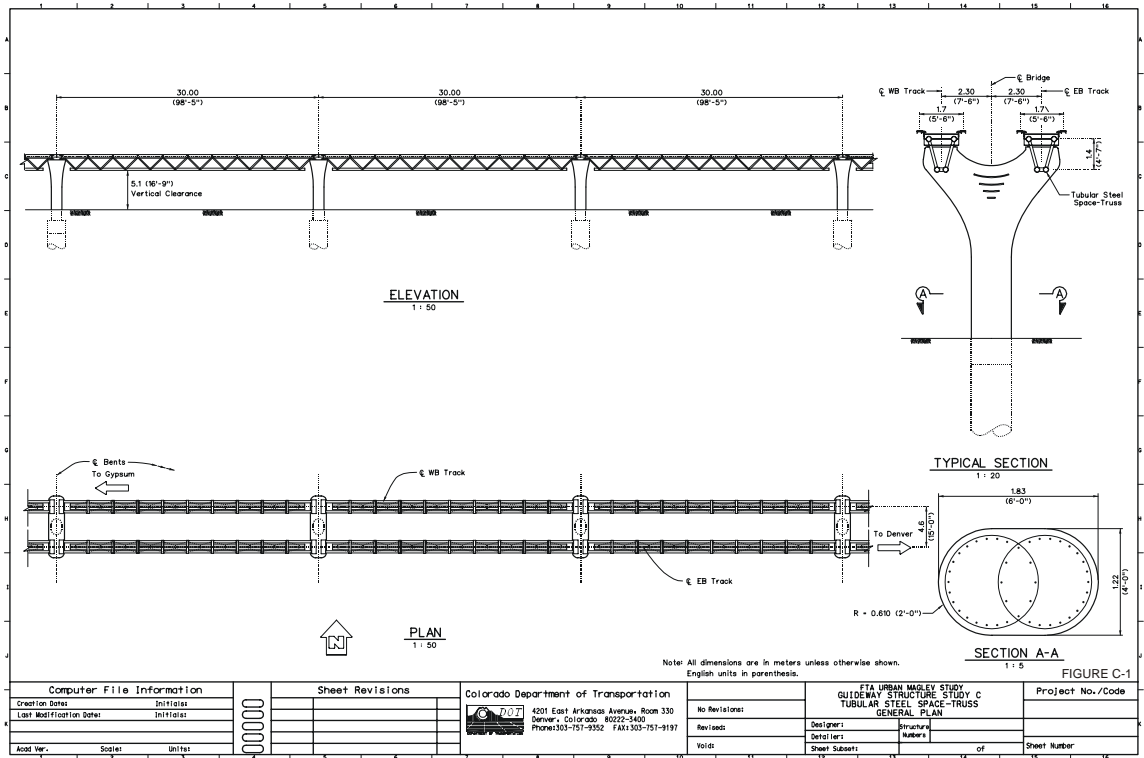


Figure 35: Alternative C-1

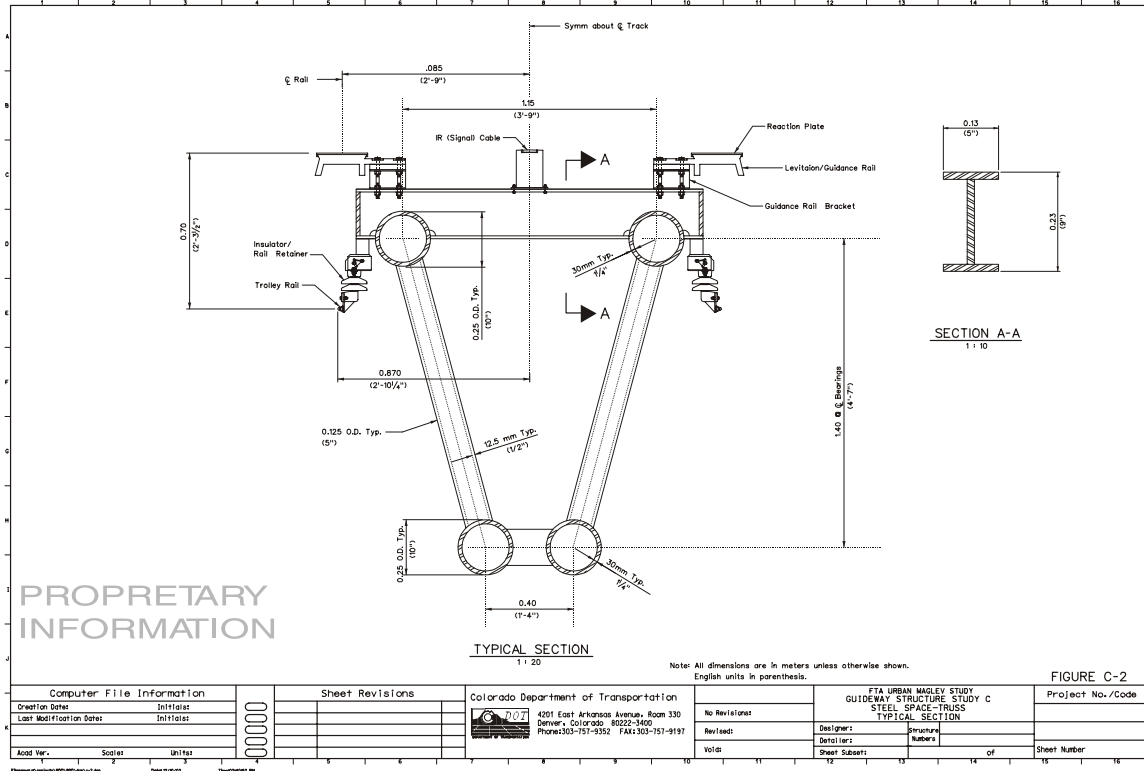


Figure 36: Alternative C-2

7.7.4.2. Foundation

For the purposes of this study, a single 1.83 m (72-inch) diameter drilled caisson was used for the foundation system. No specific geologic information was available for selection of this foundation type although it is considered to be adaptable to a variety of conditions that might be expected along the guideway alignment. This type has the advantage of requiring minimal space and can be constructed rapidly. The required depth of the caisson would vary depending on the competence of the geology. Pile lengths of 18.3 m (60'), 15.2 m (50') and 12.2 m (40') were assumed for Alternatives A, B and C respectively. The varying depths recognize the advantage of the lightweight superstructures on the cost of the foundations.



**Figure 37: Concept A - Rendering of Concrete U-Girder Guideway**



**Figure 38: Concept B - Rendering of Steel Box Girder Guideway**



**Figure 39: Concept C - Rendering of Steel Truss Guideway**

**7.8. SWITCHING**

In order to operate the CMP effectively and efficiently, guideway switches will need to be used at various locations to move vehicles from one guideway to another or to reverse directions at the end of the line. Properly designed switches are a critical component of an effective maglev system.

Since there is little operational experience with any maglev switching technologies (high-speed or low-speed), there is limited confidence in a detailed switch reliability analysis. For example, if the designer sets a goal of  $6\sigma$  reliability, corresponding to 3.4 failures in each million operations, testing to verify the switching system reliability will take years, even if the system is cycled continuously and in minutes per cycle. In addition, the Colorado project is unique and represents geographical and climatological constraints that have not heretofore been considered. Considering switch designs that have the demonstrated potential to be deployed within the next few years also limits the potential field of switches available for use. Several switch designs are considered and evaluated in this analysis based on design criteria established for the Colorado Project.

People Mover ride comfort criteria provided by the American Society of Civil Engineers (ASCE) are shown below in Table 7.8-1.

**Table 7.8-1 - Acceleration and Jerk Limits for Comfortable Rides in People Movers**

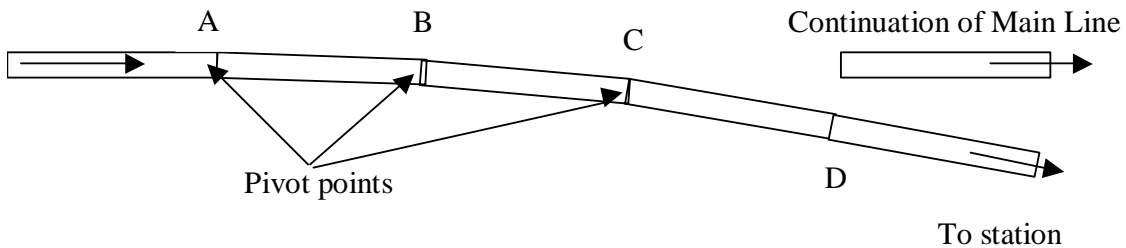
<b>Component</b>	<b>Comfort Limits (gravity units)</b>	<b>Comfort Limits (SI units)</b>
Maximum Vertical Acceleration	0.1 g (up) 0.4 g (down)	1 m/s <sup>2</sup> (up) 4 m/s <sup>2</sup> (down)
Maximum Lateral Acceleration	0.25 g	2.5 m/s <sup>2</sup>
Maximum Longitudinal Acceleration	0.25 g	2.5 m/s <sup>2</sup>

Maximum Braking Acceleration	-0.25 g	-2.5 m/s <sup>2</sup>
Emergency Braking Acceleration	-0.36 g	3.5 m/s <sup>2</sup>
Maximum Vertical Jerk	0.3 g/s	3 m/s <sup>3</sup>
Maximum Lateral Jerk	0.25 g/s	2.5 m/s <sup>3</sup>
Maximum Longitudinal Jerk	0.25 g/s	2.5 m/s <sup>3</sup>

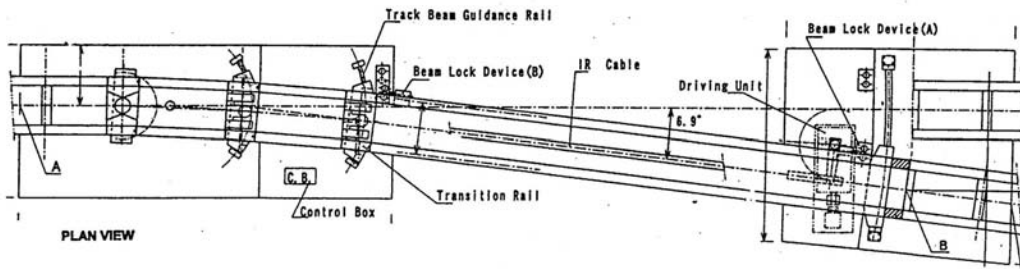
Values selected based on ride comfort values for seated passengers as stated in ASCE 21-98-Part 2, Table 7-1 and Technical Assessment of Maglev System Concepts, Special Report 98-12, Appendix A.

**7.8.1. CHSST Segmented Pivoting Switch**

Low-speed pivoting switches, used by CHSST, are designed using an articulating guideway that introduces lateral deviation at pivot locations, persisting to the end of each segment. This switching geometry is shown schematically in Figure 40, and in greater detail, as implemented by CHSST, in Figure 41.



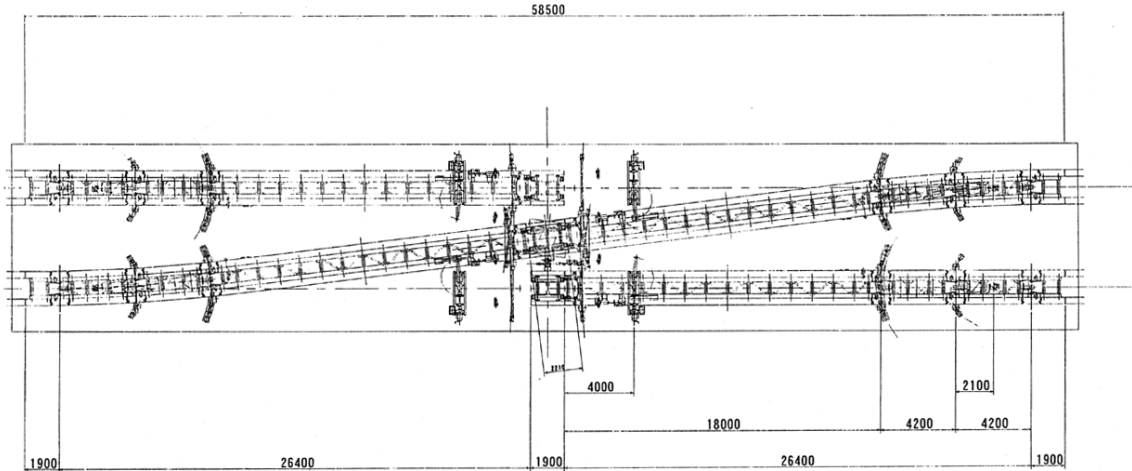
**Figure 40: Segmented Guideway Pivoting Switch**



**Figure 41: Low-Speed CHSST Switch Detail**

In a document entitled "The Linear Technology Guide", this implementation of the CHSST segmented switch is described as powered by a 7.5 kW electric drive motor. The switch dimensions provided are 30 m long, 4.9 m wide and 18 m deep with a switch mass of 50,000 kg.

Additionally, CHSST has used combinations of these switches to produce a crossover switch, for interconnecting two parallel guideway segments. A diagram of this switch geometry is shown in the following detail.



**Figure 42: CHSST Crossover Switch**

**7.8.2. High Speed Design Criteria for Pivoting Switches**

The following discussion focuses on the kinematic design criteria for high-speed switching required to realize an appropriate pivoting guideway switch. This discussion is necessary since heretofore, only low-speed versions of this switch have been produced.

**7.8.2.1. Optimal Track Geometry**

A fundamental step in developing a reasonable estimate of cost for a high-speed switch is to define the turn out geometry so that the length of the switch between standard guideway sections can be determined. Based on the concept of a pivoting guideway switch, the cost should be proportional to the length and thus, the objective is to develop geometry that results in the shortest length of switch. The basic criteria used for geometric design are shown in Table 7.8-2:

**Table 7.8-2 - Geometric Design Criteria**

Design Parameter	Design Value
1. Design Speed	160 km/hour
2. Lateral Acceleration	0.25 g
3. Vehicle Stability	Vehicle Resultant within Middle 1/3 of Track Gauge
4. Superelevation Transition Rate	2.0 mm / m
5. Lateral Jerk	0.25 g / second
6. Dynamic Vehicle Envelope	3.1 m track centers (Chubu CHSST Criteria)

Based on these criteria, circular curve, superelevation and spiral transition geometrics can be developed. The basic steps of the approach for optimizing the geometry are:

1. Establish relationships between superelevation and circular curve radius based on passenger comfort (lateral acceleration) and vehicle stability.
2. With a selected superelevation and circular curve radius, determine the required length of spiral transition based on passenger comfort (lateral jerk) and superelevation transition rate.
3. With the geometry of the spiral and circular curve defined, determine the length from the beginning of the turn out (beginning of spiral or tangent-to-spiral point) to the point at

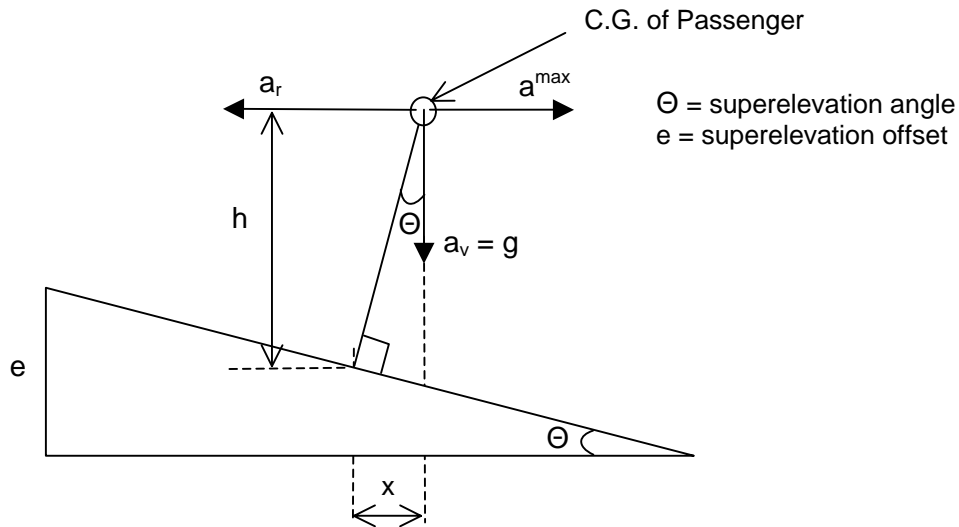
which the minimum horizontal clearance is achieved based on the dynamic vehicle envelope.

**7.8.2.2. Curve Radius and Superelevation**

For a given design speed and superelevation, the minimum radius of the circular portion of the horizontal curve may be determined based on either the passenger comfort criteria (lateral acceleration) or the vehicle stability criteria, depending on which criterion results in the smallest curve radius.

**7.8.2.3. Passenger Comfort**

The passenger comfort criterion is based on the American Society of Civil Engineers People Mover standards. These standards provide a maximum recommended lateral acceleration on the passenger,  $a^{max}$ , of 0.25g. The lateral acceleration is a function of the velocity and the radius of curvature ( $a_r=V^2/R$ ). However, this neglects the effect of superelevation, which should counter the effect of curvature tending to pull the passenger to the outside of the curve. In order to account for the benefit of superelevation, in terms of increasing the allowable radius of curvature, the equilibrium of the passenger is evaluated as shown in the following diagram, Figure 43.



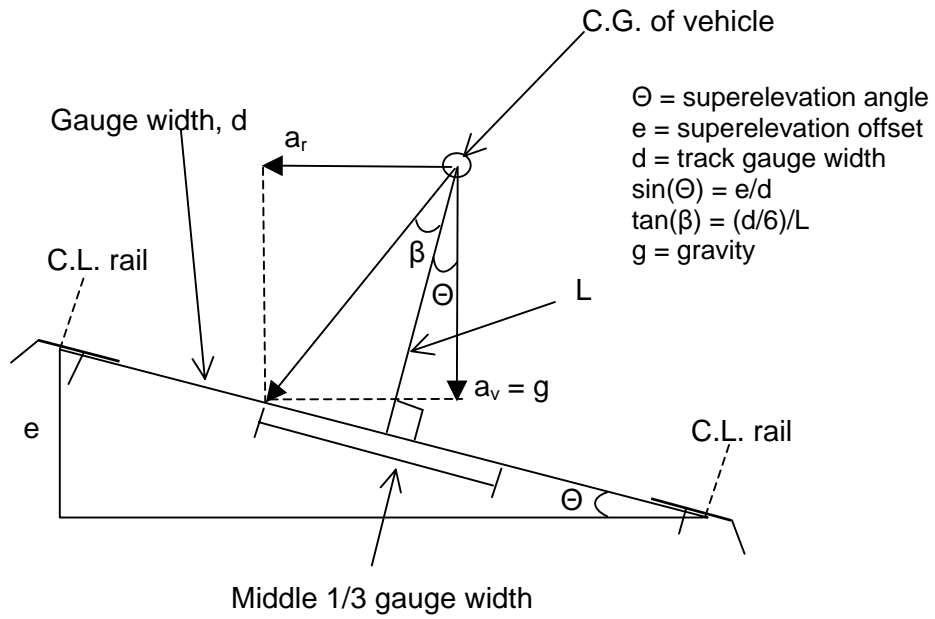
**Figure 43: Passenger Equilibrium**

The allowable lateral acceleration is accounted for in this diagram by subtracting it from the  $V^2/R$  term. Solving for the radius in terms of the superelevation results in the following equation:

$$R = \frac{V^2}{g(\tan(\Theta) + a^{max})}$$

**7.8.2.4. Vehicle Stability**

In addition to passenger comfort, the stability of the vehicle itself needs to be considered in the relationship between allowable curve radius and superelevation. In order to maintain positive pressure on the inside rail, the vehicle's resultant force must be maintained within the middle 1/3 of the track gauge. The superelevation/minimum radius relationship for this criterion is determined based on the following free-body diagram of the vehicle, as shown in Figure 44.



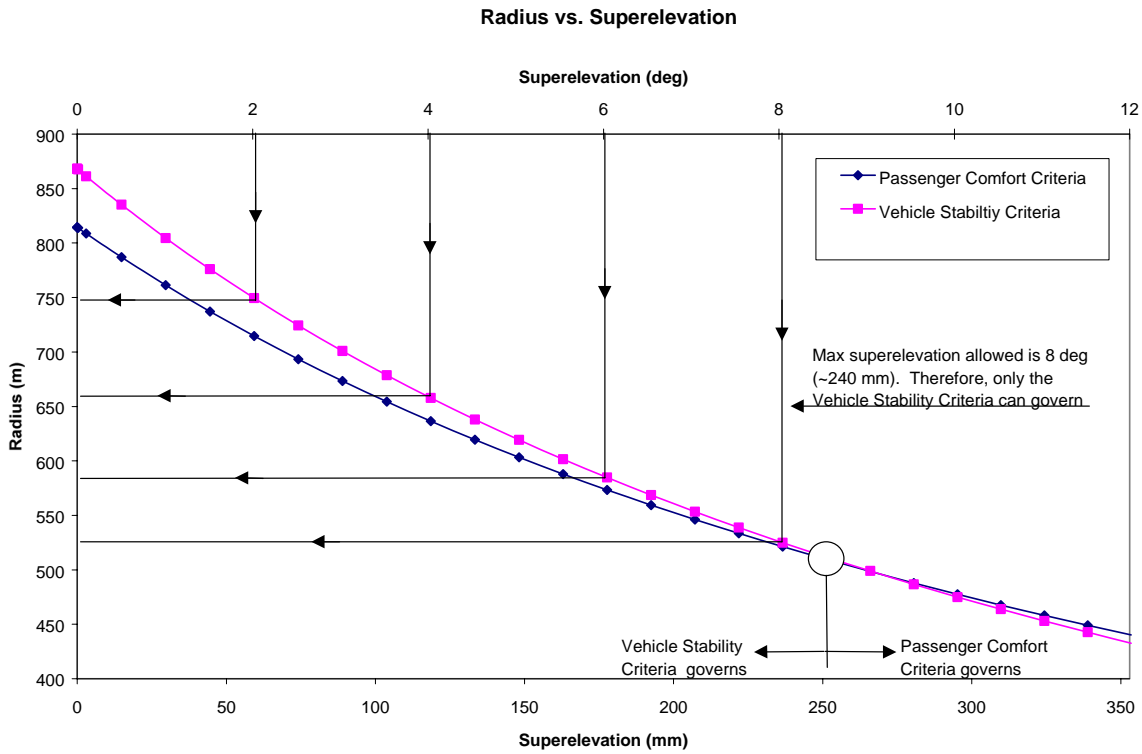
**Figure 44: Superelevation / Minimum Radius Relationship**

Solving for the radius in terms of the superelevation results in the following equation:

$$R = \frac{V^2}{g(\tan(\Theta + \beta))}$$

The equations of minimum radius as a function of superelevation for both passenger comfort and vehicle stability are plotted in the following graph, Figure 45.





**Figure 45: Radius vs. Superelevation**

As shown in the graph, the vehicle stability criterion will govern for superelevations of less than about 8°, which is cited by Chubu CHSST as a maximum superelevation rate for their system.

**7.8.2.5. Spiral Transition**

A spiral transition is commonly utilized on both ends of a circular horizontal curve to minimize the rate of change of lateral acceleration (jerk) and to accommodate transition to superelevation. The length of the spiral transition required is thus dependent on these two factors, which relate back to the circular curve radius.

The minimum spiral length required based on jerk is given by the following equation:

$$L_s = \frac{V^3}{g \cdot R \cdot \text{Jerk}}$$

The minimum spiral length required based on superelevation transition is given by the following equation, where *v* is the maximum allowable superelevation transition rate:

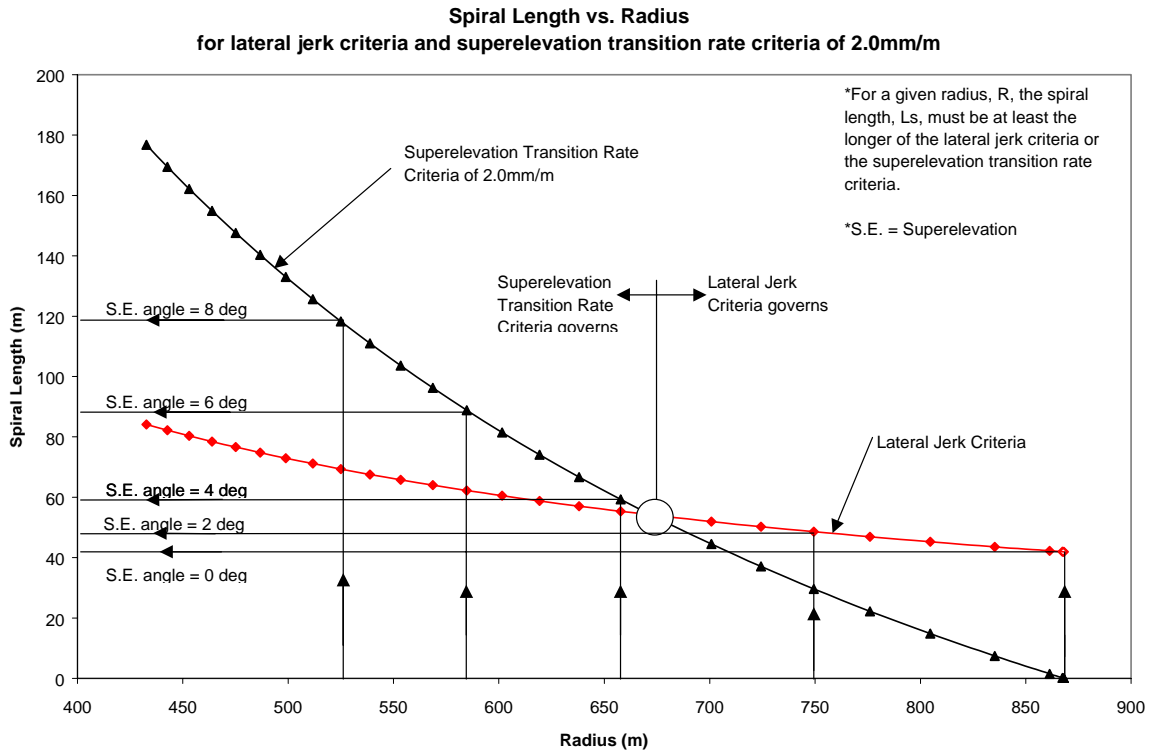
$$L_s = \frac{e}{v'} = \frac{d \cdot \sin(\Theta)}{v'}$$

Recommendations of superelevation transition lengths for highways are based on a variety of factors including safety, comfort, and appearance. Transition rates of up to 4% in 20 m may be applicable to certain constrained highway design situations. Recommended superelevation transition rates for high-speed railways are much less with values on the order of 1.125 in/sec. These rates correspond to the following superelevation dimensional values given a track gauge of 1.7 m (CHSST):

Highway: 3.4 mm / m  
 Railway: 0.64 mm / m

For purposes of this study, a maximum superelevation transition rate of 2 mm/m has been assumed for conceptual switch design purposes.

The required spiral transition lengths for both the lateral jerk and superelevation transition rate criteria are plotted in the following graph, Figure 46.



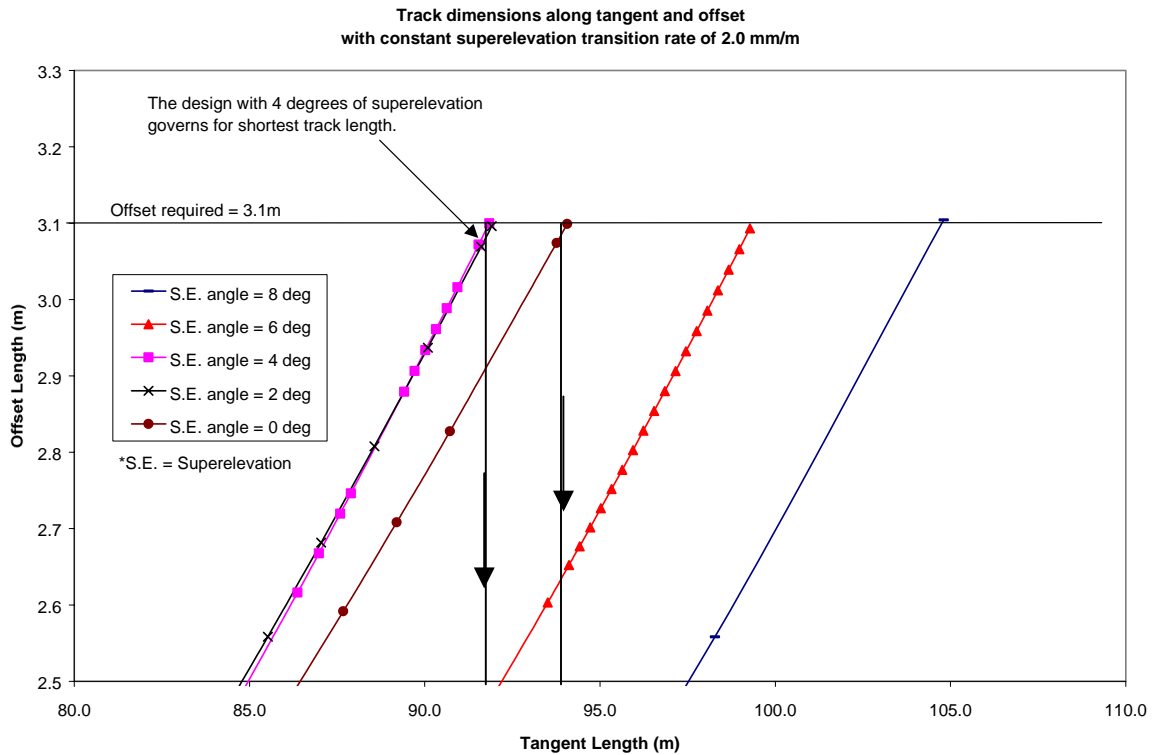
**Figure 46: Spiral Length vs. Radius**

As shown in the graph, superelevation transition rate governs up to a curve radius of about 670 m and lateral jerk governs for greater radii.

**7.8.2.6. Switch Length**

The length of the switch is defined as the distance required along the mainline track to obtain the required minimum clearance to the turnout. In highway terms, this is analogous to a tangent offset. For the CHSST system, a center-to-center track spacing of 3.1 m is required to provide the minimum horizontal clearance.

Thus, the coordinates of the track centerline for various turnout geometries may be plotted to graphically determine which provides the minimum switch length. Plots of the centerline coordinates for the geometry based on various values of superelevation are shown in the following graph, Figure 47.



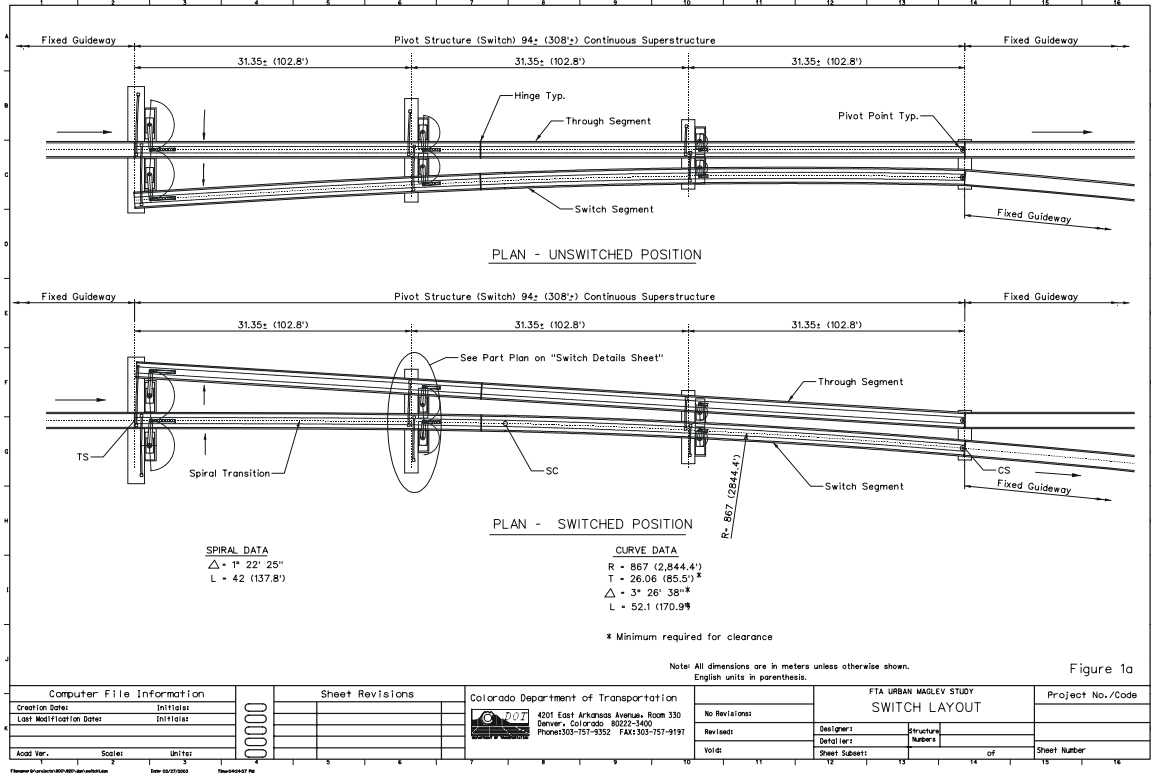
**Figure 47: Track Dimensions**

The graph shows that a superelevation and corresponding circular curve and spiral result in the shortest switch length of about 92 m. However, a geometric with zero superelevation requires only about 2 m of additional switch length. Considering the complexities of introducing superelevation and superelevation transition on a guideway structure, the slightly longer switch is easily justified.

**7.8.3. High Speed Pivoting Switch Concept**

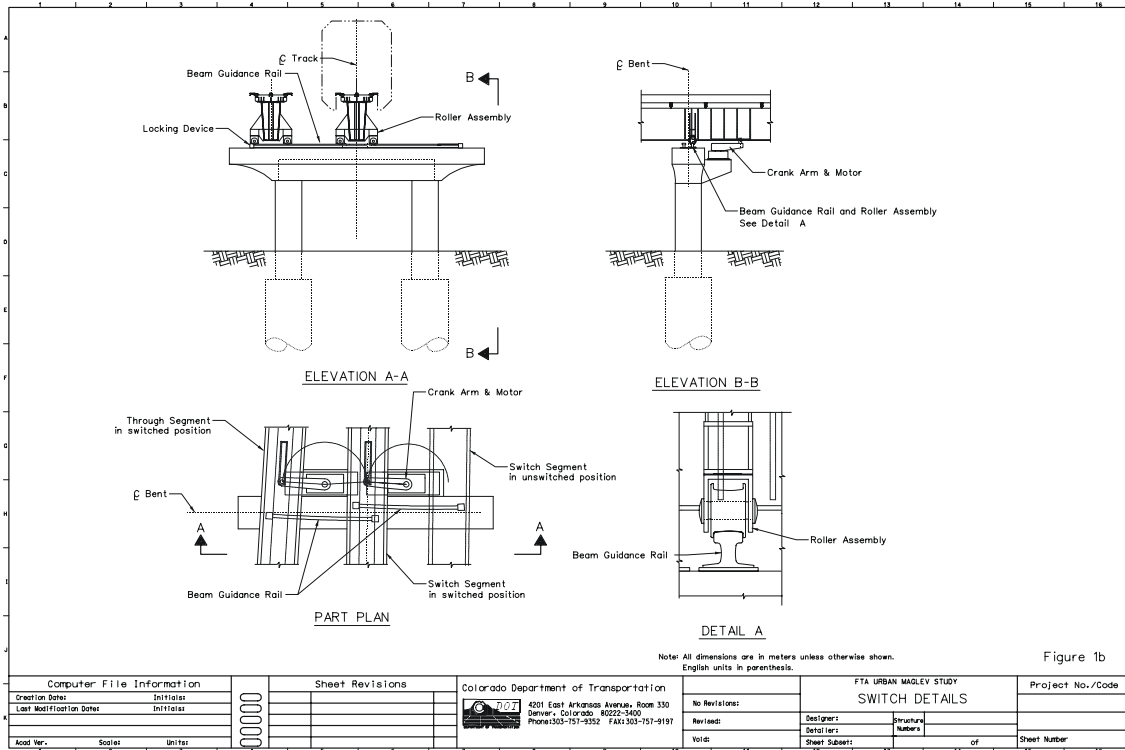
As noted before, the CHSST system currently does not employ a high-speed switch. The CHSST switches are designed using an articulating guideway that introduces angle points at the pivot locations. For the switch geometry resulting from the foregoing procedure, these angle points would be too large to accommodate high-speed operation. This means that a new geometry must be calculated in order to use the pivoting concept as a high-speed switch.

Accordingly, a high-speed pivoting guideway switch concept, similar to the translating table, has been developed, as shown in Figures 48 and 49. The geometry of this switch utilizes zero superelevation, a circular curve radius of 867 m and a spiral transition of 42 m, for an overall switch length of 94 m to achieve a center-to-center track spacing of 3.1 m. This geometry is based on the approach described above to achieve a minimum switch length.



**Figure 48: High-Speed Pivoting Switch Layout**

The switch functions by pivoting the tangent through segment to the side and then pivoting the curved switch section into alignment with the approach track. The switch functions over three guideway spans.



**Figure 49: Switch Details Guideway Actuation Mechanism**

The guideway segments are moved using electric motors attached to the bent caps. One motor is required at each bent for each guideway direction, resulting in the need for six motors. Each motor turns a crank arm that is attached to the guideway structure. The crank arms vary in length depending on the distance of guideway translation required.

At each bent, the guideway is supported on roller assemblies that follow fixed rails mounted to the bent caps. The rails are curved to guide the rollers on the proper radius.

Based on the inertia of the guideway structure and frictional resistance of rollers, it is estimated that 20-25 kilowatt motors operating at a gear reduction of 1:425 would be required to actuate the switch. Conical solenoid-operated devices could be utilized to positively lock and align the guideway at the turnout entry point. Sensors would be required to independently communicate secure switch engagement, and the entire switch is a vital mechanism.

**7.8.3.1. Switch Actuation Time**

Based on the selected actuation mechanism, motor power and gearing, it is estimated that this switch could be actuated within a time of 15 seconds, where 7.5 seconds is required for each guideway. This actuation time is comparable to other switch designs and is sufficient for the anticipated headways of the Colorado project.

**7.8.4. Docking Switch Concept**

First invented and mechanized in the early 1970's, the docking switch is uniquely suited for use at end of the line stations and possibly at bypass or off-line stations. There is also a dock configuration similar in concept to railroad roundhouses, which offers many advantages for vehicle maintenance yards. The docking approach offers potential cost savings as well as enhanced reliability. The docking switch category also includes the sliding table high-speed switch, as actuation for each is similar (though the switch mass is quite different). The sliding

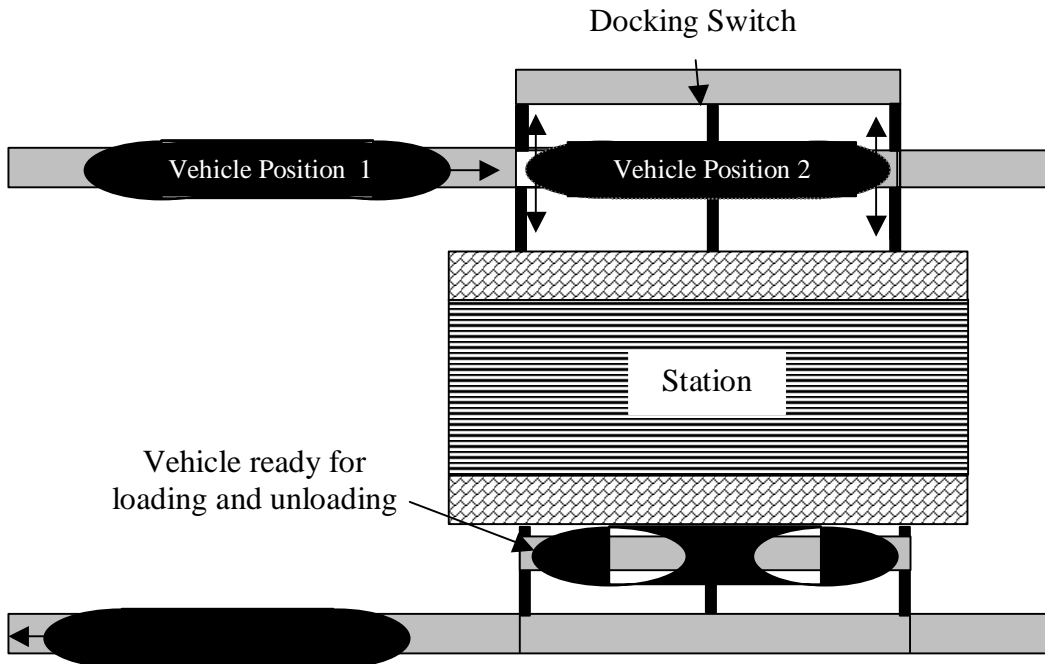
table variant of the docking switch is discussed in more detail below. Lack of familiarity with the docking concept in the industry makes it necessary to provide a full exposition here.

A docking switch employs a transfer mechanism to move the vehicle or train laterally at right angles to the normal direction of vehicle motion, stopping when the station platform has been reached. Because of this lateral motion, the docking switch carries a small operating time penalty, which is only an issue during peak transit hours. Even with this small penalty (tens of seconds), the docking switch offers unique advantages in construction costs, reliability, and operational flexibility. Normally, the dock motion time would be added in as a component of the station dwell, and could be ignored unless headways become comparable to dock actuation times.

The docking switch requires that the vehicle come to a complete stop precisely adjacent to the dock. When positioned, the vehicle is firmly seated on the dock mechanism, secured either by its brakes or by delevitation (which saves power). The dock is then laterally translated to a position in front of the station allowing the passengers (with baggage) to disembark from and embark onto the vehicle. At the same time, an identical section of empty track, also moved by the dock, replaces the removed main line guideway section, allowing other vehicles to pass by during the loading and unloading of the docked vehicle.

To minimize the force required to translate the dock and to enhance reliability, air pads would be used to allow the dock to float on a cushion of air. The actuator force must then only overcome the inertia of the dock and vehicle and the friction associated with the air film.

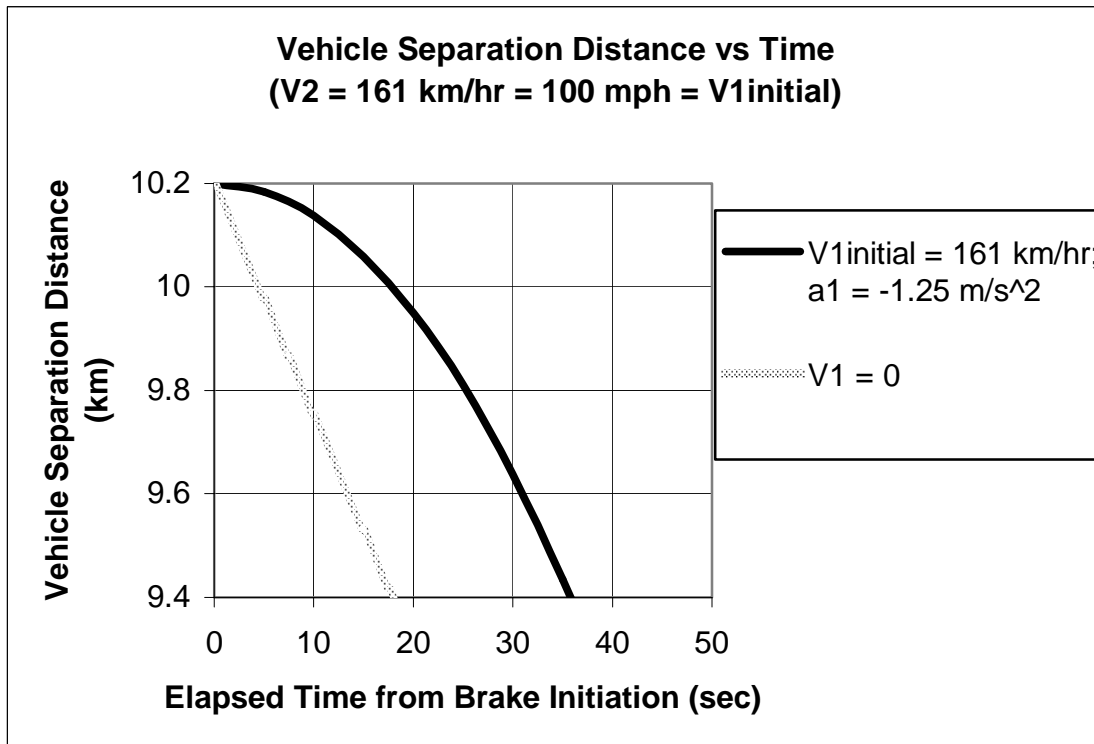
A plan view of the station with docking switches is shown in Figure 50. Note that an obvious station configuration for this arrangement would be the east and west-bound portions of the guideway on either side of the station. Identical docking switches would be employed on either side.



**Figure 50: Conceptualization of the Docking Switch for the Colorado Project**

If the vehicle must slow down to switch off or onto the main line, the capacity of the transit system is reduced. The following is an assessment of the significance of this issue for the Colorado

Project. For purposes of calculations an assumed minimum headway requirement of 3.8 minutes has been used for the following analysis. Shorter headway calculations can also be used in the hypothetical cases. For the CMP, the assumption is that there will be a combination of both local and express trips; to properly determine the headway requirements for a potential dock would require additional detailed operational simulation, which is beyond the scope of this phase of the project. Using the results of analysis shown in Figure 51, it is known that a vehicle moving with a velocity of 161 km/hr (100 mph) can travel 10.2 km in 3.8 minutes. According to the results shown in Figure 51, the lead vehicle that begins to slow with a deceleration  $1.25 \text{ m/s}^2$  (approximately one-half of the maximum allowed according to the ASCE People Mover specification for seated passengers) will have approximately 3.38 minutes to complete the docking switch operation before the following vehicle traveling at 161 km/hr (100 mph) will reach the docking location. ( $V_2 = 161 \text{ km/hr}$ ) when lead vehicle ( $V_1$ ) is decelerating and when it is stopped.



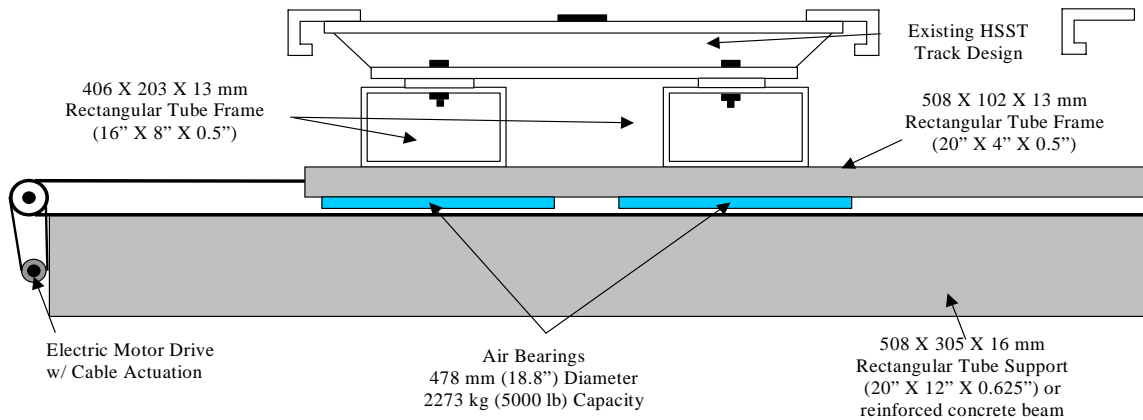
**Figure 51: Comparison of Vehicle Separation Distance Between Two Vehicles**

In this example, Vehicle 1 is initially separated from Vehicle 2 by a distance of 10.2 km [3.8 minutes at 44.7 m/s (100 mph)]. Vehicle 1 hits the brakes and decelerates at  $-1.25 \text{ m/s}^2$ . At this deceleration rate, Vehicle 1 will require 35 seconds and nearly 800 m to stop. In the same time interval, Vehicle 2 has closed the gap and travels the same distance in just over 18 seconds. There remains a distance of 9.4 km between the two vehicles which corresponds to  $(9400) \text{ m} / (44.7) \text{ m/s} = 220 \text{ sec}$  minus the 17 seconds (the additional time required for Vehicle 1 to travel the same distance that Vehicle 2 has traveled). The result is a  $220 \text{ sec} - 17 \text{ sec} = 203 \text{ seconds}$  (3.38 minutes) vehicle time separation in which to complete the docking operation.

This example illustrates a number of critical safety aspects of the docking process. First, the docking switch is a vital mechanism, just as a standard switch is, and second, the dock presents a true brickwall for oncoming vehicles until it has completed its motion and is vitally locked in fully retracted position. Similarly, it presents a brickwall as it is extended from the platform, and the condition persists until the undocked vehicle leaves the station under its own power.

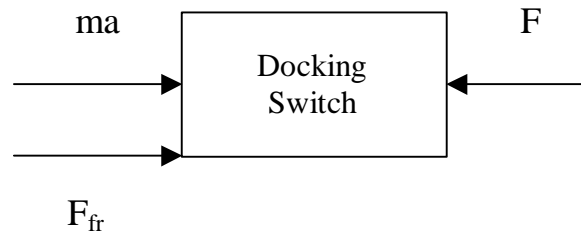
**7.8.4.1. Docking Switch Mechanism**

The docking switch under evaluation utilizes air levitation pads that minimize the lateral force required to dock the vehicle and ease the mechanical constraints for the supporting guideway structure. A cross section of the docking switch is shown in Figure 52.



**Figure 52: Cross Section of the Docking Switch**

If the docking switch is levitated above the support structure, then the force  $F$  that must be applied to move it is given by Newton’s Second Law as shown below in Figure 53.



**Figure 53: The actuator force,  $F$ , must overcome the inertia and friction forces.**

Here,  $m$  is the mass of the levitated structure and vehicle,  $a$  is the acceleration of that structure,  $F_{fr}$  is the friction forces that must be overcome, and  $F$  is the force that must be provided by the actuator prime mover. The mass was estimated from photographs of the CHSST track taken from the internet and through assumptions of the materials used to fabricate the track. The mass was determined for two sizes of trains: the CHSST 100S (modified) and the CHSST 200. The pertinent docking switch specifications are provided in the Table 7.8-3 below.

**Table 7.8-3 - Specifications for the Docking Switch for Two Different Trains**

<b>Vehicle Body Style</b>	<b>Switch Length (m)</b>	<b>Switch Mass (kg)</b>	<b>No. of 478 mm dia. Air Pads</b>	<b>Switch Levitation Height (mm)</b>
CHSST 100S	32	109,940	63	13
CHSST 200	60	229,228	123	13

To meet the switch velocity and acceleration characteristics required to move the switch and latch well before the following train passes the station, the Sigmoid function has been selected because it leads to gradual increases in acceleration. Since these are massive devices, the designer must be careful to select a velocity and acceleration profile that can be achieved at a reasonable cost and operate in a short time. The cost is directly related to the quantity of force that must be exerted in both accelerating and decelerating (braking) this switch.



As shown in Figures 54-56, the maximum lateral displacement for the switch is 4.5 m, the maximum velocity for the switch is 0.8 m/s (2.6 ft/s) and the maximum acceleration is  $\nabla 0.21 \text{ m/s}^2$  (less than one fifth of the maximum suggested in the comfort specifications). Using this motion profile, the switch will complete its traverse in 15 seconds. Only a few seconds would then be required to air levitate the switch and vehicle and for the latch and interlock operations. Neglecting frictional resistance forces, the maximum force required to move the switch in 15 seconds is:

$$F = ma = (229,228)\text{kg} (0.21)\text{m/s}^2$$

$$F = 48138 \text{ N} = 10,822 \text{ lbf}$$

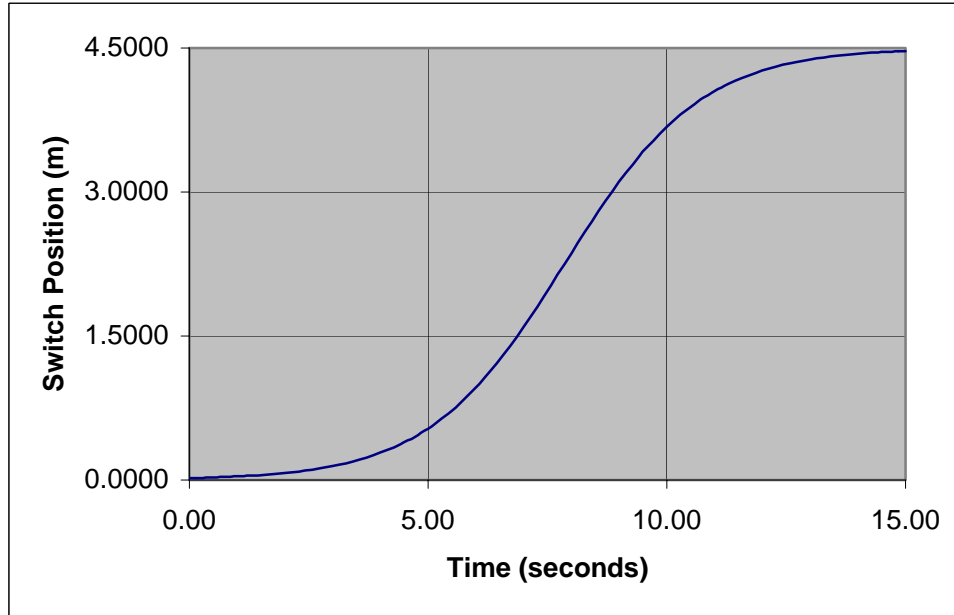


Figure 54: Switch Position vs. Time

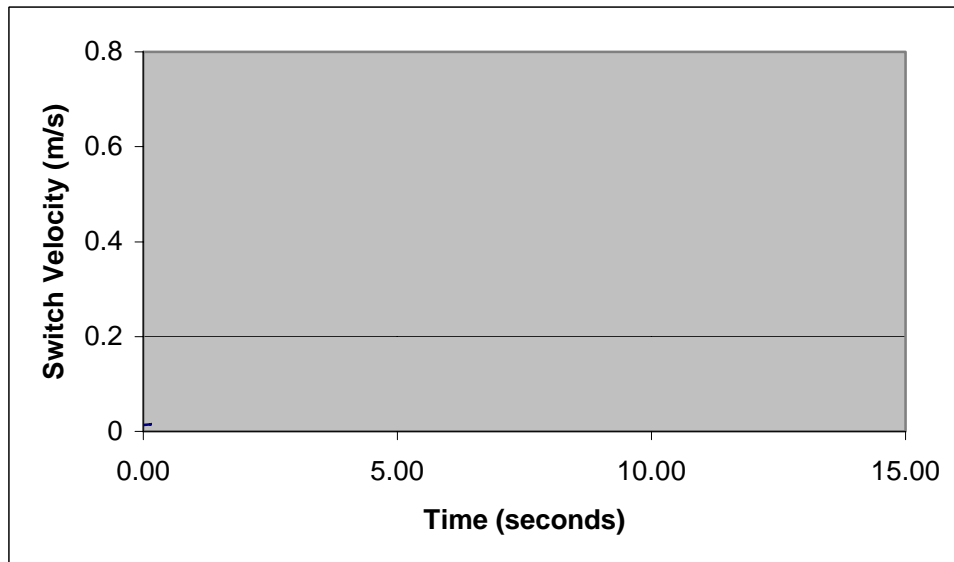
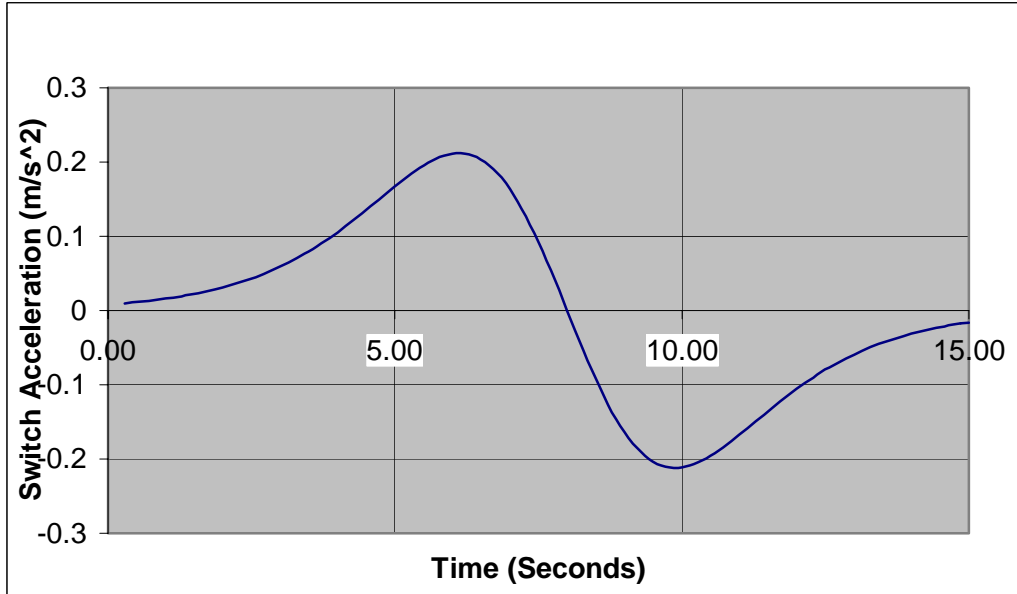
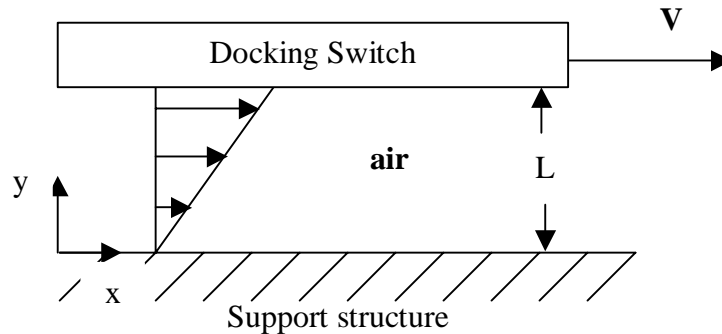


Figure 55: Switch Velocity vs. Time



**Figure 56: Switch Acceleration vs. Time**

Now consider the friction force  $F_{fr}$ . One way to analyze this is to treat the resulting flow system as a journal bearing or a Couette flow. Manufacturer's data indicate that the air pads will cause the switch to hover 13 mm above the support structure. If the switch is being translated laterally with a maximum velocity of 0.8 m/s, then it is similar to the Couette flow situation illustrated in Figure 57 below.



**Figure 57: Schematic used to estimate friction force due to lateral motion of the switch**

The friction force can be determined from the fluid (air) shear stress and the exposed area.

$$F_{fr} = \tau A$$

The area is assumed to be that associated with the air pads. The shear stress is given as

$$\tau = -\mu \frac{du}{dy}$$

For this situation

$$\tau = -\mu \frac{V}{L} = -\frac{(1.85 \times 10^{-5}) N \cdot s / m^2 (0.8) m / s}{(0.013) m} = -1.14 \times 10^{-3} Pa$$

$$F_{fr} = \tau N A_p = (1.14 \times 10^{-3}) N / m^2 (123) \pi / 4 (0.478)^2 m^2 = 2.6 \times 10^{-2} N = 5.86 \times 10^{-3} lbf$$

This is an insignificant force when compared with that required to overcome the switch inertia. Therefore, it will be neglected.

#### 7.8.4.2. Hydraulic Actuation

Hydraulic systems offer the best potential option for actuating the docking switch. Hydraulics provide a simple, robust and a well-known process. Another technique studied for this effort was to consider a combination of hydraulic cylinder with scissor linkage. This results in the need for a hydraulic cylinder of short stroke but with a larger force than that of hydraulic cylinders directly translating the docking switch.

After considering the scissor jack actuator and the added complexity introduced by the large number of joints and moving parts, it was decided that a straight hydraulic system would provide the simplest and most robust switch.

#### 7.8.4.3. Electric Motor with Cable Actuation

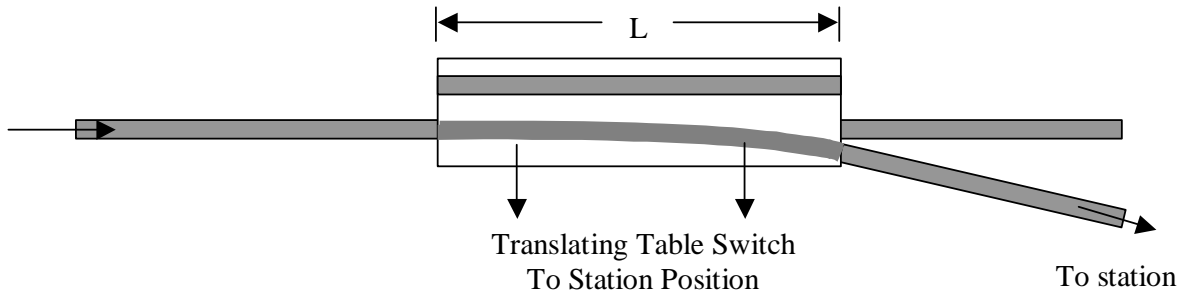
As shown in Figure 52, a rotary electric motor with a system of cables and pulleys can be incorporated to actuate the docking switch. However, with the snow and ice that may accumulate around the mountain stations, it is thought likely that this design may result in a costly maintenance item with the significant reliability requirements. On the other hand, much of the mechanism is likely to be protected from the elements due to its proximity to the station. Hence, consideration should be given to provision of this type of mechanism as a backup in case of hydraulic failure.

#### 7.8.4.4. Linear Induction Motor Actuation

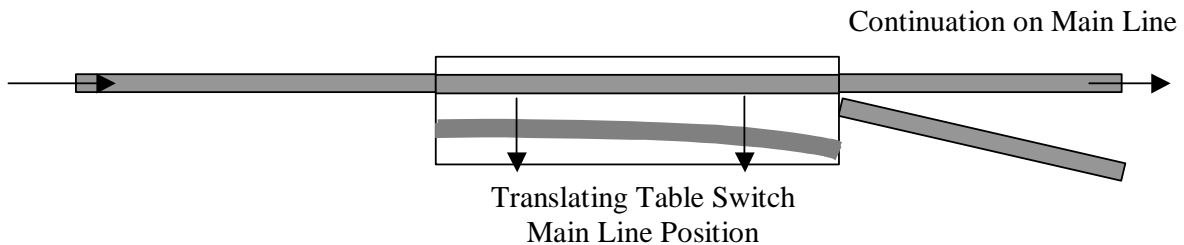
Linear Induction motors were investigated as docking switch actuators. However, off-the-shelf actuators could not be found that met the force and displacement requirements. It is not clear that a linear motor actuator would offer any benefit over other actuator types, even if feasible.

### 7.8.5. Translating Table High-Speed Switch

The translating table high-speed switch is conceptually similar to the docking switch, except that the moving table switch can accommodate a vehicle moving at high-speed. Figures 58 and 59 provide illustrations of two positions of the switch. The switch length would be a function of maximum vehicle speed. For a 160 km/hr maximum speed, the switch length should be 128 m. The mass of this switch is estimated to be 150,000 kg and the translation distance would be on the order of 4.5 m. If similar air bearings were used as suggested in the docking switch, then a similar but roughly doubled quantity of equipment (and cost) can be expected for the table itself. Additional cost of the deceleration and acceleration guideway lengths for all high-speed switches must be added to the switch costs at stations.



**Figure 58: Translating Table Switch in the "To Station" Position**



**Figure 59: Translating Table Switch in the "Continuation on Main Line" Position**

**7.8.6. Switch Summary**

The switch analysis has evaluated a number of standard guideway switches as well as the unconventional but effective docking switch. The preferred high-speed guideway switch selection is the segmented guideway pivoting switch.

The docking switch may be beneficial for use at stations where additional land may be at a premium, if available at all, and could be particularly useful for end-of-line and maintenance yard situations. In ordinary station use, the docks can provide distributed storage for surplus vehicle inventory during off-peak hours, and can contribute to potentially lower operating costs through vehicle positioning strategies similar to those used by airlines (reduced deadheading). When taken together with its potential for much higher reliability and lower maintenance demands, the docking switch is an attractive alternative for selective application.

**7.9. Special Bridge Sites**

The Colorado I-70 corridor offers a wide variety of site conditions and constraints that will influence the layout, design and construction cost of the maglev guideway structures. The range of factors that influence guideway cost have been presented previously as part of this study. In addition, conceptual designs with associated estimates of probable construction cost have been developed for a "standard" maglev guideway that is considered applicable to the relatively unconstrained site conditions of much of the I-70 corridor. However, given the variation in conditions and challenging terrain of the alignment, it is recognized that there are a number of locations where the standard guideway design will not be applicable. These "special" sites are the focus of the following section.

Based on a broad overview of the alignment, three specific locations have been selected as representative special sites. For each of these locations, a preliminary guideway layout has been completed to determine the effect on potential guideway span lengths and height. Based on the most complex of these, a conceptual guideway design has been prepared for quantity take-offs

and estimating of probable construction cost. When compared with the cost estimates for the standard guideway, this study provides a reasonable assessment of the incremental guideway cost premium for the special sites.

### 7.9.1. Selection of Special Guideway Site Locations

The route alignment for the maglev transit way along the I-70 corridor is typically located within the median area of the divided highway section. The profile grade of the guideway is anticipated to generally follow the highway profile, although it would be elevated to provide sufficient vertical clearance for existing or future highway lanes below the overhanging sections of the guideway superstructure members. The following types of crossings are all potential candidates for special guideway sites:

- Rivers
- Canyons
- Rail Yards
- Highway and Arterial Crossings and Interchanges
- Environmentally Sensitive Areas
- Heavily Skewed Crossings
- Tight Horizontal Curves

These types of crossings have the potential to require span lengths that exceed the capabilities of the standard guideway design. In addition, these types of crossings may require high profiles that compromise the economics of the standard guideway due to disproportionate substructure cost.

Based on a broad overview of corridor mapping and direct reconnaissance of the I-70 alignment, three special guideway sites were selected as discussed below:

#### 7.9.1.1. Special Site Number 1 – Rail Yard in Central Denver

I-70 crosses a rail yard in Central Denver that includes eight tracks. The distance between the outermost tracks measured along I-70 is approximately 88.5 m (290'). This site was selected because of the potential lack of available guideway support locations between the closely spaced tracks and the resulting need for long guideway spans.



At this location, I-70 is on a tangent alignment and crosses an eight-track rail yard on a contiguous overhead structure with the median area decked-over. The maglev alignment is anticipated to be running along the north side of I-70. Based on the layout of the tracks, it appears that there is a good chance that a guideway support column could be placed within the rail yard between two of the tracks that are widely spaced. The guideway would require a span of

about 60 m (200') over the five tracks to the west of this support. An adjacent span of similar length could span the remaining tracks and allow for additional space within the rail yard. The remainder of this special section of guideway would consist of 40.5 m (133') end spans to balance the frame.

The maglev guideway would have a vertical clearance of between 8 m (26') and 12 m (39'), which should be sufficient over the railway, while allowing clearance for temporary falsework beams required for cast-in-place construction. Also, falsework bents would be required between certain tracks.

#### 7.9.1.2. Special Site Number 2 – Highway Interchange in Western Suburbs of Denver

As I-70 passes through the City of Denver, it crosses over or under a multitude of surface arterials as well as numerous major highway corridors. Special Site No. 2 is located at a heavily skewed interchange where I-70 crosses over a major highway in the western suburbs of Denver. Because of the skew of the crossing and the potential lack of available guideway support locations, long guideway spans may be required.



I-70 at this location is divided by a wide, open median and crosses over U.S. 40 on a grade separation structure with a slight amount of horizontal curvature. It is anticipated that the maglev system guideway would be located within the median area and would be on an elevated profile with a vertical clearance of 5.1 m (16.7') from I-70 to the bottom of the guideway deck overhang.

It is possible that one or more guideway support columns could be located within U.S. 40; however, for the purposes of this study, a full span of U.S. 40 is assumed. This results in a central span length of 60 m (200'). Continuous, balancing end spans of 40.5 m (133') complete the frame for this special section of guideway. The guideway would provide a vertical clearance of about 10 m (33') over U.S. 40.

#### 7.9.1.3. Special Site Number 3 – River Crossing East of Vail

As I-70 negotiates the rugged mountain terrain, there are a number of locations where long guideway spans may be required to cross rivers or canyons. At Special Site No. 3, located east of Vail, I-70 follows the contours of a deep canyon and crosses a river on a heavy skew. Although it may be possible to place guideway supports within the main riverbed, there is the potential that a full span of the main active stream may be required to minimize environmental impacts and to avoid difficult construction conditions.



At Special Site No. 3, I-70 is on a gently curving alignment and crosses Gore Creek on a heavy skew. The highway is divided with an open median between the eastbound and westbound bridge structures over the creek. It is anticipated that the maglev guideway would be located in the median area between the highway bridges. Once again, the guideway may be elevated to provide clearance above the I-70 traveled way.

Considering environmental and water quality issues, and the challenges of construction within a live stream, it may be necessary to provide a full span of the guideway over Gore Creek at this site. Based on the Layout shown in Figure 60, a central span of 90 m (300') may be required to fully span the creek, considering the skew geometry. Continuous, balancing end spans of 60 m (200') each would complete the frame for this section of special guideway.

Depending on the profile grade of I-70, the guideway may be fairly tall at this site. The preliminary layout indicates a height of about 25 m (82') above the creek bed. In addition, the guideway may be on a steep grade approaching 7% at, or somewhat to the west of, this location.

### 7.9.2. **Special Guideway Structure Type Selection**

The maximum required guideway spans for the three special sites selected for this study range between 60 m (200') and 90 m (300'). For this range of span lengths, full-span precast girders, the least costly of the types studied for the standard guideway design, are not considered feasible because of physical limitations in transporting girders of this length and the difficulty of erecting girders of the required size and weight. Viable structure types for this span range include the following:

*Cast-in-place, Prestressed Concrete Box Girder Using Falsework* – This type is likely to be economical as long as ready-mixed concrete is available within a reasonable transport distance. Otherwise a portable concrete batch plant would be required, which would increase the construction cost. For spans of the length required, haunching of the box girder (using a deeper section at the supports and a thinner section at mid-span) is expected to result in reduced costs based on greater material efficiency.

Time-dependent deflections of cast-in-place concrete structures are a concern for use as a maglev guideway because of the strict alignment tolerances required. However, these effects can be mitigated through the use of additional prestressing. Haunching of the box girder also tends to reduce the deflection problem.

*Precast, Prestressed Segmental Concrete Box Girder* – This type is probably not economical because of the relatively small quantities involved with each special guideway site. Also, for the span lengths required, the segments near the supports would become very large and difficult to transport and erect.

*Cast-in-place, Prestressed Segmental Concrete Box Girder Using A Form Traveler* – This construction method would be selected only if falsework was not feasible. The form traveler itself is very expensive and construction using this method is very slow.

*Welded Steel Plate Girder* – This type could be an attractive option depending on availability and cost of the steel. Live load deflection criteria may result in very deep sections.

*Welded Steel Box Girder* – For the span lengths required, this type may offer advantages over the steel plate girder because of its superior torsional properties; however, fabrication is complex and expensive.

A detailed comparative type selection analysis considering all of these types has not been completed for this study. Since the cast-in-place concrete box girder is clearly a viable alternative and it offers a great deal of flexibility in terms of span lengths and adaptability to site conditions, it has been selected as the basis for cost comparisons with the standard guideway.

### 7.9.3. Preliminary Structural Design

For cost estimating purposes, a conceptual design has been developed for Special Site No. 3 based on the use of a cast-in-place, prestressed box girder structure type. The vehicular live loading and design criteria utilized for the special bridge design is the same as for the standard guideway design based on the CHSST 200 vehicle.

For preliminary design of the special guideway, the Service Load Design Method has been used to obtain a reasonable proportioning of members and for estimating material quantities. Aside from the specific criteria listed above, the AASHTO Standard Specifications for Highway Bridges were generally followed for design with the exception that no tensile stress in prestressed concrete was allowed under full design load in accordance with the AREMA specifications. These criteria results in the use of additional prestressing, which has the benefit of greater control of time-dependent deflections.

Conventional structural analysis methods were employed to determine maximum dead and live load moments and shears for preliminary design of the special guideway structural section. No detailed dynamic, vibrational or stress analysis has been performed at this stage since these factors are not expected to materially affect the basic superstructure design.

The prestressed concrete box girder section that supports both maglev tracks consists of a single cell with a width of 2,972 mm (9.75') to the outside faces of the webs. The deck slab cantilevers out on both sides of the box to provide a deck width of 5.33 m (17.5'). The maglev system rails are supported on transverse steel sleeper beams mounted on reinforced concrete plinths.

For the 90 m (300') span of Special Site No. 3, the box girder superstructure is haunched for greater material efficiency and to provide better control of deflections. The depth of the structure is 3.66 m (12.0') at mid-span and 5.49 m (18.0') at the supports. The preliminary design results are as follows:

<b>Design Parameter</b>	<b>Design Value</b>
Prestress Jacking Force:	8,730 kips
Required Concrete Compressive Strength:	4,450 psi
Live Load Deflection:	0.052m/0.17 foot



Initial Dead Load + Prestress Deflection: (L/1,734) 0.012m/0.04 foot

The deflection due to dead load plus prestress is very small, which indicates that the time-dependent deflection problem is mitigated effectively by the high prestressing force and the haunched box girder.

The design of the substructure is also very important and accounts for a large proportion of the overall cost of the guideway. The design of the special guideway utilizes single-column bents with 1.83 m (6.0') by 2.44 m (8.0') rectangular columns. For the purposes of this study, a single 2.44 m (96-inch) diameter drilled caisson was used for the foundation system. Although geologic conditions are expected to vary significantly at each special guideway site, this foundation type is likely to be workable for most conditions.

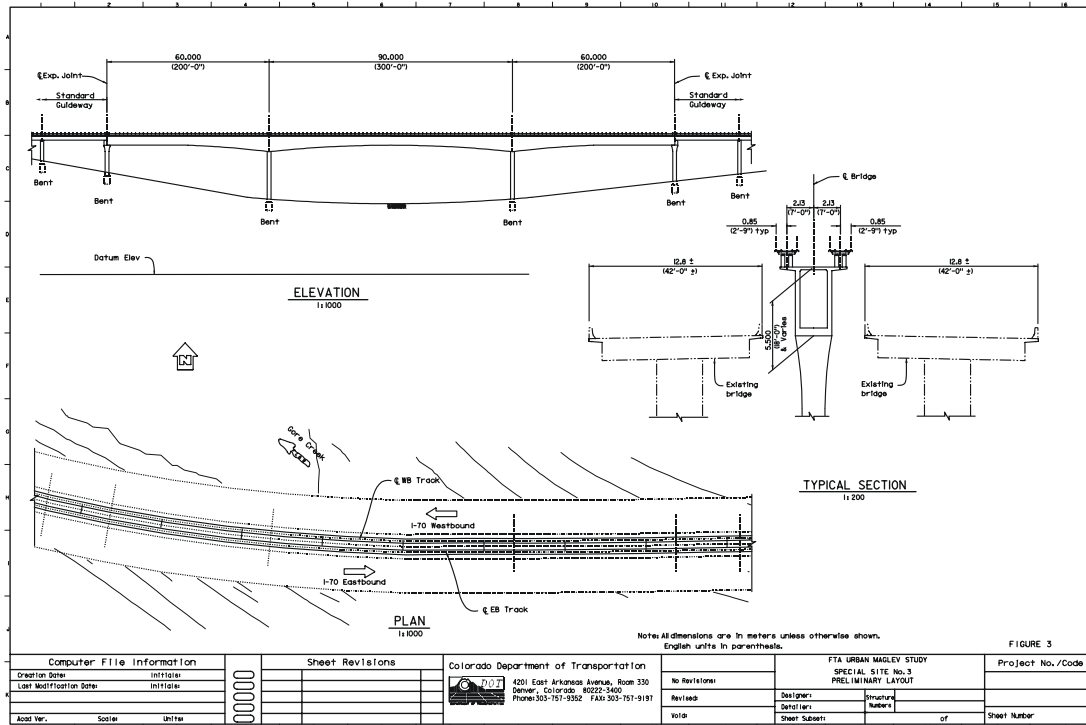


Figure 60: Special Guideway Site Number Three

7.10. DRAINAGE

Like any bridge structure, the accumulation of water on a maglev guideway, resulting from precipitation in the form of rain, snow, sleet or freezing rain, needs to be effectively controlled by means of positive drainage. Methods of controlling the flow of water and collecting and discharging it from structures are well established for highway, railroad and transit bridges. However, with the heavy snowfall and freeze-thaw conditions of the Colorado project, the issue of drainage control for a maglev system guideway requires special consideration.

7.10.1. Guideway Drainage Considerations

Following is a brief discussion of basic bridge drainage concepts:

7.10.1.1. Drainage Classifications

Drainage on structures is typically segregated into one of the following two classifications:

*Class I:* Locations where drainage must be carried by piping to a suitable disposal point. These usually include urban locations and crossings of railroads or highways, where it is not permissible or may be unsafe to allow drainage to free-fall to the ground below. Class I drainage requires disposal by either discharge at ground level adjacent to a gutter or other drainage facility, or piping underground to a catch basin or storm drain.

*Class II:* Locations where drainage may be disposed of by free-fall directly below the drain. These are usually rural locations where traffic or existing improvements would not be impacted by the drainage. However, these locations may be subject to storm water pollution regulations that do not permit direct runoff from the structure to enter a watercourse. Class II drainage is more economical than Class I since drain piping is not required.

For much of the Colorado I-70 corridor, Class I drainage is anticipated because of the portions within the Denver urban area and the sections within the I-70 right-of-way.

### 7.10.1.2. Drain Inlet Locations

Drain inlets are normally required at the following locations:

- At low points in a sag vertical curve;
- Near supports when deck grades are very flat;
- At locations of reversal of superelevation;
- Adjacent to deck expansion joints;
- Upslope of bent or abutment outlets to provide for maximum piping slope.

### 7.10.1.3. Drain Inlet Types

Various drain inlet types are employed to address specific drainage needs. The primary inlet types are described as follows:

*Grated Basin Drains:* This type is commonly used for bridge deck applications where a curb controls drainage and the inlet is placed in the path of flow or at a low point to intercept or collect the drainage. Grates are utilized to prevent debris from entering the basin and clogging the outlet and to provide a riding surface on top of the basin. These drains are primarily used for Class I drainage and are connected to a pipe that runs to the disposal point.

*Slotted Drains:* This type is only used to intercept sheet flow and can be placed either longitudinally or transversely.

*Drop-Through or Scupper Drains:* These types are for Class II drainage and may be furnished with or without a grate. Drop through drains are installed vertically in the surface carrying flow, while scuppers are horizontal openings through curbs that provide a path for drainage off the edge of the structure.



#### 7.10.1.4. Drainage Piping

Piping should generally be concealed to improve the appearance of the structure. Pipes can often be embedded within concrete deck slabs, routed inside or between the bridge girders and cast within columns for routing to the disposal point.

Some general guidelines for piping details include:

- Piping should be 150 mm (6") minimum diameter welded steel pipe with 3 mm (1/8") minimum wall thickness. 200 mm (8") diameter pipe is preferred for multiple inlets, flat slopes or runs over 15 m (50 ft) or more.
- Pipe runs should be on the maximum slope that conditions allow.
- Pipe runs should include a maximum of four inlets per run.
- Pipe bends should be smooth and on a 450 mm (18") minimum radius for 150 mm (6") pipe and 600 mm (24") minimum radius for 200 mm (8") pipe.

Expansion couplings must be used where piping crosses a bridge expansion joint. The use of cleanout openings must be considered carefully to avoid proving a "blind alley" for cleaning equipment.

#### 7.10.1.5. Drainage Design

Drainage design methods for controlling flow on bridge decks involve runoff analysis using the Rational Method, inlet capacity analysis (considering debris accumulation) as a weir or an orifice, and flow width in gutters using a modified version of the Manning Equation. Given the average rainfall intensity and based on a specific criterion for the amount of flow allowed to accumulate, the required spacing of inlets can easily be computed.

#### 7.10.1.6. Freezing Conditions

Freezing conditions are commonly encountered on highway and transit structure facilities in much of the United States. Although the conditions along I-70 in Colorado are severe, the issues of freezing related to drainage are basically the same. By necessity, snow and ice accumulations must be controlled to allow for reasonably safe operations. In certain mountain pass areas, this may not be feasible and the facility may need to be closed for the winter. However, given the mission of the I-70 corridor project this will not be acceptable for a maglev transit system, except possibly during periods of extreme storm events.

The general philosophy for drainage design is that positive drainage is not required when the drainage is frozen and no flow is occurring. When the drainage begins to thaw and flow, the drains will begin to work. Drain piping is typically large enough to prevent plugging due to ice accumulation. If necessary, oversized drain pipes can be employed to help mitigate the possibility of ice plugging.

For the maglev system guideway, snow and ice accumulations will need to be controlled by use of special removal equipment or by duty cycling of the vehicles. It is possible that resistance wire heating elements could be used for the rails to control ice accumulations intermittently when required.

### 7.10.2. Structure Drainage Characteristics

The issue of drainage control depends on the configuration of the guideway structure and how precipitation will accumulate and flow on the structure. Following is a discussion of the drainage characteristics of the four guideway structure concepts that have been proposed as part of this study.

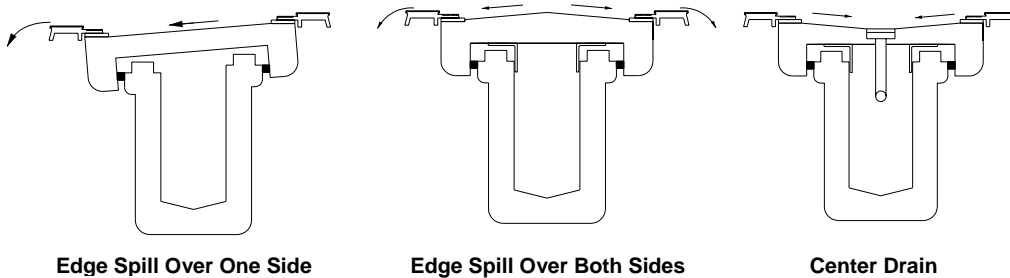
**7.10.2.1. Precast, Prestressed Concrete U-Girder & Welded Steel Box Girder with Composite Concrete Deck**

The width of deck that will accumulate precipitation of an individual guideway is only about 2 m (6.5 ft). As such, there is very little area to generate drainage. The methods for controlling drainage for this alternative may consist of the following approaches:

*Edge Spill Over (Class II):* Since the volume of flow along the structure is expected to be very small, it may be permissible to allow the drainage to simply spill over the edge of the deck, across the rails. This could be accomplished by providing a small (1.5%) superelevation in the deck so that the water flows over one side. Alternatively, the deck could be crowned so the drainage is reduced by 50% and the flow spills over both edges. The volume of edge spill over would need to be checked to ensure that it would not interfere with the function of the rails. Also, the effect of edge spill over onto existing facilities below would need to be acceptable.

*Center Drain (Class I):* The guideway deck could be sloped to the center in a “V” configuration so that drainage could be routed to a grated basin inlet at the low end of each span and piped down the column to a disposal point. Alternatively, a slotted drain could be placed along the center of the deck at the bottom of the “V” to intercept flow and convey it to an outlet pipe.

*Drop Through (Class II):* This could be done in the same ways as the center drain, except the flow could be dropped from the deck to the ground in areas where this is permissible.



**7.10.2.2. Tubular Steel Space Truss**

This alternative has major advantages in terms of drainage and snow accumulation. As a result of the open truss design, there are no surfaces for precipitation to accumulate and flow, so drainage issues and snow removal problems are effectively eliminated.

**7.10.2.3. Cast-In-Place, Prestressed Concrete Box Girder (Special Bridge Sites)**

The concept proposed for the special bridge sites carries both tracks on one structure with the rails mounted on sleeper beams that are in turn supported by concrete plinths. This guideway design has a greater deck width and more surface area for precipitation to accumulate.

The drainage options would be similar to the precast and steel box girder types. Scuppers could be provided through the plinths for the spill over option.

As discussed above, Class I drainage is likely to be required at many locations along the I-70 corridor. Thus, the center drain concept is probably the most suitable as a standard drainage system for the maglev system guideway. Deck drainage computations have been performed to confirm the feasibility of the center drain system for the standard box girder guideway alternatives. The quantity of flow (Q) collected over the length of one span for a rainfall intensity of 127 mm (5”) per hour is 0.00175 cubic meters per second (0.0618 cubic feet per second). For this Q, a single grated drain inlet with plan dimensions of 425mm (16.75”) x 425mm (16.75”) will be sufficient.

### 7.10.3. **Switches**

The concept that has been developed as part of this study for switching, which consists of pivoting segments of guideway, is largely insensitive to issues related to drainage and freezing. The roller bearings ride on rails that are elevated to minimize such problems and the crank arm guide pin is on the underside of the superstructure where it is protected. The motors will be exposed so they will need to be weatherproof.

Drainage and snow and ice control will be an important design consideration to ensure safe and reliable operation of a maglev transit system in the Colorado I-70 environment. Based on the results of this evaluation, conventional bridge drainage solutions are expected to be effective in this application. For all guideway alternatives studied, with the exception of the tubular steel space truss, snow will need to be removed from the guideway structure using special equipment.

For the box girder guideway types, a center drain system with piping down the columns is likely to be the most suitable for the majority of the alignment. This type of system will have an insignificant affect on the overall cost of the guideway structure, considering the precision of estimates at this stage and the magnitude of the contingency factor applied.

The tubular steel space truss guideway alternative requires no drainage system or snow removal operations due to its open design. This advantage over the other standard guideway types may provide sufficient justification to recommend it over the box girder types despite the higher initial construction cost.

## 7.11. **EMERGENCY EGRESS**

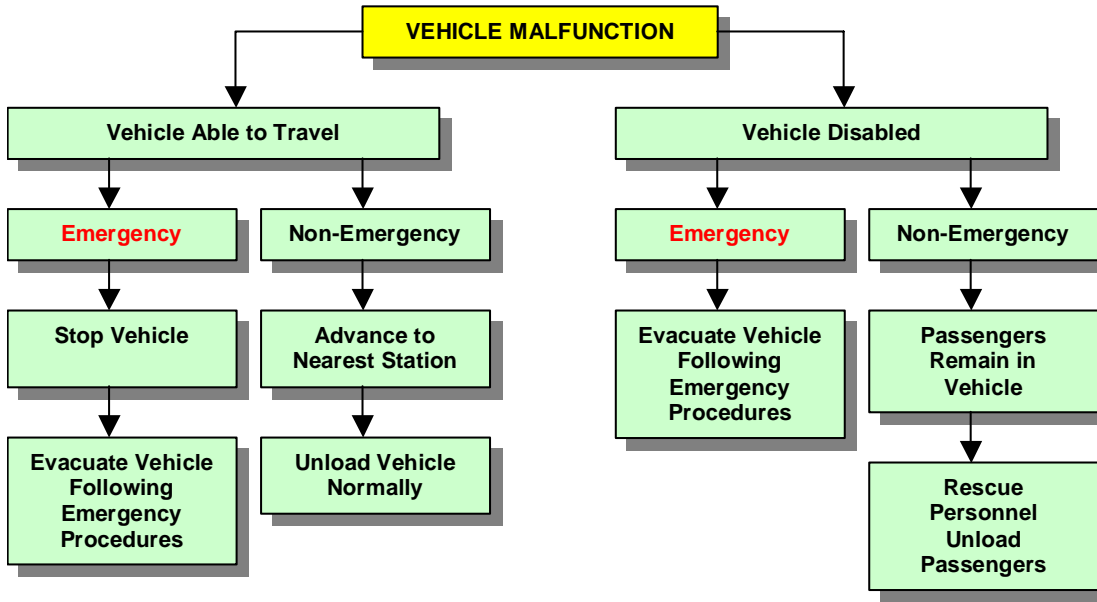
Maglev transit system technologies have been developed with passenger safety as a central design objective. Because these systems are entirely electrical with no highly combustible materials aboard the vehicle, the risk of an accidental emergency situation that could threaten the safety of the passengers is considered minimal. However, the high safety standards for transportation systems within the United States require consideration of provisions for evacuation of passengers from the vehicle of a maglev transit system in an emergency situation with the vehicle stopped between stations. This section explores the issue of emergency egress and presents several guideway modifications that could provide a safe evacuation route for passengers.

### 7.11.1. **Unscheduled Vehicle Unloading Situations**

Normal unloading of a maglev transit system would occur during scheduled stops at station platforms. Unloading at scheduled stops will follow normal operating procedures. However, there are any number of situations that may be anticipated that would require maglev vehicles to be unloaded following unscheduled stops that may occur at locations between stations. Unscheduled stops may involve emergency situations that require rapid evacuation of the vehicle.

A fire of some kind on the vehicle would be the primary emergency situation that would require rapid evacuation. Fire could originate from the electrical levitation and propulsion equipment or could be initiated by passengers within the vehicle. The presence of smoke and flame would likely necessitate immediate evacuation to minimize the likelihood of passenger injury or death.

A vehicle may become stranded on the guideway between stations for other reasons that do not pose an emergency. In this type of situation, there would be several options for accommodating the passengers. They could remain aboard the vehicle while it is towed to the nearest station prior to being removed for repair. Alternatively, the passengers could utilize the emergency evacuation systems or wait for assistance from rescue personnel and equipment. It is likely that most of the maglev system guideway would be accessible by fire trucks or other equipment that could be used to remove passengers. The flowchart below illustrates how unscheduled unloading would be accomplished depending on the vehicle malfunction situation.



### 7.11.2. **Emergency Vehicle Evacuation Procedures**

Provisions for helping to ensure the safety of passengers of a disabled maglev vehicle in an emergency could be based on one of the following three concepts:

- Safety/evacuation system incorporated into the vehicle
- Evacuation walkway provided along the guideway
- A combination of vehicle system and guideway walkways

The approach to be taken will depend on relative reliability and cost. Concepts for both vehicle and guideway systems are discussed in the sections below.

### 7.11.3. **Vehicle Systems**

If the safety/evacuation system can be incorporated into the vehicle itself, the cost of providing an evacuation route along the entire length of the guideway might be avoided. However, some vehicle systems may add excessive weight that could reduce operational performance. If the vehicle system is complex, transit property personnel may be required aboard the vehicle to assist passengers with safety system operation/deployment. Nonetheless, the following concepts for vehicle systems could be considered.

#### 7.11.3.1. **Aircraft-Style Inflatable Slides**

Inflatable slides are used on commercial aircraft to transfer evacuating passengers from the cabin to the ground. Manufacturers include BF Goodrich Aerospace and the Zodiac Group. These units consist of an inflatable structure (slide), a reservoir of compressed gas, the inflation system (aspirator and hoses) and the aircraft interface. Large slides that would be needed for a maglev vehicle are very expensive and require high maintenance.



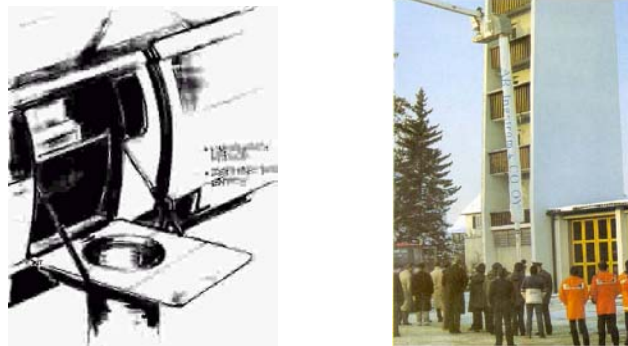
**Figure 61: Inflatable Slide**

On an aircraft, the slides are typically housed in the cabin door structure or in a space below the deck under the door. The space required to house the units may make them difficult to incorporate into a maglev vehicle. They would also add significant weight, which would be undesirable.

The geometry of the slide is designed to control the decent of the passengers. The floor of the maglev vehicle would typically be located about 7.6 m (25') above the ground. To provide the proper geometry, the deployed slide normal to the centerline of the guideway would need to extend at least a similar distance horizontally. At many locations, sufficient space within the median of I-70 may not be available. In addition, the guideway may be elevated well beyond 7.6 m (25') at many locations, rendering the slide infeasible.

#### 7.11.3.2. Tubular Chutes

Tubular chutes have been proposed for evacuation of people from buildings and transit vehicles. The friction of the sides of the elastic chute material controls the descent speed. Although this system has been shown to work, it can be dangerous if more than one person uses it at the same time. It would also be relatively slow and would be limited by the height of the guideway similar to the inflatable slide.



**Figure 62: Tubular Chute**

#### 7.11.3.3. Extension Ladders

The use of extension ladders that could be deployed downward to the ground from the vehicle are not considered feasible since they would be very slow and difficult for passengers to use. They would also be limited by the height of the guideway.

#### 7.11.3.4. Use of Adjacent Vehicle

Passengers could be transferred from the distressed car of a multi-car consist to an adjacent car. The distressed car could be decoupled and the remainder of the consist could proceed to the

nearest station. Assuming that the design of the maglev vehicles could accommodate this approach, it would be a reliable and economical solution.

#### **7.11.3.5. Fire-Suppression Equipment**

The materials of the maglev vehicle will be required to meet stringent combustibility criterion to minimize the danger of smoke and flames from a fire. The most likely source of a serious fire would be the electrical equipment for the levitation and propulsion system. These units could be equipped with fire extinguishing systems designed to stop the spread of fire to the remainder of the vehicle. This equipment would be subject to reliability issues and would add weight to the vehicle.

#### **7.11.4. Guideway Systems**

The alternative to equipping the vehicle to provide emergency safety capability is to provide walkway capacity along the guideway for evacuating passengers to proceed longitudinally to a stairway down to the ground. Since the need for emergency egress is expected to be very infrequent, only a small fraction of a guideway evacuation walkway would ever be pressed into service. However, this may be the safest and most reliable means of ensuring passenger safety in the event of an emergency on the train.

The Japanese Chubu-CHSST vehicle is designed to wrap around the outside of the trackwork and the single guideway support beam. As such, safety railings cannot be attached along the edges of the guideway beam. This renders the guideway beam itself unsuitable as an emergency walkway. Thus, the emergency walkway would need to be supported adjacent to the guideway beams. Locating the walkway between the two guideway beams would allow a single walkway to be used by either train.

Following is a discussion of several concepts for providing an adjacent walkway for emergency egress.

##### **7.11.4.1. Double-Track Guideway Structure**

A guideway cross-section was presented for the special guideway sites that carried both track directions on one full-width structure. This design provides an opportunity to provide an emergency walkway on the guideway deck between the two maglev tracks. Because of the long spans of the special guideway sites, cast-in-place concrete box girder construction was selected for those locations. However, for the modest spans of the standard guideway sections, precast girders could be utilized that likely offer cost savings due to the repetition involved.

Since the guideway deck is located well below the floor of the vehicles, a deployable stair or slide would need to be provided in the vehicle to transfer passengers to the walkway.

##### **7.11.4.2. Separated Walkway Beam**

If the dual mono-beam guideway concept is maintained, a third beam could be located in between to support the emergency guideway. This beam could consist of a precast concrete box girder with a safety railing mounted along both sides. The safety railing would require hinged rails that could be manually released to allow passage within any panel of the railing. Other types of beams such as composite steel box girders or tubular steel space trusses could be adapted for the walkway as well. The beam would be designed for a pedestrian loading of 416 kilograms per square meter (85 pounds per square foot).

The separated walkway beam could be located at the floor level of the vehicle so that a stair or ladder would not be required to provide access from the vehicle to the walkway. Snow removal may be required to provide a safe walking surface.



In order to provide space for the walkway beam the center-to-center spacing of the tracks would need to be increased by approximately 0.8 meters (2.7 feet).

**7.11.4.3. Metal Grate Supported On Guideway Beams**

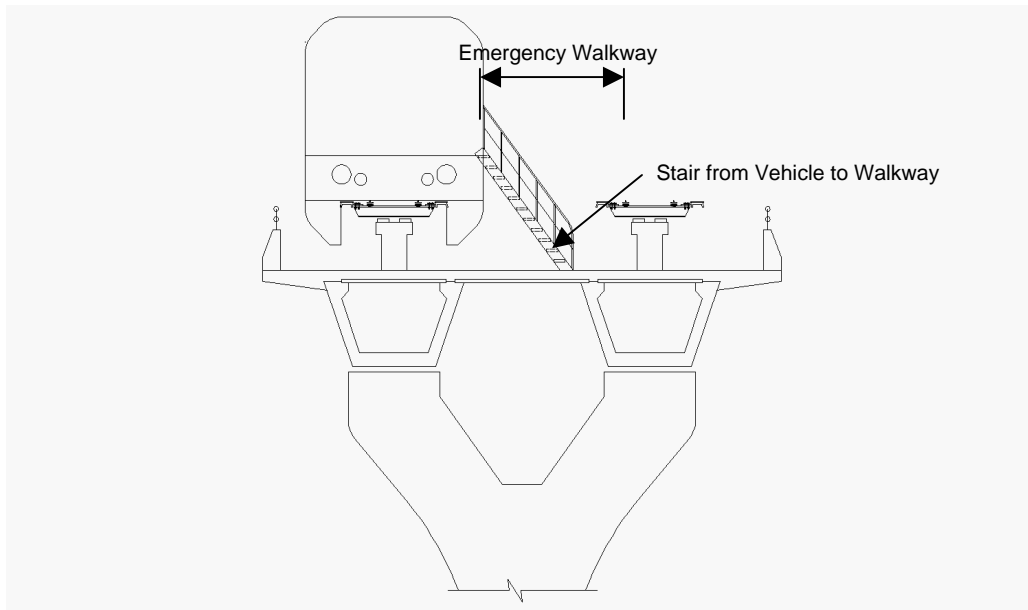
A simple and economical solution for the emergency walkway would be to install welded metal grate panels between the lower sections of the inside of the guideway beams. The guideway beams would support the grate panels, which would span transversely. Since the grate panels would need to be located below the level of the rails, a ladder or stair would be required down to the emergency walkway from the vehicle. The metal grate would be designed for the same pedestrian loading as the separated walkway beam. The metal grate panels may require removal of accumulated snow and ice.

**7.11.4.4. Transfer from the Emergency Walkway to Ground Level**

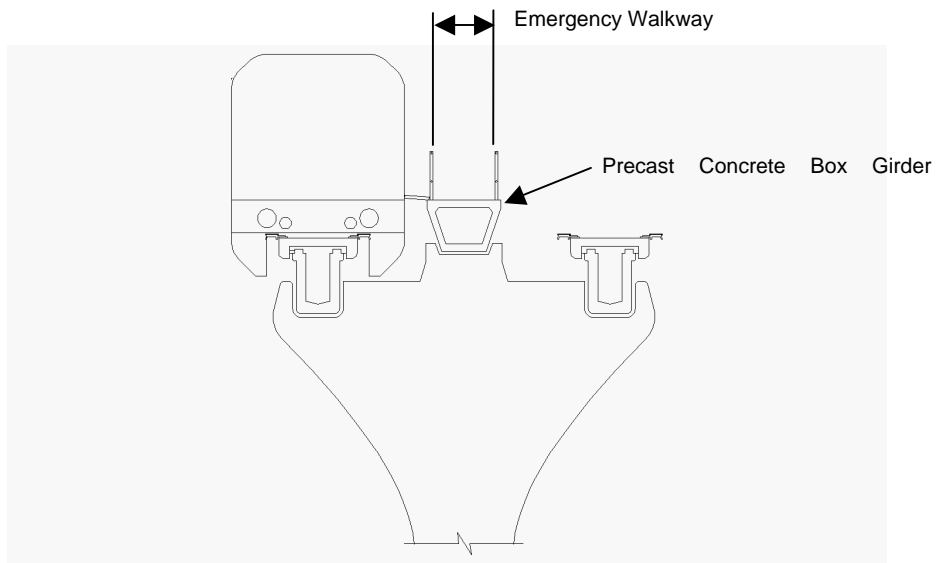
A means will be required to transfer passengers from the emergency walkway to the ground unless rescue vehicles are used to remove passengers from the walkway. The proposed method of egress from the emergency walkway is a pair of hinged stairways located within one guideway span where the walkway beam would be discontinuous.

The stairways would be hinged at the end of the walkway beam and would be attached to dampers that would control the lowering of the stair. The passengers would need to activate a manual release mechanism and then the stair would lower by gravity, slowed by the dampers.

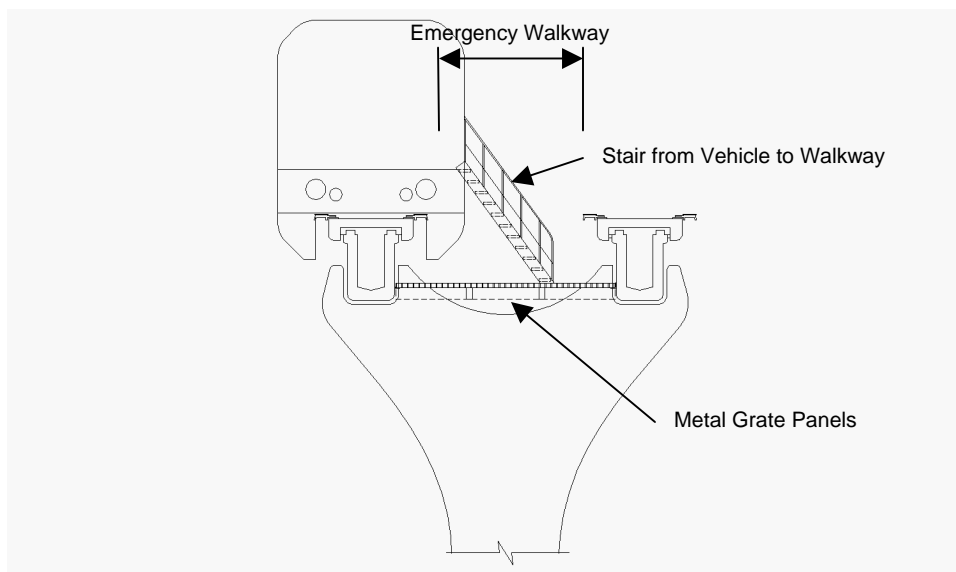
The stairways would need to be located at intervals that are a reasonable walking distance. An interval of 0.40 kilometers (¼ mile) has been assumed for cost estimating purposes. Signs would be mounted on the emergency walkway that direct passengers to the stairways and indicate the distance from their present location.



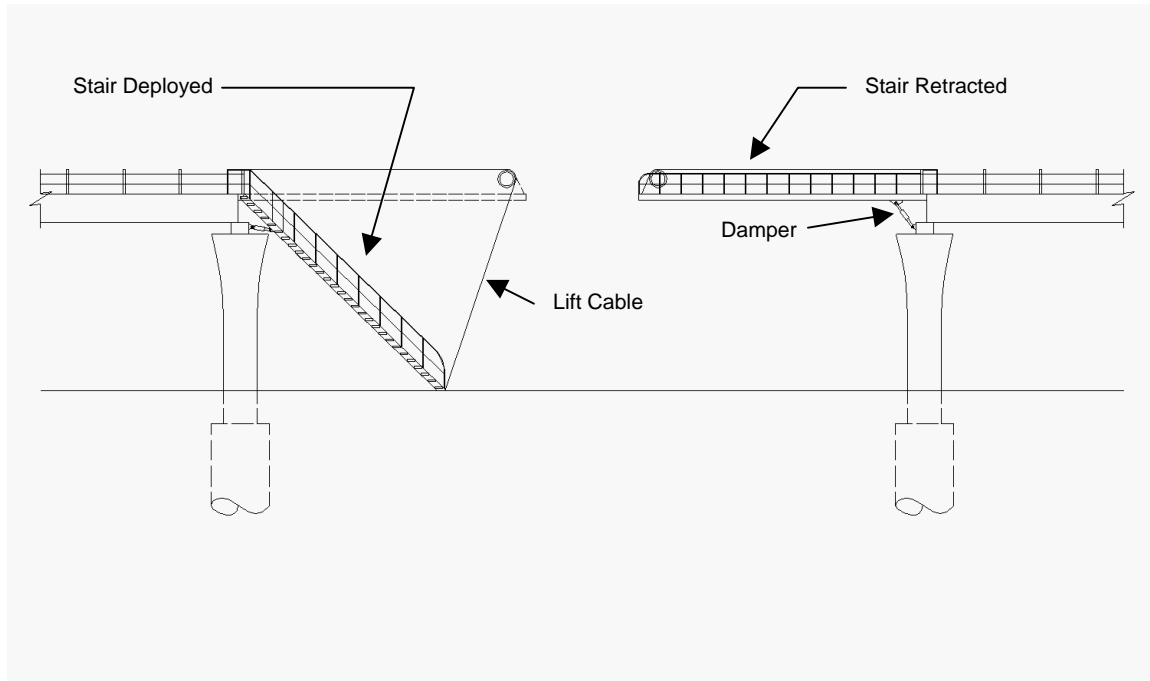
**Figure 63: Double-Track Guideway**



**Figure 64: Separated Walkway Beam**



**Figure 65: Metal Grate Panels**



**Figure 66: Stairs from Emergency Walkway to Ground**

## 7.12. AVALANCHE PROTECTION

The maglev system guideway will run continuously along the I-70 corridor and will traverse locations of known avalanche activity. Depending on the specific site conditions and guideway location within the I-70 cross-section, the lateral forces generated by an avalanche may be too large for the maglev system guideway to resist. In avalanche locations, protective measures may be required to protect the guideway and minimize safety issues for passengers.

### 7.12.1. Types of Avalanches

Avalanches can be described as wet or dry, and also as either loose snow or as a snow slab. Loose snow avalanches result from a surface failure of the snow itself. The avalanche tends to start in a small area and spread out as it descends the mountainside. This is due to the lack of cohesion necessary to form layers. Extreme cold and low wind can prevent dry snow from forming layers. Wet loose avalanches result from melting snow or rain, which results in high water-ice moisture contents.

Slab avalanches have a deep failure mechanism and typically have starting zone slopes of 25 to 55 degrees. A slab avalanche (which may be wet or dry) results when there is a layer of snow bonded together that is supported by a weaker layer that becomes a failure plane. For a dry slab avalanche, the failure plane is a weak, cohesionless layer of dry snow. Slabs can vary in depth by 0.3 to 1.0 m (1 to 3 feet). Wet slab avalanches result from a layer of very moist snow, either from snowmelt or rain that forms beneath the slab. Dry slab avalanches often develop into powder avalanches or a combination of the two, as the denser slab material down low churns up more and more dry snow, and the slab material disintegrates due to frictional forces. Wet slab avalanches do not tend to stir up much powder and tend to follow more fluid like paths such as channels and gullies.

### 7.12.2. Avalanche Path

The avalanche path is described in three parts. Avalanches begin in a region called the starting zone. Typically, this region is relatively steep and is located near the mountain crest, although it

can also occur wherever there are discontinuities in the path (i.e. rock faces, tree lines, etc.). An avalanche accelerates up to its maximum velocity throughout the length of the starting zone, where it then reaches the track. In the track, the avalanche maintains its maximum velocity and is no longer accelerating. In this region the avalanche can continue to grow, gathering more and more material. Finally the avalanche reaches the run-out zone, begins decelerating, and decreases in size as more and more debris is left behind until the avalanche comes to rest.

### 7.12.3. **Avalanche Dynamics**

The dynamics of an avalanche are very complex. To a certain extent, an avalanche can be comparable to a fluid, and fluid dynamics equations can apply. In reality, an avalanche is comprised of materials varying in densities and speeds. During avalanche flow, the density can also continuously be changing as frictional forces wear down larger blocks of snow, and any additional concentrations of solid material such as trees, rocks, and ice that are swept up in its path. For this reason, prediction of an impact loading is complicated. First the terrain must be analyzed. Besides the slope, the terrain can be anywhere from smooth and open, to rough and channelized. Secondly, the depth and densities of snow along the path must be determined. Both of which are highly dependent on the amount of snowfall along the path, the terrain, and existing weather conditions. Different types of modeling techniques can then determine avalanche velocities. These techniques take into account the inertial, frictional, and velocity dependent regimes that an avalanche can experience throughout its path. Even today, modeling techniques can only loosely determine actual avalanche dynamics.

### 7.12.4. **Impact Loads**

The actual impact load on a structure is dependent on the velocity and density of an avalanche. For simplicity, two equations can be used for determining the impact load. For fluid-like impacts, the fluid-dynamic stagnation pressure can be used. The standard equation for impact pressure is the following:

$$P = \frac{\rho V^2}{2g} \quad (\text{U.S.})$$

Alternately, avalanches also involve non fluid-like impacts and will not flow around an object, but will be brought to rest against it. This can be found in slower speed, more dense impacts. The impact pressure is then simply:

$$P = \frac{\rho V^2}{g} \quad (\text{U.S.})$$

In both of the above equations, P is the impact pressure in pounds per square foot,  $\rho$  is the avalanche density in pounds per cubic foot, V is the velocity in feet per second, and g is the gravitational constant 32.2 feet per second squared. Also, a variation between the two equations may be required to determine the impact load.

Avalanche impact loading can come from one or a combination of forms. The first type of impact is an air blast. This results from an air pressure wave that is running ahead of an incoming avalanche. Impact loads are between 20 to 100 pounds per square foot (1 to 5 kpa).

Powder avalanches typically can cause impacts reaching up to 2,000 pounds per square foot (100 kpa) or more. Although powder avalanches are very fast moving, they have low densities resulting in lower impact loads. Flow densities are typically around 0.6 pounds per cubic foot (10 kg/m<sup>3</sup>), although they can vary from 0.1 to 2.0 pounds per cubic foot (2 to 30 kg/m<sup>3</sup>) and speeds can range from 80 to 300 feet per second (25 to 90 m/s) depending on the size of the avalanche.

Wet snow avalanches can cause impacts that may range up to 4,000 pounds per square foot (200 kpa) or more. Densities range from 15 to 30 pounds per cubic foot (250 to 500 kg/m<sup>3</sup>). Maximum velocities can range from 30 to 100 feet per second (10 to 35 m/s). Dry snow avalanches can be relatively high speed and dense at the same time. Densities are typically 10

to 13 pounds per cubic foot (150 to 200 kg/m<sup>3</sup>), although they can be as high as 20 pounds per cubic foot (300 kg/m<sup>3</sup>). Speeds can vary from 80 to 300 feet per second (25 to 90 m/s) depending on avalanche size. Impacts from dry flowing avalanches are by far the most destructive and can cause upwards of 20,000 pounds per square foot loads upon impact.

#### **7.12.5. Avalanche Control Methods**

Mobile control techniques usually consist of artificially starting smaller, controllable avalanches to prevent the likelihood of larger devastating avalanche conditions from ever happening. This requires the continued surveillance of avalanche prone areas and determining when to take action. Typically explosives are used to start an avalanche. The charges can be placed by hand, dropped from helicopters, or by use of artillery cannons.

Static control methods consist of diverting and controlling the flow of an avalanche by the way of dams, channels, earthen mounds, deflectors, tree-establishment or the like. In the state of Colorado, static control methods are rarely used.

#### **7.12.6. Avalanches and the I-70 Corridor**

According to the Colorado Avalanche Information Center/Colorado Department of Transportation Avalanche Atlas, there are three avalanche areas designated along the I-70 maglev system corridor: Vail Pass, Tenmile Canyon, and Georgetown to Frisco. All three areas contain avalanche paths with run-out zones that cross I-70.

*I-70 Vail Pass* - Two documented avalanche paths at I-70 mileposts 183.0 and 187.3 are contained in this area. Avalanches have occurred at both paths that either reach or cross I-70. Avalanche activity affecting I-70 ranges from 0.02 to 2.00 events per year; 0.8 km (0.5 miles) of total length of roadway can be affected. In recent times, avalanche debris covering I-70 has been between four and seven feet in depth. Mobile control methods such as helicopter-bombing and hand charges are currently used here to control avalanches.

*I-70 Tenmile Canyon* - This area extends from Frisco to just a few miles west. Twenty-five documented avalanche paths are found in this area, from I-70 mileposts 195.3 to 200.8. The majority of these paths cross I-70, and avalanche activity affecting I-70 ranges from 0.02 to 0.04 events per year. The total length of affected roadway is about 2.9 km (1.8 miles). In the past, avalanche debris has covered I-70 up to 15 m (50 feet) in depth in this area, but with the modern avalanche control methods that are presently used such as helicopter bombing, roadway coverage has been significantly decreased to a depth of around 1.5 m (5 feet). Helicopter bombing is the typical control method used in this area.

*I-70 Georgetown to Frisco* - This area reaches from just west of the Eisenhower Memorial Tunnel east to Georgetown. This area contains twenty-eight avalanche paths from I-70 mileposts 211.4 to 226.6. Almost all of these paths reach or cross I-70, and the total length of affected roadway is approximately 2.9 km (1.8 miles). Avalanche activity affecting I-70 ranges from 0.03 to 0.20 events per year. I-70 has been covered by 1.0 to 2.5 m (3 to 8 feet) of avalanche debris in recent times. Current methods of control are primarily helicopter bombing and "Avalauncher" stabilization.

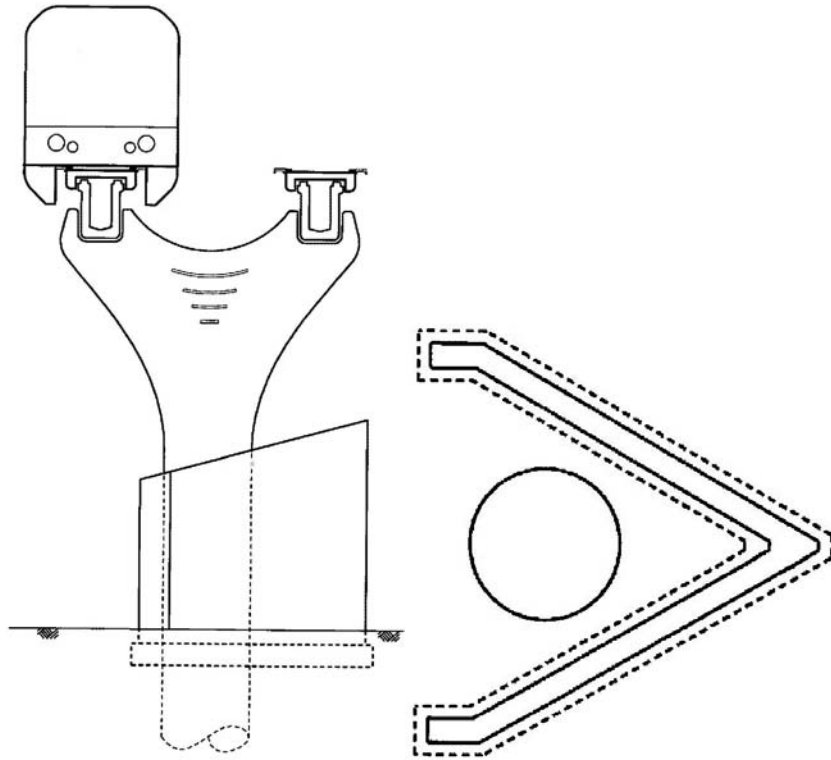
#### **7.12.7. Avalanches and the Guideway Structure**

Location of any structures in an avalanche zone must be closely scrutinized. For the most part, the proposed guideway structure follows the median of I-70 and is located in the run-out zone of an avalanche path. Typically, guideway columns running down the middle, or alongside of I-70 would be able to withstand most, if not all of the incoming avalanches. The resulting impact forces can easily be accommodated into the column design. It is critical, however, that the superstructure remains above the impact area, and that the brunt of the impact force is taken by the supporting columns.

### 7.12.7.1. Avalanche Fenders

Wherever the typical guideway columns are incapable of withstanding an avalanche impact, the use of a splitter or fender may be used (see Figure 67). This structure would probably be required further up the mountainsides where the guideway travels through the track or starting zone of an avalanche path. The fender is placed immediately adjacent to the column, and will split and deflect the incoming avalanche. This leaves the remaining upper part of the guideway structure susceptible only to powder impact forces, which are significantly lower, and can be accommodated into the structural design. The fender is inexpensive and would be used on a case-by-case basis. Alternately, the column itself can be formed into the shape of a fender for a similar effect.

Additionally the fender could also be used for rockfalls. The fender is designed using impact forces be it from an avalanche or a rockfall. The fender design can easily be configured for force impacts from rockfalls as well as avalanches.

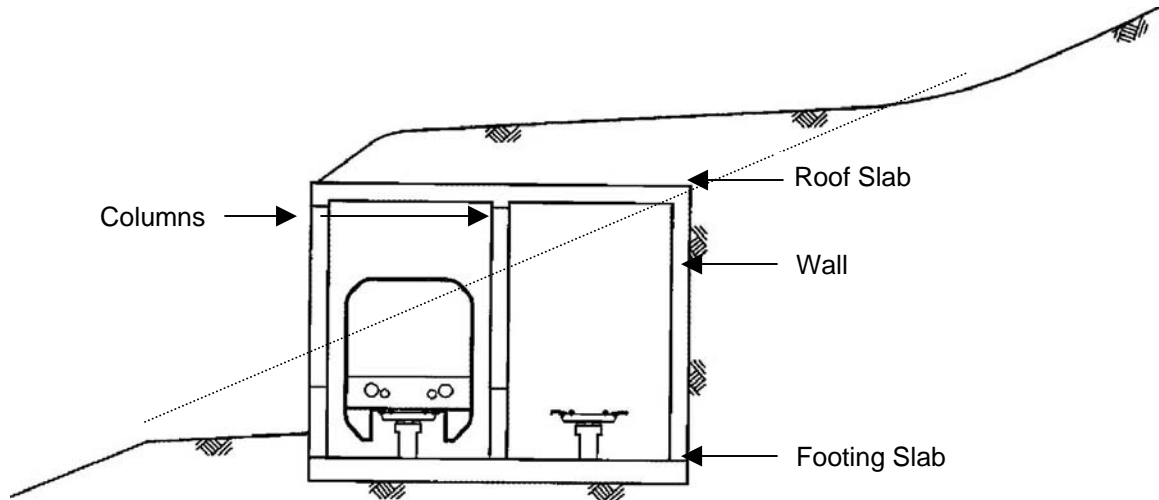


**Figure 67: Avalanche Fender**

### 7.12.7.2. Snow Shed

At any location where the superstructure cannot be located clear of potential avalanches (i.e. adjacent to a nearby mountainside), a structure such as a snow shed or cut and cover tunnel should be used (see Figure 68). This will be the case when the structure is located away from I-70, and up in the mountainsides. This structure is capable of completely shielding the guideway from avalanche activity. The structure is comprised completely of reinforced concrete, and is made up of a slab on grade with three parallel bearing walls that support the roof structure. The middle and outside walls will be open to provide ventilation and views to the outside from the guideway. Construction requires benching the structure into the side of the mountain. Material that is excavated is placed on top of the structure to help re-form the avalanche path. The goal is to ease the incoming avalanche over the structure, so the backfill should gradually meet the original slope with no sharp changes in slope occurring immediately above the structure.

Typically the structure is completely self-supporting; however, existing site conditions may require parts of this structure to extend beyond the bench cut requiring the use of supporting columns and caissons.



**Figure 68: Snow Shed**

For the reasons stated above, the location of the guideway structure greatly influences the type of design loading that can be encountered, and the type of protection that may be required. Due to the complex nature of avalanches, and the lack of standardized design practices, it is highly recommended that the recommendations of local avalanche experts be sought when determining the final guideway alignment, and also when beginning structural design of the guideway. An experienced person in this field through the use of current analysis methods would be able to provide recommendations when dealing with each of the many avalanche paths that the guideway structure will encounter throughout the I-70 corridor.

#### 7.12.8. **Guideway Constructability**

Substantial effort has been devoted to guideway materials review and analysis. Although guideway development in Europe and Asia has produced workable guideway solutions guideway cost optimization is still not complete. In particular, lowered cost guideways intended to meet the civil structures lifetime requirements, while preserving acceptable maintenance profiles, still require development.

The primary issue in maglev system guideway structural design is deflection. The weight of the vehicles compared to the guideway structural weight is such that the designer must primarily search for a way to produce a lightweight, stiff structure at minimum cost. This search naturally leads into lightweight steel structures, since steel is roughly three times stiffer than alternative metals. Concrete solutions, although cost effective, have other issues including weight, creep, and operational limitations (potential snow and ice buildup) in harsh environmental conditions.

The results of this analysis have pointed to tubular steel space frame trusses as the guideway system most likely to satisfy all the system requirements in Colorado. Structurally, this design is the most economical in its use of materials, with a ratio of strength to weight higher than that of any alternative structure. The integration effort has focused on a thorough examination of the cost issues associated with this result, since the initial cost of this type of structure may potentially be slightly higher than the costs of concrete or steel box beam structures used to achieve the same result.

The guideway analysis effort has:

1. identified viable suppliers of the materials for construction of these trusses;
2. sought the advice and processes of fabricators who could assemble these materials into trusses for both straight and curved sections;
3. obtained probable costs from both sources;
4. reviewed material handling and assembly techniques through the entire truss manufacturing process;
5. examined structural lifetime and maintenance issues associated with the trusses; and
6. developed recommendations for the lowest cost mechanisms for producing these structural elements.

Because the Colorado system would require more than 16,000 of these trusses, this cost is a central element of system capital cost; accurate definition of this cost is a critical Project task.

#### **7.12.8.1. Tolerances**

Careful examination of the necessary tolerances for guideway alignment has led to analysis of techniques for achieving the necessary accuracy in guideway placement. Two factors have influenced this analysis.

First is the experience that, once aligned, the guideway can maintain its alignment over a long period of time. In this regard, it is not like the high-speed train systems, Shinkansen and TGV, which require continuing and extensive track maintenance. So, for example, the Nagoya test track of CHSST has required only minor incidental maintenance over a period of nine years.

Second is the experience that the largely manual initial alignment during construction is extremely labor intensive and time consuming. This alignment has been conducted so far with traditional surveying instruments, basically transits and tapes. This approach is challenging in complex curves and needs to be replaced with more modern, electro-optical techniques. The use of new techniques for this construction task will improve accuracy and reduce costs.

This analysis has disclosed real opportunity for reducing the labor cost during the construction process. In the construction processes, the greatest leverage comes from focusing on those structures employing steel members. Two of these have been put forward: one based on a prefabricated steel box truss, and the second on a prefabricated steel space frame truss. Either type offers the prospect of automated construction, and therefore, pre-alignment of rail attachments to the truss. The truss, with aligned rails, can be transported and installed with only limited final alignment in the field. This contrasts sharply with concrete construction, where a rapidly steam-cured, green concrete beam must cure for a considerable amount of additional time, creeping all the while. Only when it has been erected and the pre-cast deck put in place, can the creep be evaluated and the rails installed. The rails and sleepers must be installed and shimmed as a unit, rechecked after a period of time to verify that further creep has not destroyed the alignment, and readjusted if necessary.

#### **7.12.8.2. Construction Issues**

The guideway effort has also dealt with issues of guideway construction that are separate from the materials issues of guideway elements. Chief among these construction issues are transport of large, prefabricated, pre-aligned guideway components to construction sites and erection and alignment of guideway structural elements. The reasons for examining these issues is to make sure that cost integrity is preserved through the estimation process, and to make sure as well that important system attributes in the vehicle/guideway interface are not compromised by the construction process. Examination of these issues early in the process can help to assure a consistently usable guideway. As the largest item of capital expenditure in the project, it is



important that guideway integrity and functionality not be compromised by unforeseen conditions. This has happened repeatedly in early maglev projects and cannot be tolerated in a project with the scope of the Colorado initiative.

The sizes of girders that must be transported range from 20-30 meters in length. The upper range of these lengths is likely to require special handling in over-the-road transport to insure that such long girders are not a hazard to normal traffic. These lengths are at the upper limits of handling for this type of transport, although they can be handled with appropriate care. The weights are also significant, ranging from sixteen tons for the tubular steel truss, to thirty tons for the concrete girder.

Earlier in the effort, it was suggested that the guideway itself could be used to transport new guideway sections for installation. That approach, as it turns out, is in use in Japan with good success. The following figures illustrate assembly and movement of guideway sections over completed sections of the guideway for installations:



**Figure 69: Levitation Rail Section Assembly Prior to Installation**



Figure 70: Guideway Section Staging for Transport Over the Guideway



Figure 71: Guideway Sections Ready for Transport on the Guideway

### 7.12.8.3. Guideway Materials

Choices for guideway structural materials have been detailed previously in this section. Basically, the choices are pre-stressed concrete structures or steel structures. System tolerance requirements have narrowed the choices for potentially adequate structures to the pre-stressed concrete box beam girder, with a separately cast deck structure, and two steel alternatives, the prefabricated steel box beam girder and the steel space frame truss.

Each of these alternatives has advantages and disadvantages, although other associated factors that contribute to system cost are not captured in a simple discussion of structural alternatives. These factors include economic factors of manufacturability related to a particular alternative, including manufacturing processes and economy of scale, transport factors, and assembly, erection, and alignment factors in the field. These factors have unique implications for each of the alternatives, and are particularly significant for a project with the potential scale of the Colorado Project.

Careful consideration of all of these factors can have significant impact on the choice of a technological alternative and on the cost for a particular system.

A brief summary of the key considerations for each alternative is instructive.

The principle concern for the concrete alternative is control of creep to achieve the required long term dimensional stability needed to meet the very close tolerances required for maglev system rail structures.

Concrete structures of this type would be fabricated by pouring concrete around pre-stressed reinforcing rods already set in the forms. Several connected long sections would be poured at once and after a quick steam cure, would be cut apart and stacked for curing. During this period, attempted relaxation of the pre-stressed rod generally will cause upward bowing of the girder. This process will continue until the concrete is fully cured, and is basically unpredictable in individual cases depending on the mix, temperature, curing period, and other factors. The process stops with erection of the girder, when addition of the pre-cast deck basically prevents further creep by balancing the creep-producing forces in the girder with the weight of the supported deck. The upshot of this chain of events is that assembly and adjustment of the maglev system rails to the necessary tolerance must be accomplished manually in the field following guideway assembly.

It can easily be argued that the field activity with the guideway is the portion of the construction effort least under control, and that shortening the assembly and erection time for a guideway is the best way to reduce construction costs. These criteria point toward a guideway solution wherein as much prefabrication as possible has been accomplished prior to guideway installation.

One factor that runs counter to this overall goal is transport. Fortunately, in Colorado, that is not a problem. Concrete girder fabrication, if required, could easily be established in the Denver area. Pueblo, Colorado has been a steel fabrication center in the Rocky Mountain area since 1881, making railroad steel, bridge steel, and pipe. Consequently, it would be straightforward to create a guideway component fabrication facility in Colorado, moving preassembled guideway elements either over the highway or over the previously constructed guideway for final erection.

A review of the I-70 route indicates that few problems would be encountered in hauling oversize loads during late night hours. As the guideway is constructed, Section 7.12.8.2 above shows that it is entirely feasible to move guideway components over the finished sections to the erection site, using special equipment. This would avoid interference with traffic, and would completely free the work schedule.

The principal concern for the steel alternatives is fabrication cost and subsequent environmental protection. Fabrication issues beyond basic material choices include weld integrity and associated labor costs, while the protection issues include choice of painting or coating systems. Long experience with bridge construction and maintenance has made it abundantly clear that the steel structures must be fabricated properly and protected in use to achieve system lifetime and performance goals.

Additionally, the relatively lighter weight of the steel structures when compared to concrete makes the erection phase simpler and less accident-prone.

Steel structures needed for the guideway concepts proposed for the CMP are fabricated by welding. Welding is a highly evolved discipline, and with proper verification, excellent metal joining can be achieved. The Colorado guideway structures should be welded in an automatic fabrication facility employing robots for reproducible, uniform, rapid, lowest cost results. A facility of this type could be constructed at the finished components delivery staging area for maximum efficiency. Steel would be delivered to this facility by rail, plentiful in the Denver area.

There are many choices for protection systems for these structures. The first is the use of weathering steel in their construction. This steel does not require additional external protection, instead developing its own oxide coat that prevents further oxidation and corrosion. This steel is widely used in small bridges in the US, and could be considered for guideway construction. However, it is a specialty steel, and is not widely manufactured, and there may be welding issues that would require further research before its use could be approved in this application. Presently, the small manufacturing base has inhibited attempts to price its use in steel guideways.

Other coating systems include sacrificial zinc galvanizing, accomplished even for large structures by full hot dipping. While unattractive, this type of coating would be extremely durable. There would be severe air quality considerations attendant to a large scale galvanizing plant in the Denver area, so this approach may be infeasible.

One can look further to electrostatic powder coating. These durable finishes could be applied as the last fabrication step in the prefabrication process, and could easily be integrated with the assembly operations. These coatings really depend on the polymer employed in the coating, and one with excellent UV characteristics would have to be chosen. Other conventional painting systems could be adopted, including epoxies, urethanes, alkyds, silicones, and even teflons, for selected guideway elements. This matter will have to be studied further with an eye to durable lifetime, cost of application, environmental toxicity, and aesthetics.

Presently, information concerning these protection systems would rely on bridge experience. However, guideways differ in some important respects from bridges, and it seems clear that finishing techniques specialized to guideways can be developed, which will be superior to present bridge protection techniques. The opportunity for prefabrication of the truss significantly enhances the painting or coating options as compared to painting in the field.

The choice of concrete versus steel cannot be dogmatically decided, since the requirements of proposed applications vary. Generally speaking, however, use of steel structures potentially offers more benefits than use of concrete. These benefits include deadweight, dimensional stability, failure tolerance, and aesthetics.

Lightweight steel structures are easier to transport and erect and, if properly protected, have equivalent lifetimes and better dimensional stability than concrete. Dimensional stability is not particularly important for many types of structures, although it is important to the maglev system. The prospect of full assembly of complete spans, including rails, prior to erection offers potential reduction of construction labor and should yield a superior finished product, so far as dimensional

stability is concerned. This approach does require further innovation in mounting pier design and construction, although this is well within the state-of-the-art.

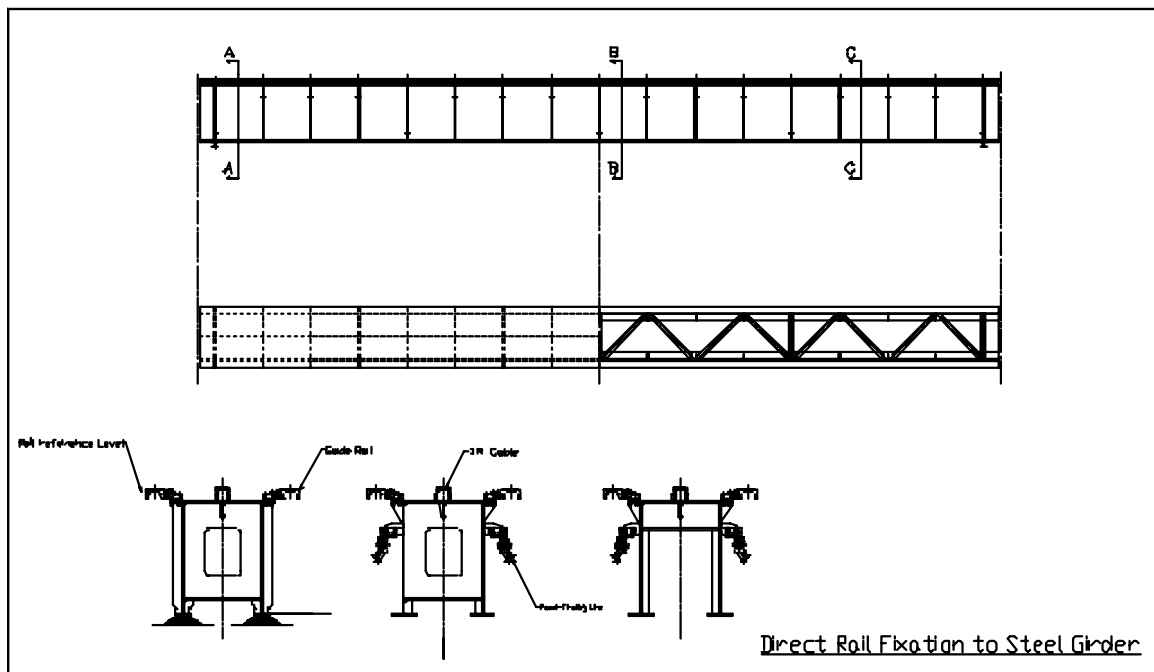
Aesthetically, the steel tubular space frame truss has been selected by most viewers as the preferred guideway type. This is due to its lower visual obstruction and its unobtrusiveness. With a proper painting system and color selection it is likely to become unnoticeable, and therefore well accepted in many applications. For example, the opportunity for the use of sophisticated camouflage techniques with guideways has never been explored, and this is another area for further research. This is likely to be economical only during the prefabrication process, but a series of unique techniques could be used to customize the appearance of each truss to make it nearly invisible in the particular surroundings where it will be installed. This concept has been christened the “stealth guideway” concept.

**7.12.8.4. Guideway Fabrication Process**

**7.12.8.4.1. Straight Sections**

Fabrication of guideway straight sections is straightforward. The rails are made by hot rolling steel billets to the required near net shape and then applying a variety of finishing techniques to obtain the final cross-section and tolerance. Mounting holes must be machined into the rails, involving precise drilling, spotfacing, and counterboring. This process has been well developed, and is well within the state-of-the-art.

Fabrication of guideway beams to carry the rails is a different matter, and has been alluded to in earlier discussion of guideway materials. Much greater familiarity exists for these construction techniques, since they are widely employed in the construction of conventional civil structures. Both concrete and steel box girders are constructed with entirely standard techniques. As noted earlier, concrete girders are constructed using forms and falsework in a manner similar to the construction of large pipes. Conventional steel box girders are constructed of welded plate, as shown in the example of Figure 72.



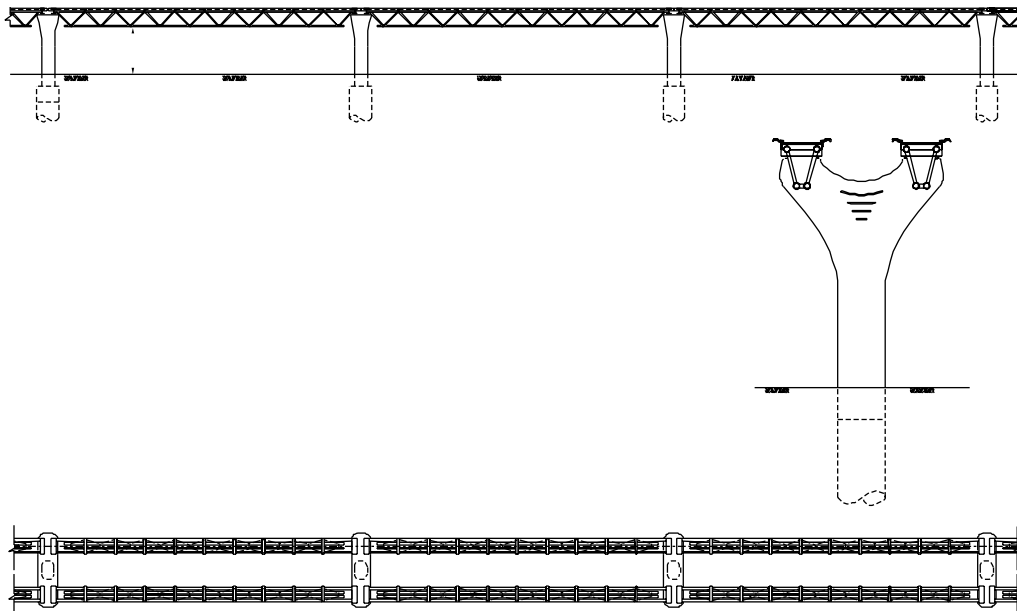
**Figure 72: Steel Box Girders**

The fabrication of this structure by conventional welding is straightforward.

The structural fabrication of the tubular steel space frame truss, on the other hand, presents challenges. These challenges have heretofore prevented the widespread use of these structures, since they carry increased cost. These structures, depicted in Figure 73, require many full penetration welds to insure the truss integrity under load. Basically, longitudinal stringers carry the loads, and lateral stiffeners are used to transfer loads and stabilize the longitudinal members. These trusses are very economical in their use of materials, but their efficiency derives from the geometrical nature of their structure, which transfers applied forces to bearing elements in a most effective manner.

These structures work correctly only if carefully made. Poor fit between elements and sloppy joining of elements can combine to keep the structure from fulfilling its function. This is particularly important if the truss members are pipe sections, as proposed for the Colorado Project. In this case, the members not only meet at compound angles, but the ends of members must be contoured to conform to their destinations. Joining the members in accurate alignment is another challenge, since the truss geometry must be maintained while the joining is underway, and artifacts of the joining process, such as warpage and shrinkage must be controlled. If these challenges can be met, the result is a superior, potentially long-lasting, structure.

Another issue is mass production. Implementation of the CMP with these structural elements requires the production of roughly 16,630 girders, of the length shown in Figure 73. To fabricate these in a reasonable time frame, a factory or factories must churn out girders at a rate of 5,000 per year. That is a production rate of tens of structures per day, which cannot be economically achieved without automation. Recent investigations in Britain have focused on automating the creation of these trusses using robot welders, with very encouraging success. These welders have demonstrated reproducibly high quality, full penetration welds on compound joints between rigid pipe members. Costs and potential production rates are in the process of being worked out by these researchers, and will be of direct interest to maglev system builders.



**Figure 73: Guideway Truss**

Another issue in truss construction is the manufacturing process for the truss elements. Steel pipe of the type needed for truss construction is manufactured at a number of specialized mills around the country. The common technique in pipe manufacture is successive roll-forming of

long flat steel billets, closing the joint along the length of the pipe by electric resistance welding as the billet edges come together under pressure of the forming rolls. This process is well worked out, and very controllable. The requirements for truss element materials from this source are easily met.

However, in the case of the truss longitudinal elements, standard mill lengths are not adequate for the truss lengths required by the maglev system. Generally, pipe lengths as manufactured are around 10 meters. The maglev truss design requires 30-meter longitudinal chords, so this must be achieved by joining shorter segments.

Fortunately, there are many choices of joining techniques to meet this requirement. The pipeline industry has long used flash-butt welding, wherein a pair of collars, energized typically by a homopolar generator, heat the pipe ends to welding temperature. When ready, the ends are simply pushed together to make a strong joint.

Another technique is magnetically assisted plasma arc welding. In this technique, a plasma arc is moved around the pipe ends until they reach the proper temperature. The pipe ends are then brought together under pressure and a good weld is formed.

Finally, there is magnetic pulse welding, which is used to make clad metals as well as for other purposes. In this technique, a magnetic coil around the parts to be joined creates a shock wave that moves through the weld zone, instantly fusing the surfaces.

These techniques all appear to be adaptable for the creation of long straight segments of pipe.

By present analysis, each truss weighs around 16 tons, less rails. At an average materials cost of \$500 per ton, the materials in a truss would be valued at \$8000. Finding the materials without significant cost penalty in a period of continually rising commodity prices is another challenge. There is an enormous surplus of shipping containers sitting idle in American seaports, which are uneconomical to return to foreign shippers. A container, that is all steel, weighs around four tons. Four containers can make a truss, and sixty four thousand containers can make sixteen thousand trusses. The port of Newark/Elisabeth complex unloaded more than 1.6 million full containers in the first 11 months of 2002, and shipped out 688,000. The remainder is presumably sitting idle in storage yards in the port area. Worldwide, containers are a serious security problem, and recycling them as a raw material source for guideway construction would be prudent.

#### *7.12.8.4.2. Curved Sections*

Fabrication of curved guideway sections is not widely discussed in maglev system literature. However, it is a central element of guideway construction technique and can become a major consideration in guideway cost. Therefore, it had to be examined as part of the integration cost integrity effort. As noted above, levitation rails are made by hot-rolling processes. These processes are not suited to the manufacture of curved sections, which leaves only two alternatives. Either straight sections previously rolled must be bent, or the curved section must be carved by machining from a single billet of steel. Requirements for these processes can be met with current technology, although the requirements depend on the radii of curvature that are appropriate to a specific system.

In the Colorado system as currently designed, there are no requirements for curvature radii less than 150 meters, matching the capability of the Colorado 200 vehicle. At these radii, induction bending is a potential solution to the manufacturing problem. Computer controlled induction bending of architectural steel, primarily large diameter pipe, has been conducted in the US for some time, although there is only a single supplier. This supplier has experience with guideway requirements, creating guideway for Raytheon's foray into Personal Rapid Transit systems.

This approach is preferable to the approach taken in China, requiring the construction of a gigantic 183 meter (600 foot) long machine shop, wherein rail sections could be trued and curved sections fabricated by numerically controlled machining.

Normal rail sections as fabricated in Japan are typically 10 meters in length. This limit comes from the rolling mill's capability to handle billets. The maximum length in the United States for similar operations is likely to be 12.5 meters (41 feet), based on vendor discussions. However, the technology to roll much longer sections has been developed, and could be employed with further capital investment.

Rolling to close tolerances and producing rails of required straightness is likely to require some type of final finishing operation. This may be achieved by stretching hot finished rails in a specialized rolling process, in the case of straight sections, or by computer controlled induction bending in the case of curved sections. With adequate experience and quality control, it is unlikely that further finishing by machining would be required. If needed, it would be desirable to evaluate finishing in place after rail installation. A specialized mobile grinder that could produce a finished track *in situ* would be preferable to theoretical conformations produced in a large numerically controlled machining shop. This effort has identified these issues as open research areas.

### 7.13. SUMMARY AND CONCLUSIONS

Design and construction of economical and aesthetically pleasing guideways for a maglev transit system on the Colorado I-70 corridor or elsewhere within the U.S. is feasible utilizing conventional materials and construction techniques. With proper guideway design, the cost of the system can be both manageable and competitive with other transit technologies. Three standard guideway structural systems have been developed that show great promise for cost savings, especially given the economies of scale possible on the Colorado project. Ample opportunity exists to make the guideway attractive in appearance so that visual impacts are minimized. Operational needs such as switching and emergency egress can be incorporated without serious cost implications, as can protection from avalanches that are present in the mountain area.



## 8.0 **THE MAGLEV STATION**

Fundamentally, a maglev station is equivalent in planning, design, and operation to an inter-city or commuter railroad station. There is only one technical aspect of maglev that constrains station planning and design: unlike railroad tracks, the maglev guideway cannot be crossed by passengers and vehicles at grade. As a result, maglev station designs (except for “terminal” stations) must provide grade-separated passenger access to the station platforms. This form of access requires “vertical circulation” (stairs, elevators, escalators) to connect the platforms with tunnels under or bridges over the tracks.

The nature of stations (railroad, maglev, or other technologies) can vary widely depending on location, target markets, volumes of use, and potentials for revenue generation. The simplest railroad station may consist of nothing more than a paved platform alongside a track. The most ambitious railroad stations rival modern airline terminals in terms of scale, architectural design, and range of passenger amenities. The nature of maglev system stations along the Colorado I-70 Corridor will fall somewhere between these extremes, determined primarily by the target market and secondarily by locations, volumes of use, and other technical factors.

### 8.1 **TARGET MARKETS**

The primary market for the maglev system service – that is, the passenger sector that will provide the most revenue – has two segments: one segment is made up by the Colorado Front Range skiers who transfer onto the maglev system at key stations such as the Golden station. The other is composed of travelers arriving in Colorado from a broad range of national and international points of origin, traveling to the ski resorts along the I-70 Mountain Corridor as the “last leg” of an airline journey. In effect, the maglev system will serve as a “connecting flight” for these travelers, an extension of their air travel experience. It is anticipated that most airline originating maglev system passengers will travel non-stop between DIA and a selection of stations near major ski resorts at the west end of the corridor.

Given the nature of the ski resorts, these passengers are likely to represent a very broad spectrum in terms of culture, nationality, occupation, family type, and economic status. The maglev system must offer all of these passengers a service that meets their expectations in terms of cost, convenience, comfort and style.

For the airline passenger, the maglev system experience starts as soon as passengers arrive at DIA or Eagle County Airport. Fundamentally, the transfer from airline to maglev system should be more like transferring between flights or boarding commuter rail at airports, and not like transferring to ground-based travel modes such as buses, taxis, and rental cars.

Residents of Metropolitan Denver and Front Range cities from Colorado Springs to Fort Collins represent the most significant target market for maglev system service. During the winter resort season, the maglev system will provide alternative access to the ski resorts when travel conditions along the I-70 corridor are at their worst. This local market population is best served by a station within the Denver region, close to the Front Range foothills, and accessed conveniently by freeways and local public transit. A Golden intermodal station represents the most logical site for this critical service point. A high level of passenger amenity is important at all maglev system stations, although at a Golden station, the major draws will include easy vehicular access, high parking capacity, and direct connections to Light Rail Transit, buses, and other local transit modes.

The Metro Denver station will also serve an additional secondary market: residents and guests of the mountain communities that travel to and from the Denver metro region. The speed of the maglev system makes commuting to Denver from as far away as Vail a real possibility and also opens Denver’s urban, cultural, and commercial amenities to mountain residents and guests

alike. The needs and expectations of this market are those of the transit rider: reliable schedules, frequent service, personal safety, and excellent intermodal connections.

By combining these key markets, a picture of the maglev system emerges: part premium train, part commuter railroad. The closest models in current practice are modern, high-speed, intercity passenger services such as Japan's "Shinkansen" (Bullet Trains) and Europe's "Train à Grande Vitesse" (TGV). The engineering excellence, the generous passenger amenities and the modern design of these trains are complemented by their stations. For the maglev system also, train and station can work together to create a seamless, exciting, high quality travel experience.

## 8.2. STATION FEATURES

The CMP guideway is roughly 250 kilometers (155 miles) long. Fourteen potential station sites have been identified. These stations will provide the proper functions of typical transit stations including:

- Platforms
- Shelter
- Vertical and Horizontal circulation
- Amenities and Services
  - Climate controlled waiting room
  - Public restrooms
  - Snack service
  - Public telephones
  - Changeable message display
- Safety

All the station designs are planned to be consistent with the character of the buildings in the area of operation or predicated on the community standards of the local area where each station is located.

The station subsystem must meet certain performance requirements. Specifically, it must support the safe movement of passengers through the station at specified flow rates and must also support particular levels of vehicle traffic.

### 8.2.1. Locations

1. **DIA** (DIA, mile 0): This station represents one terminus of the entire system, serving the DIA.
2. **Rolla** (96th Street & I-76, mile 16.6): This station serves the developing north Denver area, potentially connecting with other transit presently under development.
3. **Downtown Denver** (I-70 & I-25, mile 25.0): This station is located at a major transportation interchange, and will capture a large portion of riders coming from the northern Front Range cities, including Boulder and Fort Collins.
4. **Golden** (I-70/Colfax Avenue & US 40, mile 37.0): This station would serve as the collector for riders coming from South Denver, Pueblo, and Colorado Springs.
5. **Evergreen** (Bergen Park/Route 74, mile 47.4): This station would provide access to Evergreen Park recreation area, and also serve numerous small, urbanized areas along Route 74 to the south.
6. **Idaho Springs** (mile 59.0): This station would provide access to this historic mining town, and also serve local population in the town and in the surrounding canyons.

7. **Georgetown** (mile 70.7): This station would serve the three small communities of Empire, Georgetown and Silver Plume.
8. **Loveland Pass** (mile 82.4): This station would provide access to the Loveland Ski Area just east of the Continental Divide.
9. **Silverthorne** (Dillon, mile 91.9): This station would serve the local communities of Silverthorne and Dillon. There are areas of scattered residential development all along Route 9 and US 6. These routes also provide access to Keystone Resort, Arapaho Basin, and Breckenridge Ski areas.
10. **Frisco** (mile 97.9): This station would serve the town of Frisco and the Breckenridge Ski Area.
11. **Copper Mountain** (Wheeler Flats, mile 103.3): This station would provide access to Copper Mountain Ski Resort, and serve residential development along Route 91 as far south as Leadville.
12. **Vail** (mile 122.5): This station would serve communities of Bighorn, Vail, and West Vail; Vail Ski Resort; and residential development south along US 24.
13. **Avon** (mile 131.9): This station would serve Eagle Valley, Avon, Beaver Creek Ski Area and Edwards.
14. **Eagle Airport** (mile 156.3): This would be the terminal station that would serve Eagle and Wolcott; also Beaver Creek Ski Area to the south, and residential areas along Route 131 to the north.

### 8.2.2. **Unique Station Characteristics**

The Colorado system is unique for its length. This length imposes specific requirements for reliability, availability, and serviceability. Based on examination of these requirements, an approach has been identified for distributed maintenance that would be effective in meeting system availability goals.

In this approach, each station will support maintenance activities requiring replacement of failed vehicle elements. These actions will be restricted to field replaceable units of the vehicle, and will be accommodated in the section of the station reserved for vehicle storage.

#### 8.2.2.1. **Maglev Stations: Common Elements**

Based on the patron markets the following elements, features, and design standards should be common to all maglev system stations, regardless of location or patronage volumes. The expression of these standards will vary and additional features may be added, depending on station location.

- **Architecture:** Innovation, coupled with a solid commitment to market-tested context-sensitive design, should govern. In this way, the stations fit in to their communities, although they should also mirror the excitement of the maglev system itself, just as DIA's soaring tensile roof mirrors the technology and excitement of air travel. This approach may counter a trend, at least in the United States, to create overly "nostalgic" or traditional architecture for public buildings of all uses, including train stations. By contrast, the architecture of Europe's TGV is "cutting edge" and features the world's finest examples of contemporary station design.

- Platforms: The standard arrangement should be a twin side-platform station with each direction served by a single platform. At the DIA and Eagle County Airport terminus stations, additional platforms and tracks may be provided. Platforms will be elevated, allowing direct access through train doors without steps or ramps. No free passenger access to the guideway will be permitted, for safety reasons. This is mandatory due to the speed and low noise profile of maglev systems. The CMP is not a commuter-system, wherein every train will stop in, or necessarily slow fully for a given station. The use of docks and in-station transfer switches means that passing trains, while not necessarily in close proximity to platforms, could injure anyone who strayed into the active main guideway. The only alternative to this is expensive station bypass paths, with large and costly external switches and transition spurs.

The electrical hazard common in commuter rail is not present in the same way with the maglev system. The mounting and shielding of power rails make them very difficult to contact unintentionally, and so electrical hazard is not a primary reason for access restriction.

However, another hazard for anyone attempting to negotiate an open guideway is falling. The open nature of the guideway, and the significant elevation, would make a fall very hazardous, if not fatal. Accordingly, free open access to the guideway must be eliminated for passengers.

- Instead, guideway access is controlled by elevator-style lobby doors, synchronized to the position of the train. Use of these doors requires precision train positioning, accomplished either by docking, or by platform based stopping control. This design approach has reliability implications, and all access equipment selected for use must have proven reliability characteristics.
- Shelter: All stations will be climate-controlled using platform doors in the same manner as DIA's people mover stations.
- Vertical Circulation: For vertical circulation all maglev system stations will provide escalators and elevators as the primary elements and stairs as the backup.
- Station Amenities and Services: At a minimum, the following should be provided:
  - Full climate control
  - Public rest rooms
  - Snack service (may be limited to vending machines at minor stations)
  - News stand with attendant/cashier (may be combined with snack service at minor stations)
  - Staffed ticketing and information center (at terminal stations and at some urban/suburban stations)
  - Public telephones with internet and e-mail capability, and computer work station positions
  - Facilities (operated as concessions) catering to all-season recreational activities appropriate to location (ski shops, bike & skate shops, ski and bike storage, changing rooms, luggage storage, etc.)
  - Access to traveler services such as shared-use "station cars", conventional car rentals, and hotel shuttles (access to services may be limited to "hot lines" or dedicated telephones at minor stations)
  - A changeable message display showing train schedules, "real time" train performance, system messages, and other content of interest to the traveler (weather reports, news headlines, limited advertising, etc.).
  - Advertising displays

- **Intermodal Facilities:** The number and size of intermodal facilities will vary by station location. At a minimum, all maglev system stations should provide a sheltered curbside for vehicular pick-up and drop-off, an area for motorists to await arriving passengers before picking-up, parking in the form of lots or garages, and sheltered, secure storage for bicycles. Depending on station location, additional intermodal facilities would include Light Rail and transit bus stations, intercity bus stations, rental car facilities, and air terminals. To the degree possible, all such facilities should be contained within (or be connected to) the maglev system stations to create a seamless climate controlled or sheltered travel experience.
- **Security:** It is recommended that stringent security measures be applied, and the design of stations must accommodate this possibility. At a minimum, all stations should limit platform access to specific control points. This is in direct contrast to most railroad and Light Rail stations that allow free access to platforms. The provision of access-controlled platforms would assist in achieving another system service objective if security details aboard the trains could be resolved: the automatic transfer of checked baggage between select maglev system stations and DIA.
- **Public Art:** All stations would feature public art appropriate to their locations. Public art is an excellent adjunct to station design and a popular feature at DIA and in RTD's Light Rail Transit stations in metro Denver.

### 8.2.3. **Maglev Station Prototypes**

The *Maglev Station General Prototype* (see Figures 83 – 86) is a representative architectural design station concept based on the integration of the elements, features, and standards described above. Although not intended to limit the architectural expression of future stations designs, the prototype nevertheless represents a level of functional and aesthetic quality appropriate to the market and vision.

This section describes three station prototypes by location that cover the range of stations likely to be developed along the I-70 corridor from DIA to Eagle County Airport. Each prototype is described and compared across a common range of topics and the information is also summarized in Table 8-1, *Comparison Matrix: Prototypical Maglev Stations*, at the end of this section. Each prototype also includes a conceptual site plan (see Figures 74 - 80).

**Terminal station.** This station type possesses functions unique to high volume origin/destination traffic, providing intermodal interchange without substantial station-specific automotive traffic. The DIA and Eagle stations are likely to be the only stations of this type in the Colorado system. The DIA terminal station benefits from the traffic infrastructure already put in place to support the airport. The Eagle station, although a lower passenger volume station, will have similar characteristics. The "Terminal Station" (Prototype 1) is integrated with the functional and aesthetic design of DIA at the eastern terminus of the alignment and reflects the special requirements of an end-of-line station. By comparison, the western end-of-line station at Eagle County Airport could likely, in architectural terms, match the architecture and function of the airport.

**Urban/suburban collector station.** This station type aggregates traffic from other transportation modes (automobiles, vans and buses) for entry/exit to and from the maglev system. The I-70/I-25 station and the Golden station are examples of this station type.

**The rural destination station.** This type of station typically receives traffic from the urban/suburban stations, and returns the same traffic over the course of a day (although in the case of mountain-based commuters, the flow is reversed). Most of the mountain corridor stations will be this type. These stations must only support limited amounts of wheeled traffic and must have good support for hotel shuttle and rental car modes.

The “Urban/Suburban Collector Station” (Prototype 2) and the “Rural Destination Station” (Prototype 3) are based directly on the General Prototype.

### **8.2.3.1. Prototype 1: Terminal Station**

- Station Type: Terminus.
- Station Locations: At DIA and Eagle County Airport.
- Prototype Location: DIA.

#### **8.2.3.1.1. General Description**

The terminus station at DIA (see Figure 78) is the gateway to the I-70 corridor for national and international visitors arriving in Colorado by air. The DIA station could share access to a host of traveler services and amenities, including extensive retail uses in DIA. DIA itself provides most of the supporting features appropriate to this maglev system station prototype: arrival and departure curbsides, short and long-term parking, climate-controlled ticketing areas, rental car facilities, and connections to a wide range of ground transportation services.

The proposed planning concept (see Figure 78) shows the station accessed off a common concourse joined to the terminal building’s main floor (arrivals level).

To allow for operational flexibility, the station has three platforms: two side platforms serving passengers and a secured center platform for checked baggage handling. Passengers access the platforms from a security-controlled waiting area, the functional equivalent of DIA’s secured airport concourses. All on one level, this arrangement allows airline passengers to walk directly to the trains without climbing stairs or ramps. Most station support elements (ticketing, concessions, etc.) are located in the main terminal space.

#### **8.2.3.1.2. Architecture**

The architecture of the waiting area and platforms (the only new construction in this case) should be compatible with the main terminal building. Appropriate options might include:

- A “signature” roof similar to the tensile roof of the main terminal, although of a smaller scale appropriate to the station’s size.
- A glass-walled structure similar to the style of the airport administration building and sky bridge immediately to the north of the main terminal.
- A unique architectural or structural expression in keeping with the overall high energy, high tech image of the main terminal.

#### **8.2.3.1.3. Platforms**

The waiting area and platforms are extensions of the indoor space of the main terminal. The trains enter the station hall inside glass-enclosed tubes open to the outside, thus maintaining climate control. Access to the trains is through automatic doors in the tubes that mate with corresponding train doors and open and close together.

#### **8.2.3.1.4. Shelter**

The station is a fully climate-controlled environment, extending the amenity of the airline terminal.

#### **8.2.3.1.5. Vertical Circulation**

The waiting area, station platforms, and the airline terminal main floor share a common level, thus no vertical circulation is required.

**8.2.3.1.6. Horizontal Circulation**

Passengers enter the platforms only at the head end. Moving ramps could serve the platforms in the same manner as ramps serve DIA’s Concourses A and B.

**8.2.3.1.7. Station Services and Amenities**

As one of the three major stations on the corridor (the others are the Golden Denver urban station and probably the Frisco station), the DIA station could feature a full complement of station-related services and amenities. However, most of these already exist at DIA or will be located in the main terminal space. Passengers will check in to the maglev system at a ticketing counter in the main terminal (just as rental car and shuttle services have counters) and then enter (through security) the waiting area to await boarding time. Only when a train is called will passengers pass through a checkpoint to the platforms, just as passengers board at an airline gate.

**8.2.3.1.8. Intermodal Facilities**

All intermodal services are accessed through the DIA main terminal, which features dedicated intermodal curbsides off the terminal’s main floor, the same level as the maglev platforms. It is assumed for purposes of this analysis that maglev system passenger long and short-term parking and “kiss & ride” (pick-up and drop-off) will utilize existing DIA facilities on a shared-use basis.

**8.2.3.1.9. Security**

The checkpoint between the main terminal and the maglev system waiting area will provide full passenger screening. If instituted, checked or transferred baggage will utilize the secured center platform, connected by an elevator to the terminal’s lower level baggage handling system.

*Note: If checked baggage integrated with airlines is provided, airport-level security will be required at any maglev system station offering checked baggage service. Trains would likely require a secured baggage car or a passenger car with a special secured baggage section to support this service. Additional screening procedures are avoidable if checked luggage is containerized as it comes off arriving airlines, basically supporting checked luggage to final destination.*

**8.2.3.2. Prototype 2: Urban/Suburban Collector Station**

- Station Type: In-Line.
- Station Locations: One or possibly two sites in the metro Denver region, I-25/I-70 and the Golden Station.
- Prototype Location: At the interchange of I-70 and U.S. 6 (6th Avenue) in the city of Lakewood: the Golden Station.

**8.2.3.2.1. General Description**

The urban/suburban collector station (see Figure 79) serves a broad local and regional market and relies to a great extent on intermodal connections with the automobile and other ground transportation modes. To these markets, the prototype serves as a “gateway” to the I-70 corridor, a role similar to DIA’s role in relation to national and international markets. Unlike the DIA station however, the urban/suburban station is a stand-alone facility that generates its own urban presence and has the potential to organize and shape the surrounding urban growth.

Although the urban/suburban prototype applies primarily to sites in metro Denver, at least one mountain station will likely share many of the urban prototype’s features. This station will be located near the geographic center of settlement in the resort region west of the Continental Divide, at a site with sufficient area and suitable topography for a full compliment of intermodal services. Locations most likely to meet these requirements are Silverthorne and Frisco. This prototype is included as “Urban/Suburban Collector Station” in Table 8-1 *Comparison Matrix: Prototypical Maglev System Stations*.

For purposes of this analysis, the site for the urban/suburban station prototype is at the interchange of I-70 and U.S. 6 (6<sup>th</sup> Avenue) on the boundary between the cities of Lakewood and Golden. The chosen site is in the northwest quadrant of the interchange on land that also fronts Colfax Avenue, a major commercial corridor linking east to downtown Denver. A proposed branch of Denver's Light Rail system, the "West Corridor", passes through the interchange, creating the possibility of a major intermodal connection at this station. The site is also where the I-70, U.S. 6, and C-470 freeways converge, thus providing the station with excellent regional highway connections to metro Denver and the Front Range.

For purposes of this analysis, it is assumed that the maglev system guideway will run elevated on columns down the center of I-70 and transfer over to the freeway's westbound (north) shoulder to serve the station. Generally, the station will consist of the following features:

- Elevated twin side platforms along the guideway, above the I-70 westbound shoulder.
- Vertical circulation (elevators and escalators) linking the elevated platforms to a main station house at grade.
- An at-grade Light Rail station along the north side of 6<sup>th</sup> Avenue, adjacent to the maglev station house.
- A primary access road from Colfax Avenue that serves both stations, parking (a garage is likely given the site's limited area), intermodal facilities, and the station's curbside.

The site's modest area constrains the potential for transit-oriented real estate development immediately around or in the station. However, there is significant potential for maglev system and Light Rail related development on adjacent sites (if current uses are retired) and within a 0.4 to a 0.8 km (0.25 to 0.5 mile) radius of the station. Developments of regional significance, Denver West and Colorado Mills, are also close to the station and may seek transit linkages if warranted by the future maglev system and Light Rail ridership.

#### **8.2.3.2.2. *Architecture***

The presence of the maglev system station platform above I-70 creates a special opportunity for a "signature" architectural expression. The principal opportunity is the roof over the platform, a structure that will first be visible to eastbound motorists coming down the grade on I-70 at the Morrison (old Colfax) and C-470 exits. Just as at DIA, the architecture should mix innovation and context-sensitive design and reflect the excitement of the maglev system.

#### **8.2.3.2.3. *Platforms***

Each station in the system is climate controlled. Elevator type doors will be provided for access from the platform to the train.

#### **8.2.3.2.4. *Shelter***

The station is a fully climate-controlled environment. Walls and roof would be glazed and skylights would admit generous natural light and open up views from the elevated station's vantage point high above I-70.

#### **8.2.3.2.5. *Vertical Circulation***

Elevators and escalators will connect the elevated platforms to the station at grade entry. If the platforms are located directly above I-70 (as opposed to above the shoulder), an intermediate "mezzanine" level will be required to link the platforms laterally to vertical circulation alongside the freeway.

#### **8.2.3.2.6. *Horizontal Circulation***

Horizontal circulation elements (e.g., speed ramps) are not required at this station.



### 8.2.3.2.7. Station Amenities and Services

As one of the three major stations on the corridor, the metro Denver station features a broad complement of amenities and services. Most of these services are provided in the at-grade station entry level, a climate-controlled facility that contains the ticketing system, waiting room, rest rooms, and station-related commercial uses. At this station, retail uses could include a restaurant, a food court, newsstands and boutiques, and commuter-friendly services such as dry-cleaning depots, mini-banks, and convenience grocery stores.

### 8.2.3.2.8. Intermodal Facilities

At this station, intermodal facilities would include a Light Rail and transit bus station, a generous sheltered curbside augmented with a “kiss & ride” waiting area, significant short and long term parking (likely in the form of a multi-level parking garage), and service counters connected to off-site rental car facilities. Further study of the urban/suburban station prototype might lead to development of separated arrival and departure curbsides typical of many airports and also increasingly considered for high-volume urban stations such as those developed for Florida’s formerly proposed “FOX” high-speed train system.

### 8.2.3.2.9. Security

Full passenger screening will be provided by a checkpoint located in the station at the entrance to a secured waiting area. Given DIA’s proximity within the urban region, it is likely that checked baggage facilities would not be provided at this station; however, the prototype does support this service. In practice, baggage would be transferred by containerized carts supervised by station personnel using dedicated baggage elevators.

*Note: Further study is required to determine the feasibility of transferring baggage from airlines at DIA to maglev system stations. The issue is not security but rather the ability to designate stations as baggage origins and destinations within the air travel system. However, there is likely no technical reason why checked baggage could not be implemented.*

### 8.2.3.3. Prototype 3: The Rural Destination Station

- Station Type: In-Line.
- Station Locations: Suggested locations (one of which may be based on the urban/suburban station prototype) include Evergreen, Idaho Springs, Georgetown, Loveland Pass, Silverthorne, Frisco, Copper Mountain, Vail, and Avon.
- Prototype Location: A site in the town of Idaho Springs.

*Note: The sample site in Idaho Springs (see Figure 80) is conceptual and has not been determined through a comparative site planning analysis. The following descriptions are generic in nature and do not represent the Idaho Springs site specifically.*

#### 8.2.3.3.1. General Description

Along the I-70 corridor, the typical rural destination station will be located off the freeway right-of-way. The rural destination stations typically serve limited geographic areas and will have, compared to the urban/suburban stations, smaller capacities and fewer passenger amenities. However, station “statistics” will vary considerably depending on location and all stations will share the same high standards of functionality and style.

The typical rural destination station will consist of elevated twin side platforms served by a station house at-grade. A typical site plan will place the station at the back of the site with surface parking between the station and a street that may, in some locations, be a freeway frontage road. An access road will lead from the street to a curbside in front of the station and also provide access to the parking.

**8.2.3.3.2. Architecture**

Innovative, context-sensitive architecture is encouraged in the design of the rural destination station as with all of the maglev system stations. However, since rural destination stations will tend to be located off the freeway corridor in mountain village settings, architectural designs must be especially context-sensitive and acceptable to local residents and business owners.

**8.2.3.3.3. Platforms**

Each station in the system is climate controlled. Elevator type doors will be provided for access from the platform to the train.

**8.2.3.3.4. Shelter**

Shelter would be similar to that provided for the urban/suburban station prototype, while taking into account that the mountain climate is more severe than the climate in metro Denver. Walls and roof would be glazed and skylights would admit generous natural light and open up to mountain views.

**8.2.3.3.5. Vertical Circulation**

Elevators and escalators connect the elevated platforms to the climate-controlled station house at grade. Since the station house is directly beneath and in front of the platforms, an intermediate “mezzanine” level is typically not required.

**8.2.3.3.6. Horizontal Circulation**

Horizontal circulation elements (e.g., speed ramps) are not required at this station.

**8.2.3.3.7. Station Amenities and Services**

Station amenities and services are limited at the typical rural destination station. The rationale is that the typical rural destination station serves a low-volume passenger market and is located in a mountain village setting that provides a suitable range of amenities and services close to the station.

**8.2.3.3.8. Intermodal Facilities**

Intermodal facilities will vary by location. All stations will include “park & ride” and “kiss & ride” facilities appropriately sized to local markets. Curbsides will be designed to accommodate local transit bus, shared-use “station cars”, and van stops. Rental cars will be off-site, although accessible through service counters or “hot line” telephones.

**8.2.3.3.9. Security**

Security features at rural destination stations are the same as at urban/suburban stations.

**Table 8-1 Comparison Matrix: Prototypical Maglev System Stations**

<i>Prototype</i>	<i>Terminal</i>	<i>Urban/Suburban</i>	<i>Rural Destination</i>
Typical Location	DIA	I-70 / U.S. 6 Interchange	Idaho Springs
Station Type	Terminus	In-Line	In-Line
Platform Type	Side / End-Loaded	Side	Side
Number of Platforms	3 (including baggage platform)	2	2

<b>Prototype</b>	<b>Terminal</b>	<b>Urban/Suburban</b>	<b>Rural Destination</b>
Number of Tracks	2	2	2
Platform Enclosed	Yes	Yes	Yes
Platform Covered	100%	60%	50%
Elevators	No	Yes	Yes
Escalators	No	Yes	Yes
Stairs	No	Yes	Yes
Moving Ramps	Yes	No	No
Secured Waiting Room	Extension of DIA Terminal	Station House	Station House
Curbside	DIA Curbside	Yes	Yes
Park & Ride Lots	DIA Lots	No	Yes
Park & Ride Garage	DIA Garages	Yes	No
Transit Buses	DIA Curbside	Bus Loop	Curbside
LRT or Commuter Rail	Future RTD extension to DIA	RTD West Corridor	No
Kiss & Ride	DIA Curbside	Off-Street	Curbside
In-Station Retail	DIA Terminal	Yes	Yes (limited)
Car Rental	On-site / DIA Terminal	Off-site / Counter Service	Off-site / Counter Service or "Hot Lines"
Baggage Claim (if provided)	Routed to DIA baggage carousel	Baggage counter in station house	Baggage counter in station house
Baggage Check (if provided)	Ticket counter or transferred automatically from airlines	Ticket counter in station house	Ticket counter in station house

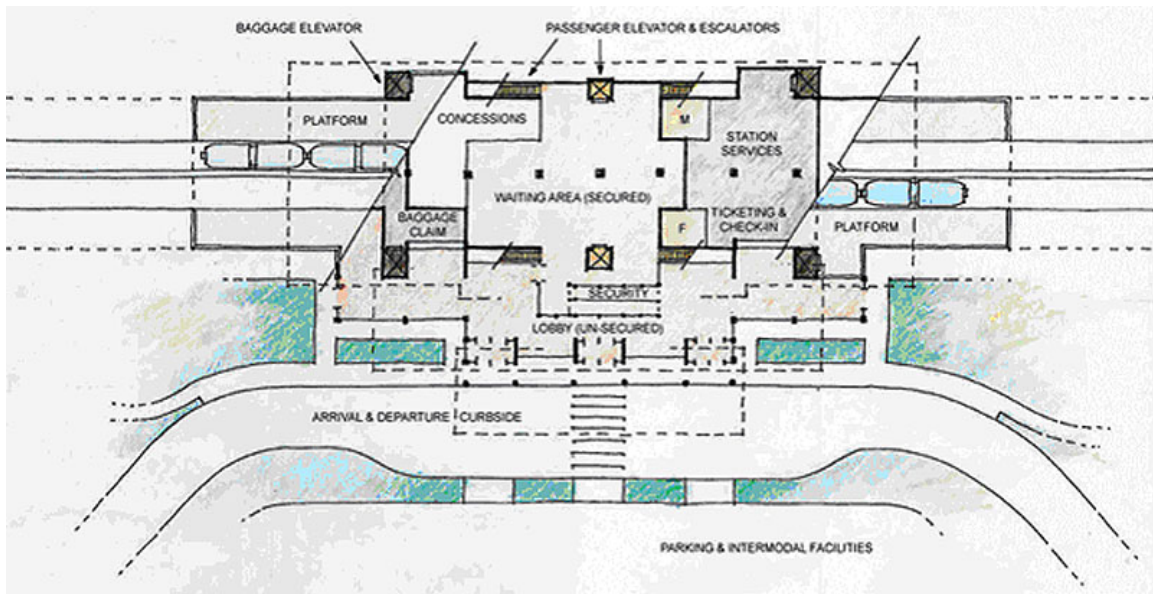


Figure 74: Maglev Station Prototype: Floor and Platform Plan

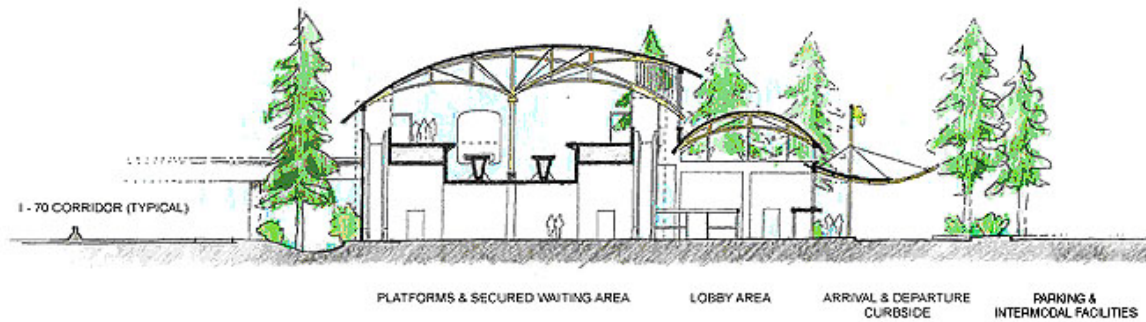


Figure 75: Maglev Station Prototype: Cross-Section



Figure 76: Maglev Station Prototype: Front Elevation

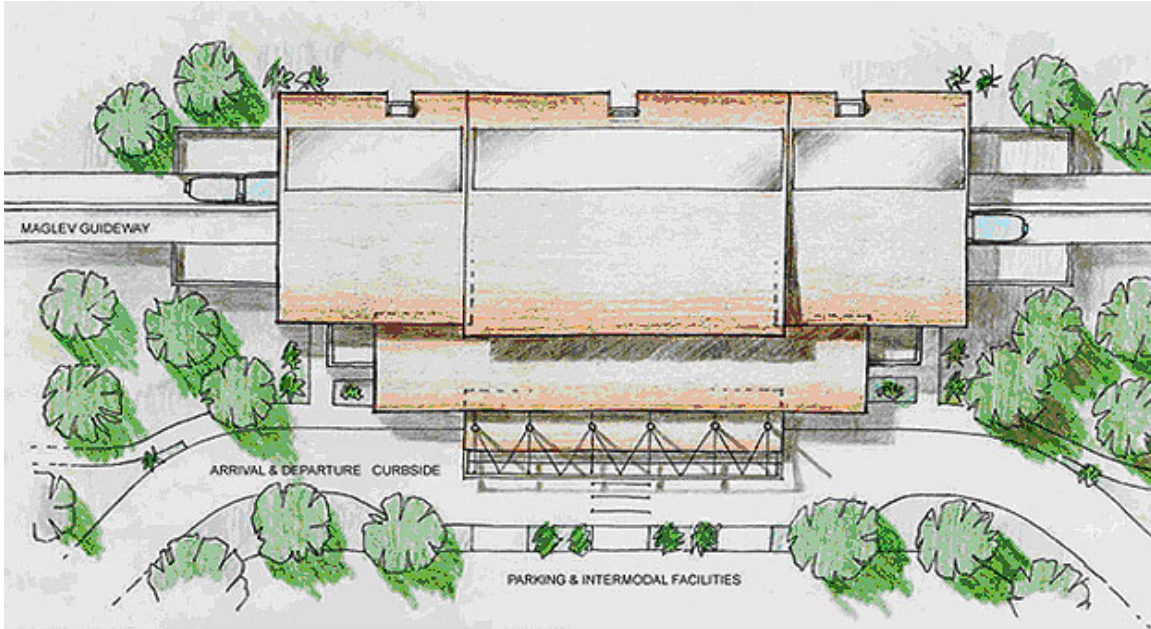


Figure 77: Maglev Station Prototype: Roof and Site Plan

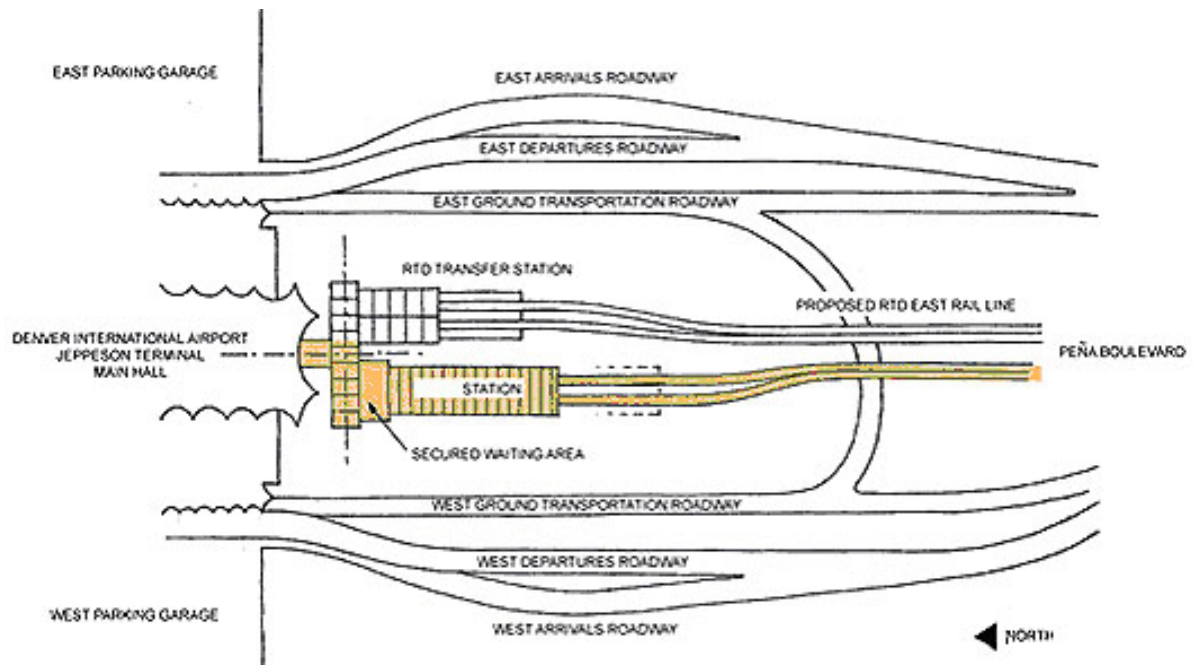
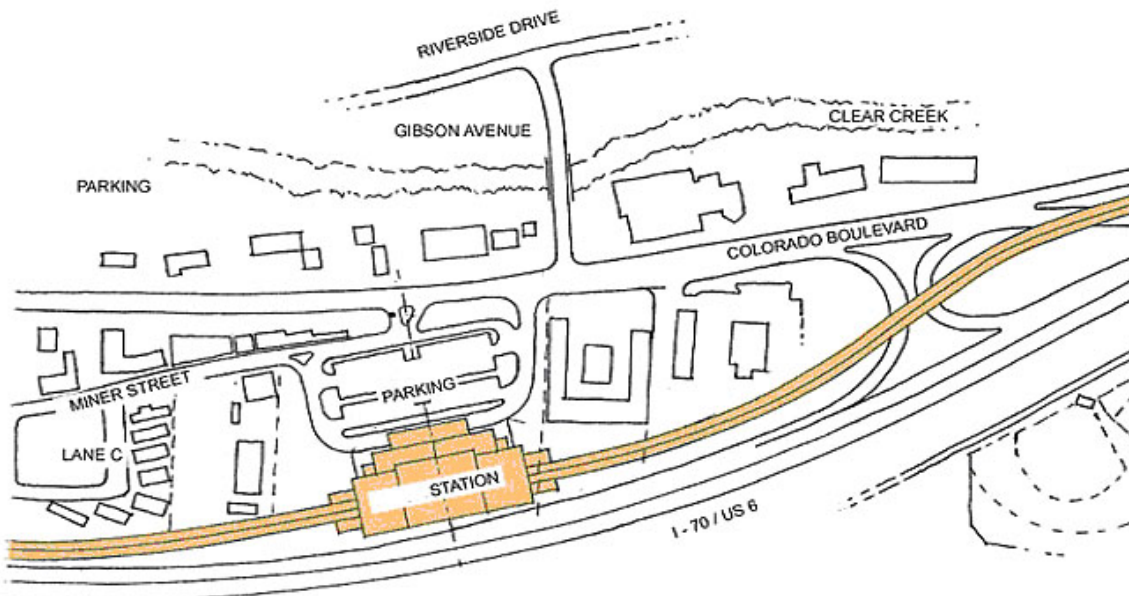


Figure 78: Maglev Station Prototype: Terminal Prototype (DIA)



**Figure 79: Maglev Station Prototype: Urban/Suburban Prototype (West Denver Metro)**



**Figure 80: Maglev Station Prototype: Rural Destination Prototype (Idaho Springs)**

#### **8.2.3.4. Vehicle Storage and Switching**

Each station must have the capability to store trains not in use, and to switch trains from one direction of travel to the other. In this approach, the main active area of the platform is associated with the dock, a mechanism that moves trains laterally from the main guideway into the station platform. From this docked position at the platform, a train can move backward one train length into the storage position. In this position, it is available to maintenance personnel. A train which is moved directly forward one train length from the docked position is in position to be transferred to the other side of the station, where it can be injected into traffic moving in the opposite direction. Hence, this capability of transferring trains from one guideway direction to the other, while not at full speed, is fully equivalent to switching, although with a number of advantages.

One advantage is that the docking mechanism is less expensive than an equivalent deceleration/acceleration lane, although it would exhibit somewhat less operational effectiveness in short headway situations. However, the headways in the Colorado system are long enough to take advantage of the dock's lower cost, and analysis of the dock's performance shows that it will not impact headway.

A second advantage is the lowered cost of a transfer table switch. Since it is located in the station, it is protected from inclement weather. Further, if properly designed, the transfer mechanism can function as a second docking mechanism, providing redundancy to the primary dock.

## 9.0 **COLORADO MAGLEV PROJECT DEPLOYMENT GUIDE**

### 9.1. INTRODUCTION

This deployment guide for the CMP addresses the step by step procedure to implement the proposed system. With modification, this deployment guide can be used for the BART Oakland Airport Connector, the Montgomery County Maryland system, potential maglev system use for WMATA and the Los Angeles Maglev Projects, as well as other maglev projects in the United States. Each additional deployment will need site-specific modifications due to local circumstances, including certification and approval requirements of the states, counties and regions where the projects may be implemented.

This deployment guide for the CMP addresses the feasibility of deploying the Colorado 200 Maglev System between the DIA and the Eagle County Airport, a distance of approximately 250 km (155 miles). This maglev system technology can provide high quality, efficient transportation service between the Colorado Front Range communities and the mountain areas.

The CMP Deployment Guide is organized as follows:

1. Deployment Objectives and Issues
2. Deployment Planning
3. Critical Deployment Elements

The Deployment Guide identifies and examines the feasibility of incorporating the Colorado 200 Maglev system into the Colorado I-70 mountain corridor. This project is under evaluation by both the Colorado Department of Transportation (CDOT) and the United States Federal Transit Administration (FTA) through the Urban Maglev Technology Development Program.

The organization of the Deployment Guide provides a template for other potential maglev applications. Using this guide, a formal Deployment Plan should be prepared upon conclusion of additional project phases, including final engineering, of the CMP.

#### 9.1.1. **Deployment Guide Summary**

The CMP Deployment Guide identifies and defines all of the critical elements required to deploy a successful maglev transit system in the I-70 corridor. Following the substitution of project-related specifications, the Deployment Guide is intended to provide a stand-alone process that can be applied to any maglev project in the U.S. Therefore, the Deployment Guide for the CMP includes limited repetition of information discussed in other sections of this report, specifically the project description, vehicle description and technical modifications for operations in the I-70 mountain corridor.

The CMP is evaluating the deployment of a maglev system in the I-70 corridor to help meet the growing travel demand created by the recreational opportunities in the Colorado Rocky Mountains. The CMP team selected the CHSST technology as the basis for all system research, development and design work for the I-70 corridor. The selection of the CHSST technology was based on CHSST's profile of demonstrated maturity, probable domestic cost, and superior performance. The project effort has produced a design for the Colorado 200 vehicle, by modification of the existing CHSST 200 vehicle. The Colorado 200 vehicle can meet all of the system requirements needed to travel along the I-70 alignment; it is capable of a medium speed of 160 kph and has a carrying capacity of approximately 200 passengers in a two car consist.

The objective of the Deployment Guide is to identify critical issues and steps that are necessary for the successful implementation of the maglev system along the I-70 corridor.



The first step is the identification of issues critical to the project. These issues include technical issues of service and performance, and issues of cost, which determine the ultimate feasibility of deployment and operation.

The second step is the development of a rational plan for staged deployment.

The Staging Plan addresses the approach necessary for staged construction of the CMP by identifying the first segment for construction, and then identifying subsequent segments and the order of construction. The Staging Plan suggests a staged sequence of segments based on a number of assumptions. If these assumptions are later modified, then the Staging Plan would necessarily be changed.

The completed Staging Plan will identify the key project milestone(s) and major project activities that are critical to successful implementation of the project, with major emphasis on the selection of the first and then logical subsequent segments to be built to respond to the growing congestion along the I-70 corridor in the most effective manner. The completed Staging Plan also provides the basis for a realistic schedule for project implementation.

The following ground rules were used to develop the staging plan analysis:

1. The first segment would be capable of operating as a transportation system without the construction of additional or connecting segments.
2. The system would be staged within the ability of the governing entity or entities responsible for construction to generate adequate funds.
3. The first segment would be selected to generate sufficient patronage to justify the decision.
4. The first segment should cause the least residential and business displacement due to ROW acquisition.

In addition, a dollar limitation will be defined as the maximum maglev system construction expenditure that could be effectively managed within the Colorado region without seriously impacting local resources and economic patterns. Taking into account project-related issues, the staging of transportation improvements should logically follow the need to relieve congestion as it occurs or to relieve the reasons and cause of the congestion. Therefore, additional area-specific travel patterns were also taken into account in the identification of the first segment, with the assumption that congestion relief is the over-riding factor in the Staging Plan.

Working in cooperation with the CDOT I-70 PEIS consultant team, technical data related to project issues has been shared between the CDOT and FTA consultant teams. The CDOT team has identified that the major congestion relief is needed between Golden and the EJMT. The FTA team has concurred with this conclusion, although from a transit perspective, the segment from Golden to EJMT would be a transit segment of approximately 72 kilometers (45 miles) in length, which is longer than traditional first segments for new start transit systems in the United States. Regardless, this segment would serve the major congestion that is occurring along the I-70 mountain corridor and is being evaluated as the CMP's first segment. Due to its rural setting, this segment would have the least negative impact resulting from residential and business displacement.

A major transit hub is already programmed by the Denver Regional Transportation District to be located in Golden with LRT, bus service, ample car parking and car drop-off areas providing access to a Golden LRT station. The Golden Station is also a major station for deployment of the CMP and would provide the necessary interface with other transportation modes serving the metropolitan Denver area. At the EJMT end of the first segment, bus service distribution to and from the ski resorts would be provided.

Potential segments for follow-on implementation should logically be taken from the interface point with the completed first segment of the system. This is desirable to avoid unnecessary turnarounds that would later become redundant in addition to providing continuity of service

without the requirement for separate supporting facilities. The next segments following the Golden to EJMT line would be from EJMT to Frisco, then from Frisco to Copper Mountain. The final mountain segment would traverse between Copper Mountain and Vail, assuming the Eagle County Airport to Vail link is operating. The final segment of the CMP would connect Golden and DIA.

As part of the Staging Plan, it is necessary to develop approaches to operation and maintenance, since both areas can have an impact on the system deployment.

The Systems Operation Plan describes the plan for operating a maglev system for the entire length between DIA to Eagle County Airport, although operations plans would be further developed for each individual segment as policy decisions are made on the construction staging. All necessary aspects of system operations are defined in the Systems Operation Plan. The Systems Operation Plan also provides inputs necessary for the development of a financing plan.

The detailed financing plan includes a cost analysis of capital costs, a maintenance plan and estimation of operation and maintenance (O&M) costs, together with mechanisms to sustain the necessary flow of funds through the system life cycle. Capital costs include initial costs of establishing the vehicle fleet, guideway construction, station construction and maintenance facility construction. Although the total system capital cost has been estimated for building a maglev system from DIA to Eagle County Airport during the project integration effort, the detailed financing plan was targeted for completion as part of the commercialization effort.

The Maintenance Plan helps to define the operations and maintenance costs by tabulating system personnel and staffing requirements as well as establishing a maintenance philosophy to account for spare parts and system upkeep costs. The operations and maintenance (O&M) cost estimates are based on the Operation Plan, the ridership estimates and experience from the previous deployments of CHSST in Japan as well as extended test track test results and other demonstration runs at various exhibits.

Finally, the CMP Deployment Guide concludes with the sequence of events and subsidiary supporting documentation, which are integral components of deployment. One of the most important documentation elements required the development of a Request for Proposal outline for the CMP deployment. A further documentation element defines the government certification / approval program that will be necessary for system deployment. This element includes requirements pertaining to the State of Colorado, RTD, USDOT (FTA, FRA and FHWA), the Federal permitting process, Environmental Agencies including EPA, and the counties through which the system traverses. It will be necessary to complete federal environmental assessment to meet the National Environmental Protection Act (NEPA) and the system will be subject to FRA safety jurisdiction.

## **9.2. COLORADO I-70 MAGLEV PROJECT DESCRIPTION**

The CMP is evaluating the deployment of a maglev system in the I-70 corridor to help meet the projected I-70 travel demand. The characteristics of the I-70 corridor require a transit system that can climb steep grades, maneuver tight horizontal curves and withstand the severe winter conditions inherent in the Colorado Rocky Mountains including heavy snow, ice and high winds. Although no maglev system has yet been deployed in the U.S., research and development has been ongoing for over 30 years in Japan, Germany, Korea and the U.S. with systems successfully tested and deployed in Japan and China.

Magnetic levitation is a cutting edge technology employing the use of magnetic fields to suspend a vehicle that is traveling over a dedicated guideway. Servo controlled electromagnetic attraction prevents any physical contact with the guideway, and the vehicle literally flies, separated by a very small gap, along the guideway. The propulsion subsystem needed to move the vehicle

along the guideway uses non-contact linear induction motors (LIMs) on the vehicle and can handle grades similar to those found in the I-70 corridor.

During the course of the CMP, technical information was gathered for maglev systems including all or most of the systems in the world that currently exist and are in a deployment or pre-deployment phase. Following review and assessment of the available systems, the CHSST system, an urban/rural regional system currently being deployed in Nagoya, Japan, was selected as the baseline for the Colorado Project. A number of system modifications have been identified as necessary for the CHSST Nagoya system deployment in Colorado, and are discussed in subsequent sections of this Deployment Guide.

In order to operate in the challenging terrain of the Colorado Rocky Mountains additional vehicle power is required, and can be provided by increasing the size and number of LIMs on the vehicle. The levitation approach used by the CHSST system has been widely used for many years, although some modifications will be required for use in Colorado.

Due to its maturity, cost, and performance profile, the CHSST technology has been selected as the basis for all research, development and design work related to the CMP. The CMP is one of the alternative transit systems (identified in the Advanced Guideway System (AGS)( category of transit systems) under consideration for the overall CDOT I-70 PEIS; a comprehensive Colorado state and USDOT Federal Highway effort to understand the transportation and environmental issues surrounding the I-70 mountain corridor while exploring alternatives to reduce congestion and address safety, environmental and other community concerns. The I-70 PEIS is assessing a variety of highway, transit and combination methods to increase transportation capacity and relieve congestion along the I-70 corridor from Denver to Glenwood Springs.

The CMP, a coordinated effort between FTA and CDOT, utilizes resources from the Urban Magnetic Levitation Transit Technology Development Program to assess the viability of deploying a maglev system from the DIA to the Eagle County Airport, generally following the I-70 freeway alignment.

The CMP team has worked to define the most cost effective, dependable magnetic levitation system possible with the goal of deployability. As part of the project, the following factors were defined and evaluated:

- Route Alignment
- System Requirements
- Guideway / Switches
- Vehicle
- Stations
- Integration of Subsystems
- Security

The I-70 PEIS and the FTA CMP worked independently, although data and analysis were shared and coordinated in order to provide a thorough and consistent analysis for both efforts.

### **9.2.1. Route Alignment**

The CMP team began work in early 2002 with the ultimate goal of working towards deploying a system with cost containment being a key ingredient for the ultimate success of the project. Definition of the transit alignment from DIA to Eagle County Airport was initiated early on in the analysis to assess the requirements of this specific corridor. There are two distinct parts of the CMP alignment: an urban alignment in the Denver metropolitan area and a mountain alignment west of the Denver area.

For the urban alignment in the Denver metropolitan area, a northern route along 96<sup>th</sup> Avenue and I-76 to I-70 was selected from DIA to Golden, while the mountain alignment closely follows the I-70 mountain corridor alignment.

The proposed maglev system generally following I-70 will be on an elevated guideway, either in the median or paralleling the highway on either the north or south side. Since the maglev system is capable of operation on grades in excess of 10 percent, alternatives to costly tunnels are available in the Twin Tunnels area east of Idaho Springs as well as at the Eisenhower Tunnel.

**9.2.2. I-70 Maglev System Requirements**

The general system requirements for any maglev transit system, as modified specifically for the I-70 corridor, are shown below. The requirements are substantially those previously produced by the FTA Urban Maglev Technology Development Program. These requirements have been modified to incorporate modifications resulting from the Colorado I-70 project alignment and anticipated ridership levels. While these requirements may be applicable to other geographical locations, they are the top-level system requirements that apply to the design, construction, and operation of a maglev system in the I-70 corridor.

**Table 9.2-1 Maglev System Requirements**

	<b>Value</b>	<b>Comment</b>
Technology	Use Magnetic Fields for Suspension, Propulsion, Guidance, and Braking	Program defined requirement. The Vehicle's suspension, propulsion and braking shall be accomplished by magnetic fields.
Throughput	40,000 passengers per day; 6,000 passengers in the peak hour, peak direction	Latest estimate. Subject to change but will be used as a basic requirement to define number of vehicles, size of vehicles, dwell time, etc. (Reference Technical Assessment of Maglev System Concepts, Special Report 98-12. Required to serve the very high volume markets.)
Accessibility Standards	American Disabilities Act	Compliance with public law 101-336 July 26, 1990 104 statute 327, Title II, Subtitle B, Parts 1 and 2.
Usage (Hours of Operation)	20 hours / day, 350 days per year	The number of cars per train can be varied based on demand over the 20 hours. 15 days a year for overall system overhaul
Passenger Minimum Waiting Time	Trip delay threshold of five minutes	Trip delay threshold for those failures, or combination of failures, that impact on-time performance (Type 1). Per IEEE standard 1474.1 – 1999.
Weather Operation	All Weather Operation	All weather operation required
Operation, Fully Automatic	Automatic Train Control (ATC) per ASCE 21-96 for Driver-less operation	Driver-less operation. The ATC system shall provide the features of protection, operation and supervision as outlined in ASCE 21-96, Chapter 5.
Grade, Maximum capability	10% for a minimum of 460 m	Vehicle shall negotiate 10% grade at line speed (which has yet to be determined) for a minimum of 460 meters. 12% grade causes degraded performance
Grade, Operating capability	7% at line speed with no degradation of performance	Vehicle shall negotiate 7% grade at line speed (which has yet to be determined) with no degradation of performance. The average maximum grade for the primary alignment is 10%
Guideway	Grade separated for exclusive use	The guideway should be designed to limit access to surface traffic, pedestrians or animals.

	<b>Value</b>	<b>Comment</b>
		Elevated guideway improves safety, allows use of existing right-of-way and minimizes impact on urban environment.
Stations	TBD	Station platform configuration along with specific dimensions shall be a function of total train length and stopping tolerance, number of passengers loading and unloading, etc. There will be one or more platform areas. The area required, number of berths, escalators, elevators, stairs, etc. will be determined.
Aesthetics Philosophy	Non-Intrusive Construction	The design philosophy of the guideway will be to minimize impact on existing structures during construction, and to be sensitive to the architecture of the area under construction. The guideway will be aesthetically pleasing to a large majority of the public, and will blend with and enhance the environment through which it passes. Areas below the guideway will be visually enhanced if possible.

**9.2.3. Guideway**

Maglev systems rely on a guideway structure to carry the vehicles and accommodate the active or passive components of the levitation, guidance, propulsion and braking systems. Whether the vehicles operate at grade or elevated, a structural guideway has traditionally been employed to maintain strict alignment tolerances and provide a secure and reliable track way. The structural guideway is widely considered to represent a majority (over 60%) of the overall construction cost of a maglev transit system.

A major component of the CMP is the development of an economical and aesthetically pleasing guideway structural system that is readily deployable along the Colorado I-70 corridor and is likely to be adaptable to other potential applications within the U.S. as well.

**9.2.4. Vehicle**

A technical objective of the Colorado Project is the integration of a maglev system design based on existing or developable technologies. The CHSST 100L vehicle is currently being deployed in Nagoya, Japan with the technology defined as mature. The CHSST 200 vehicle has been demonstrated and operated in exhibition in Yokohama, Japan. The 200 vehicle, modified for use in Colorado, is the appropriate vehicle for the Colorado application.

**9.2.5. Stations**

The Colorado Project guideway is roughly 250 kilometers (155 miles) long. There are fourteen potential stations. A number of station prototypes have been identified including:

**Terminal station.** This station type possesses functions unique to high volume origin/destination traffic, providing intermodal interchange without substantial station-specific automotive traffic. The DIA and Eagle stations are likely to be the only stations of this type in the Colorado system. The DIA terminal station benefits from the traffic infrastructure already put in place to support the airport. The Eagle Airport station, although a lower passenger volume station, will have similar characteristics.

**Urban/suburban collector station.** This station type aggregates traffic from other transportation modes (automobiles, vans and buses) for entry/exit to and from the maglev system. The I-70/I-25 station and the Golden station are examples of this station type.

**The rural destination station.** This type of station typically receives traffic from the urban/suburban stations, and returns the same traffic over the course of a day (although in the case of mountain-based commuters, the flow is reversed). Most of the mountain corridor stations will be this type. These stations must only support limited amounts of wheeled traffic and must have good support for hotel shuttle and rental car modes.

### 9.3. COLORADO MAGLEV PROJECT TECHNOLOGY CHARACTERISTICS

#### 9.3.1. Vehicle Background

CHSST has previously deployed numerous systems and is presently deploying the TKL connection in Nagoya, Japan. The CHSST system is a mature system and developed sufficiently for successful deployment in Colorado and elsewhere in North America. The CMP team has specified the CHSST system with the necessary modifications as the system for the I-70 mountain corridor.

Passenger demand, trip time, and other requirements developed for the CMP mandated a maglev vehicle(s) capable of medium speed (160 kph) and carrying approximately 200 passengers.

For the Colorado I-70 application, the CHSST-200 vehicle has the approximate passenger capacity and an acceptable level of vehicle performance. A larger propulsion motor currently available for use in the CHSST-200 has been extensively simulated and found to be well suited to the Colorado requirements.

#### 9.3.1.1. Colorado 200 Vehicle Parameters

The following vehicle parameters have been developed for the proposed Colorado 200 vehicle:

##### VEHICLE

Length (each car)	24.3 m (80')
Width	3.2 m (10'6")
Height	3.65m (11'6")
Passengers per car	103 seated
Train set	2 cars per set
Weight of single vehicle	44 Tonnes (approx. 97,000lbs)
Levitation and Guidance	Attractive Electromagnets
Propulsion	10 LIMs per car
Propulsion Control	VVVF Inverter 2000kVA, 1000a max Freq. 0-90Hz, 1 unit/car
Bogie System	5 modules under each side of each car
Electrical System	3000VDC
Environmental Control	Heat pump
Operator	Automatic Train Control

##### PERFORMANCE

Max. Speed	200 km/hr
Max. Acceleration	4.5 kph/sec
Min. curve radius	150 meters
Max. Grade	7 %

##### LONGITUDINAL CONTROL

Automatic Train Control	Packet Radio Between Vehicle/Guideway
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##### SAFETY SYSTEM

Fail-safe	Moving Block, vital components
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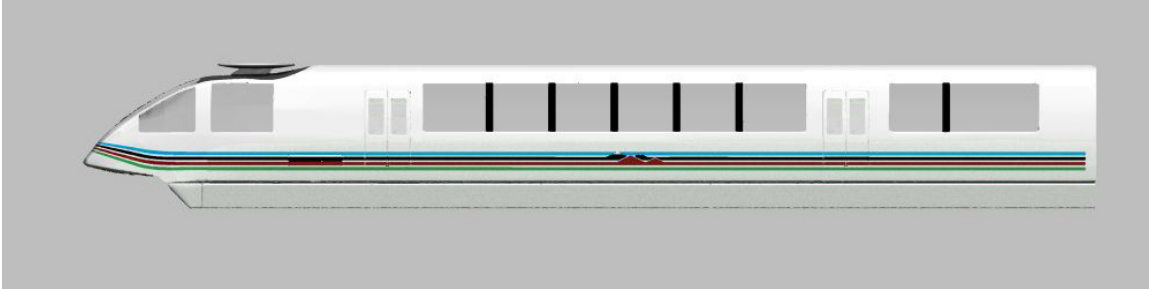
**POWER SOURCE**

Collected from Wayside

3,000VDC,

**9.3.1.2. Vehicle Description**

The modified version of the original CHSST-200 design has been designated as the Colorado 200.



**Figure 81: Colorado 200 Vehicle**

The Colorado maglev train consists of two Colorado 200 vehicles in a permanent married-pair configuration. The two cars are identical in every respect except for their seating patterns and have the same levitation, motors, and electronic controls. The vehicles are exclusively electric, taking power from local utilities at 3000 V DC through a compliant current collector running along power rails mounted on the side of the guideway. Due to the use of fully automatic controls, the train consist may travel in either direction with equal facility.

Each vehicle carries two sets of bi-parting doors on each side, through which passengers embark and disembark. Each vehicle is fully fenestrated with large window areas on both sides, and in front. The forward facing windows are made of a heat absorbing safety glass, and the side windows, including the windows in each passenger door, are tempered safety glass.

The interior of a single car offers eighty-nine lightweight seats, and positions for two wheelchairs, one close to each doorway pair. Additionally, twelve folding seat positions are available, for a total per vehicle passenger capacity of one hundred three.

**9.3.1.2.1. Structure**

The vehicle structure is divisible into two sections: car body (upper portion) and a series of levitation modules, or bogies (lower portion). Fully loaded vehicle weight, including modules, is estimated to be 44 tonnes (~97,000 lbs). Each vehicle is 24.38 meters (80') long, 3.2 meters (10'-6") wide and 3.5 meters (11'-6") high.

The car body structure is principally aluminum alloy with use of fiber-reinforced plastic and a thin aluminum plate, of semi-monocoque construction, consisting of frames, stringers and skin panels. Each Colorado 200 vehicle body is attached to ten levitation modules (five under each side of the car), which provide the levitation and propulsion for a single car. Each module is a complex assembly, carrying levitation electro-magnets and gap sensors, linear induction motors, hydraulic brakes, emergency rollers and landing skids.

**9.3.1.2.2. Levitation**

The physical principle underlying all maglev technologies is the use of magnetic forces to levitate and propel vehicles without any physical contact with the guideway. This results in vehicles having a comfortable ride, lower environmental impact in terms of noise and vehicle emissions, and lower stresses on transportation infrastructure than any other transportation technology. The magnets are carried in the levitation modules. Four individual levitation magnets are housed in

each module.

#### **9.3.1.2.3. Secondary Suspension**

While the primary suspension of the vehicle is provided by the levitation and guidance system, air springs and mechanical linkages provide the secondary suspension. The suspension system holds the car body gently so as to give excellent ride comfort and resistance to external disturbances. Various forces work between the car body and the modules in vertical, lateral and longitudinal directions. The air suspension system, which comprises air springs and its supporting devices, holds the car body in vertical and lateral directions.

#### **9.3.1.2.4. Power Conditioning**

The electrical power system of the vehicle consists of an on-board power converter/inverter apparatus referred to as the power supply unit (PSU), input switch, and battery. Two PSU's are installed on a 2-car train. The power supply unit transforms the high voltage direct current (3000 V DC) picked up by the onboard current collectors into the following three types of electrical power:

- Main DC Power 275 V DC for levitation, air conditioner
- AC Power 100 VAC 1 ph 60 Hz, for general housekeeping use
- DC Power 100 V DC for control and communication

#### **9.3.1.2.5. Propulsion**

Vehicle propulsion is provided by linear induction motor (LIM). The LIM is simply a rotary motor opened out into a flat configuration. Each primary coil (stator) of the motor is mounted in the levitation module on the underside of the vehicle. The primary reacts with a thin aluminum reaction plate (rotor) installed along the top surface of the levitation rail to propel the vehicle. This minimizes the complexity of the guideway with the added benefit that if a motor fails, only the train itself is affected, not the system as a whole.

The propulsion elements consist of one inverter and ten LIMs for every car. Each LIM is installed on the under surface of the module's main structure and is supported at multiple fixed points. Each LIM is approximately 2.9 m (9' 6") long, 0.6 m (2') wide, and 80 mm (3.2") thick.

#### **9.3.1.2.6. Variable Voltage Variable Frequency (VVVF) Inverter**

The wayside DC electrical power, supplied through the high voltage input section of the VVVF inverter, is inverted to produce AC power with appropriate voltage and frequency for the LIM.

#### **9.3.1.2.7. Braking**

The brake system features two independent components: electric service braking using the LIM (providing regenerative and reverse phase braking) for normal operation, and a supplementary hydraulic brake used when the vehicle is traveling below 5 km/hr (3.1 mph) (the transition from electric brake to hydraulic occurs at approximately 5 km/h).

However, in case of an emergency, the hydraulic brake system can be used at any speed. The hydraulic brake system is designed and sized to handle full emergency braking needs and assumes no assistance will be available from the service braking system during an emergency.

#### **9.3.1.2.8. Landing Skids**

In case of catastrophic failure with no power of any kind available to levitate or control the vehicle, it will descend onto the landing skids, which consist essentially of brake pads mounted on the vehicle under structure. These pads will come in contact with a predetermined surface on the levitation rail and the vehicle will stop safely without damaging the modules or guideway. The weight of the vehicle provides a reproducible braking force if these skids become necessary and



the stopping distance can be predicted confidently, even under adverse environmental conditions.

#### **9.3.1.2.9. Emergency Rollers**

The purpose of the emergency rollers is to support the train when the levitation has been compromised or lost. The emergency rollers and associated hydraulic actuators are installed near each landing skid at the front and rear ends of each module. When the hydraulic actuators are operated, the emergency rollers can support the total vehicle weight. Hydraulic power for the actuators is supplied by the primary hydraulic system.

#### **9.3.1.2.10. Controls**

The levitation control element of the Colorado 200 is autonomous, responding only to the command to levitate, or delevitate. Control of propulsion, braking, and doors are the central focus of on-board vehicle controls. Commands for these three control elements can come routinely from the wayside for a variety of operational reasons, but propulsion and braking can also be actively modulated by the on-board controls in response to instantaneous local conditions, including emergency conditions.

In the Colorado system design, communications with the wayside are carried by packet radio. The vehicle carries redundant packet radios on each end of the train consist. These radios supply position, velocity, and direction of motion information, along with system operational commands, to redundant non-vital controllers. These, in turn, pass commands to a fully redundant vital controller.

### **9.4. DEPLOYMENT ISSUES**

A successful maglev deployment in Colorado must address a number of specific issues. These include capacity and operations to mitigate existing and potential congestion in the corridor, technical issues requiring modifications to existing maglev technology to render it suitable for a Colorado deployment, and those issues of cost which determine the viability of the deployment.

#### **9.4.1. Service Definition**

The primary issue within the I-70 mountain corridor is that summer and winter recreational opportunities in the Colorado Rocky Mountains west of Denver cause heavy traffic and delays for visitors, commuters and local residents. The heavy traffic is further exacerbated by severe weather conditions during the winter months. The travel demand in the corridor continues to grow in both the summer and winter seasons due to both the recreational popularity of the mountain areas as well as the growing employment in the mountain communities. Since the winter ski industry provides a significant economic benefit to the State of Colorado, the state's goal for the I-70 PEIS is to ensure continued accessibility to the recreational areas for visitors and residents alike while reducing congestion and addressing safety issues.

Due to the limited right-of-way in the mountain areas of the I-70 corridor as well as the cost associated with acquiring additional land, alternative methods of increasing the capacity of the corridor, in addition to highway widening, are being explored. These additional methods include combining a transit system with the highway widening or building a transit system or a highway system with dedication of land availability for the other mode of travel for future implementation. A number of transit alternatives are being considered including rail, bus and advanced guideway transit that includes a magnetic levitation system, the topic of the FTA research project effort for I-70.

As part of the PEIS effort, historical and current traffic volumes have been evaluated and future traffic volumes have been forecasted. Historical growth trends show an increase of traffic along the I-70 corridor averaging 3-5% per year. Current traffic patterns show that the most significant congestion occurs on weekends both in summer and winter months due to recreational travel to and from the mountains. Additionally, commuter-type congestion is also occurring in the

mountain I-70 corridor during the weekdays as the population expands further west from the Denver metropolitan area. Over the next twenty years, travel is forecasted to continue increasing, and any alternative targeted to congestion mitigation must take this into account.

In addition to forecasts of automobile travel, CDOT has also forecasted potential transit ridership in the I-70 mountain corridor. Transit use is forecasted to account for approximately 40,000 trips per day during peak travel times on winter weekends using a fixed guideway transit system such as the maglev system. This forecast indicates the potential ridership success of a transit system deployment in the corridor.

For the CMP, definition of the following minimum system details is necessary in order to deploy the maglev system along the I-70 mountain corridor. This definition has been the focus of the CMP effort.

1. Ridership must be finalized to establish vehicle inventory including spares and parts
2. Geography must be finalized to establish guideway configuration
3. Guideway costs must be finalized
4. Detailed operational studies need to be completed to set:
  - a. Headway
  - b. Control requirements
  - c. Reliability requirements
  - d. Revenue projections
5. Reliability requirements must be defined using:
  - a. Overall subsystem diagram
  - b. Top-level FMEA against subsystems, or against major components
  - c. Reliability allocation against subsystems
6. Vehicle design:
  - a. Propulsion, consisting of Inverter/LIM/controls combination
  - b. Structural analysis, to obtain weight and propulsion requirements
  - c. Levitation, to handle propulsion, weight
  - d. Vehicle costing
7. Controls
  - a. Control architecture
  - b. Headway maintenance
  - c. Braking performance
  - d. Precision stopping
  - e. Controls costing
8. Vital functions/Safety system
  - a. Vital components
  - b. Vehicle equipment
  - c. Station equipment
  - d. Guideway equipment

- 9. Winterization
  - a. System operating limits
  - b. Critical component identification
  - c. Thermal excursion problems
    - **Guideway**  
ice and snow removal  
drainage  
heating  
hydrophobic coatings
    - **Vehicle**  
doors  
levitation clearance/chippers
    - **Station**  
doors  
platform weather protection/docks

These definition details and resulting necessary service levels cited above have been identified through the FTA CMP effort. The final technical reports produced for the CMP define these details to the extent necessary to support thorough policy discussion and decisions concerning the project staging sequence and financial expenditure. Depending on the project delivery approach, whether through traditional, design/build, or other approach, system designs will need to be completed.

#### 9.4.2. **Winterization**

Winterization is a primary critical issue for the CMP, since the area is subject to weather extremes generally beyond those experienced in most of the United States. There are significant changes in elevation ranging from 1,620 meters (5,300 feet) at DIA to 3,400 meters (11,158 feet) in the mountain passes. This change in elevation directly affects the changes in temperature along the route varying by as much as 30°C (54°F). Additionally, snow can fall at rates exceeding 75 mm/hr (3 in/hr) with daily accumulations of over 0.75 m (30 in). The maglev system and subsystems will require additional modification to mitigate the impacts caused by these severe wintertime conditions.

Several failure mechanisms or modes have been identified as a result of the climate and environmental conditions specific to the Colorado I-70 urban and mountain corridor. These mechanisms include:

1. Avalanche
2. Frost Formation
3. Freeze/Thaw cycles
4. Differential Thermal Expansion
5. Snow and Ice Buildup
6. Corrosion
7. Fatigue

Individual maglev system components and subsystems were analyzed for potential failure due to the above listed mechanisms. Areas that could potentially cause the greatest impact due to failure were focused upon where potential solutions were summarized and costs estimated.

Due to measurement and data archiving efforts in the I-70 corridor, probable avalanche locations are known, and where possible can be avoided for construction of the maglev system guideway. In particularly difficult areas, avalanche sheds can be constructed to allow the avalanche to pass over the top of guideway, thus preventing harmful impact to the guideway or a passing vehicle.

Frost formation can potentially cause failures in a maglev system. Ongoing research is aimed at understanding frost formation mechanisms with hopes of identifying materials and coatings that delay the formation of frost. Although the major application of this research is related to alleviating frost buildup on refrigerator and heat pump evaporators, this work could also be useful in the effort to impede frost buildup on critical components of the maglev transportation system.

Freeze/thaw cycles and thermal expansion can cause damage to maglev systems by compromising the structural integrity of beams or columns. When water freezes, it expands and causes stress to the material. Over time the cycle of freezing and thawing processes continues until there are sufficient micro cracks to form larger cracks, form paths for surface tension, and eventually, flows of water that can contribute to crack enlargement and corrosion of metallic reinforcement and thus further accelerate the failure mechanism. Although one would normally consider reinforced concrete to be the major material in question, any porous material that can absorb water is susceptible to similar damage.

Snow and ice have a tendency to build up on solid objects during the winter months, especially when insufficient drainage is incorporated into the transit system design at the outset. Much of the impact due to winter climate can be eliminated with a guideway design that allows for adequate drainage. This can minimize the impact of the freeze thaw cycle failure mechanism. Therefore, it is important to severely limit the number of horizontal surfaces that can collect and retain snow and ice.

Careful thermal design of active electrical heating elements for critical subsystems can yield large payoffs in system efficiency. It is best to incorporate these designs into the guideway at the outset so that they are an integral part of the design. Additional thermal analysis may lead to the establishment of electrical heating requirements for the guideway to help mitigate snow and ice buildup. This would include heating and insulating parts of the guideway.

Switches are used along the guideway to move vehicles from one guideway to another or to reverse directions at the end of the line. Four different types of switches have been analyzed for use in the maglev system and each was analyzed for winterization issues. To minimize the impact of snow and ice on switch guidance systems, heaters would be used to warm particular rail sections when there is substantial snowfall. The heaters should also be insulated to maintain the heat where it is needed and therefore, minimize the energy consumption.

There are three independent braking systems on the Colorado 200 maglev system. Winterization for all three of these braking systems involves keeping the structural rails, motors and brake calipers free of snow and ice. The structural rails will likely include an electrical heating system for critical elements in some locations. However, improved rail drainage may result from incorporating an incline into the rail design. Additionally, heat dissipation from the motors is expected to provide some energy that would help to dissipate snow and ice. Strategic use of hydrophobic coatings on certain guideway elements can eliminate the need for heating under many conditions.

Corrosion to the transit system metals can be caused by road salt, which is used extensively as a deicer on Colorado highways. These will add to the chemical activity of the available water, making it more corrosive than that of atmospheric water.

Corrosion and cracking due to differential thermal expansion cycling or more importantly, cyclic loading from the normal system operations and wind loads can lead to enhanced problems with component or system fatigue failure. With recent advances in microelectronic sensors, it is possible to incorporate displacement sensors within the guideway and vehicle structure during the capital construction process, so that the development and propagation of cracks or the local stress within the guideway can be monitored during later operation.

Snow removal will be imperative for safe operation of the maglev system. Specialized vehicles or transit vehicle modifications, such as fully autonomous snow/ice clearing vehicles, or the addition of snowplows to the front of the vehicles, will be necessary to assist in snow/ice removal. In addition, the transit system will rely heavily on accurate weather forecasting so that adequate preparations can be made, and smooth operations can be preserved.

#### **9.4.3. System Technical Modifications for Operations in Colorado I-70 Mountain Corridor**

Evaluation of the CHSST vehicle technology has indicated that existing vehicles have neither the grade climbing performance nor top speed necessary to meet Colorado Project requirements. Project research has disclosed that these deficiencies are easily correctable by modification of existing subsystems. Furthermore, the present system is manually operated and controlled. The Colorado Project requires full control automation, which is fully feasible for CHSST vehicles with only limited vehicle modifications.

The following modifications have been identified for the CHSST system and Colorado 200 vehicle for deployment along the I-70 mountain corridor:

1. Modification of the CHSST 200 linear induction motor as prescribed by the Propulsion Trade Study.
2. Modification of the propulsion electronics to accept 3000V DC electrical power. This may be a minor modification, depending on the method selected.
3. Implementation of a new control subsystem for the entire maglev system.
4. Implementation of new low-cost guideway designs developed for the system.
5. Implementation of new switch designs for in-station switching.
6. Modification of the CHSST 200 vehicle seating plan to accommodate 200 passengers in a two car consist.

#### **9.4.4. System Costs**

The following sections provide a discussion of the system costs including capital costs and operations and maintenance costs. These costs were carefully compiled, with the following factors in mind:

Continuing large cost overruns in transportation projects over the last few years were a primary motivation behind careful cost estimation for the CMP. The Project team was determined to produce the best possible estimates for system capital cost, with contingencies clearly displayed to accommodate unforeseen local conditions and circumstances.

Historically, cost estimation has been a hit-or-miss process, with “educated guesses” garnered from industry participants inflated by undisclosed contingencies, wildly fluctuating commodity pricing (both energy and raw materials), and uncertain project schedules all contributing to eventual uncertainty in the estimated costs. Faulty estimation has compounded the difficulties of project management, and has provided opportunities for constructors to unjustifiably inflate bid costs. Although affected agencies and properties have attempted to mitigate the impact of these factors through forward pricing models and aggressive cost containment techniques, cost escalation has been the rule. The inevitable downside of this flawed process has been considerable overrun in experienced costs.

There is also a progression of estimate refinement in any project, and the consistent pursuit of the estimate refinement process is critical to eventual project implementation. The results of the first phase of the process, for the CMP, are contained in this Final Report. Subsequent project phases will refine these estimates, particularly in the detailed examination of tunnel alternatives and station configurations. However, during this initial phase, special attention has been paid to the estimation of guideway costs, which represent by far the largest element of capital costs. Due to both the level of effort and to the nature of the estimating process, it is expected that projected

guideway costs will continue to fall within this initially estimated range during subsequent rounds of cost refinement.

Guideway costs were estimated by T. Y. Lin International, bridge designers and constructors with projects world-wide. Using three conceptual designs produced specifically for the CMP, T. Y. Lin estimated per-mile "standard" guideway costs using labor rates from recent CDOT bridge projects. Additionally, a sampling of route sections requiring special consideration for higher cost implementations was selected for further study. From these samples, per-mile cost estimates were derived for "exceptional" guideway, requiring more expensive implementations. Finally, an assessment of the overall route was conducted, and relative percentages of standard and exceptional guideway were established. Using the per-mile cost estimates for each guideway type, it was then possible to produce an estimate for the overall guideway cost. A contingency was clearly displayed at the conclusion of this process, to insure that the finally applied costs would accurately reflect additional uncertainties, which might be discovered in the next estimation phase.

At the direction of the FTA, MTG undertook to evaluate, in preliminary fashion, costs for tunneling alternatives in the Twin Tunnels and Eisenhower-Johnson Memorial Tunnel sections of the route. Tunneling costs are additive to guideway costs for these sections, but must be included in the capital costs, so it was important to demonstrate that inherent costs of different tunneling options can exhibit wide variation. This demonstration serves to establish priorities for further studies of the options in, and refinements of, the projected tunneling costs.

To collect cost data for estimation of other portions of the system, the Project team interacted directly and extensively with prospective suppliers of system and subsystem elements. These suppliers ranged from firms in the energy market to manufacturers of sophisticated electronic equipment. Although the system was divided into subsystems according to the nomenclature defined in the system integration task, pursuit of cost information went well below the subsystem level in some cases.

For example, levitation rails represent a critical element of the guideway subsystem. For levitation rail cost estimation, two independent cost estimates were obtained from widely different sources, one foreign and one domestic. In addition, raw material costs, and fabrication and transportation costs for these elements were investigated directly with steel producers and steel production equipment suppliers. The result was two independent estimates for rail costs that were well correlated. The end result could be presented with confidence as the probable cost of levitation rails during the time period when the estimate was produced. In addition, effort was also expended to characterize the elements of risk in the steel production and fabrication industries, which could influence the expected cost in the future. If the rail costs are to be refined in a subsequent project phase, the information developed in this process will guide the refinement, saving time and money.

For other system elements, time and available resources precluded the use of multiple estimation sources in most cases. In the case of stations, three types of station floor plans were produced specifically embodying features required for the Colorado system. These floor plans, complete with passenger management equipment requirements, were communicated directly to an architectural firm with extensive light- and commuter-rail transit experience. This firm provided per-square-foot estimates of recent construction costs that could be expected for the given station capabilities, and these estimates were used as the basis for station cost estimation.

System switches were estimated from single vendor estimates provided for each of the two switch configurations likely to be used in the system. Due to the high cost of switches, these costs were broken out separately in the overall system cost estimate.

Vehicle cost estimates were provided directly by the prospective vendor who developed the technology, and who has direct recent experience with vehicle construction and delivery. The

cost estimates were based on the specific "Colorado 200" vehicle configuration developed for the Colorado system.

Power equipment costs were estimated using vendor provided cost data, and was based on specifications for substation and power distribution apparatus developed by the Project team.

Communication and controls costing was derived from the experience of transit properties using comparable equipment. The configuration of the CMP was used to specify quantities and specifications for equipment to fulfill this requirement, and vendor provided cost data was used to compile the estimate.

The research has shown that deployment of this maglev system technology in Colorado could be achieved in compliance with Buy America provisions of U. S. law. All civil works could be constructed using domestic materials and sources. Electronic equipment, including the propulsion motors, could be domestically sourced. The vehicle subsystem, which would typically be manufactured in Japan, could be produced under cooperative manufacturing agreements in the U. S. The vehicle manufacturer has experience with such arrangements, and the vehicle subsystem would qualify as U. S. manufacture under this approach, with a minimum of 60 percent domestic content and final assembly in the United States, in full compliance with both the intent and wording of federal law.

During the course of the project, prospective U. S. manufacturers and vendors were identified for major critical components such as guideway girders, vehicle structures, linear motors, and controls. Public identification of these manufacturers and vendors at the present time could compromise the ability of these prospective suppliers to compete in future procurement activities. Accordingly, these contacts were made under agreements of confidentiality. Based on these contacts, it can be asserted that every element of the full system could be supplied by a U. S. firm. However, the optimization of system cost can only be achieved through U. S. firms working in concert with the Japanese developers of the technology within the Buy America framework.

**9.4.4.1. Capital Costs**

The following table summarizes the capital costs for the full CMP from DIA to Eagle County Airport. The use of M in the table specifies Millions.

**Table 9.4-1 Maglev System Capital Costs**

Unit Capital Costs:

Major System Elements

	Unit Costs
Guideway	Standard Guideway
	\$10.7-13.8 M, per mile
	Exceptional Guideway
	(Long Span Bridges, Curves)
	\$24.4M, per mile
Rails	\$1.6 M, per mile
Switches	\$2.6 M, each
Stations	\$30 M, each
Vehicles	\$7 M, per consist
Comm, Controls	\$2 M, per mile
Power	

Substations	\$4M, per substation
Electrification	\$1 M, per mile

\*Aggregated Capital Costs:

System Parameters:

Total Guideway Length – 252.6 km (156.95 miles)  
 Guideway Composition, 85% Standard, 15% Exceptional  
 Total Number of Stations – 14  
 Vehicle Inventory - 65 two car trains  
 Power Substations – 32

Guideway	\$2,401 M	\$32M per mile (With tunnel) <sup>15</sup>
Rails	\$251 M	
Switches	\$36 M	
Stations	\$420 M	
Vehicles	\$455 M	
Communication Controls	\$314 M	
Power		
Substations	\$128 M	
Electrification	\$157 M	
Emergency Walkway	\$480 M	
Total Capital Cost	\$4,674 M	
Total Capital Cost	\$30 M	per mile (Without tunnel)
Guideway Cost	62%	
Contingency, 25%	\$1,168 M	
Total System Cost	\$5,842 M	
Total System Cost	\$38 M	per mile

\* These estimates do not include additional engineering design, environmental studies, construction management costs, work zone traffic control, right of way and environmental mitigation costs.

These projected costs are attractive relative to other reported costs associated with comparable deployed maglev systems. Those higher reported costs are rooted in differences between those systems and the proposed Colorado system. For example, the system recently constructed in Japan (the TKL system), was constructed in the Japanese environment, and faced technical challenges as well. The factors which influenced the cost of the TKL system included a short route length with tunnels, requiring deep foundations and a bulkier guideway due to earthquake prone geography, high right-of-way costs through densely populated cities, and traditional Japanese methods of doing construction jobs with multiple interlinked subcontractors. In contrast, the Colorado deployment offers:

- High volume of components due to 155 mile long route, and the planned extensive use of automation and factory made modules for rapid construction.
- Innovative guideway design optimized for automated construction, to reduce costs in initial alignment and profile layout.
- Reduced foundation size due to reduced seismic risks in Colorado.

<sup>15</sup> \$32M per mile includes the use of the dedicated EJMT tunnel. Use of the higher tunneling alternative reduces the per mile cost to \$31M.



- Inexpensive right-of-way without requiring any road widening for the majority of the route, through use of the I-70 right-of-way.
- A significant amount of engineering design (including the motor) for the proposed Colorado vehicle already accomplished by the Japanese researchers.
- Unique deployment approach, including selection of competitive vendors and advanced construction procedures.

Comparison of the projected Colorado costs with reported costs for deployed high-speed maglev systems are inappropriate. These high speed systems have a completely different technology base, demanded by their operating speed profiles, and are consequently much more expensive.

#### **9.4.4.2. Operating Costs**

The CMP team drew on its long experience to construct a plausible operating scenario for the system, with a detailed staffing plan for system personnel. Personnel costs and system energy consumption make up by far the largest elements of annual operations cost. Spares, consumables, and services make up the remainder. The operating scenario is important, in that it establishes service levels and equipment duty cycles. Two bounding scenarios were created, one providing express service between high demand stations, and the other providing comprehensive local service to all stations. Between these two extremes, it was possible to bound the fleet size, reliability requirements, energy consumption, and likely operating costs. The result represents a fair picture of the operating cost profile free of revenue assumptions, which were excluded from the study.

The estimated annual operations and maintenance costs are \$43 million. The estimate flows from the detailed operating plan developed below as part of the deployment staging.

The personnel portion of the operating budget is estimated at \$13.5 million per year, including benefits.

Other line items in the annual budget will include expenses for facility utilities, including communications, garbage, sewer and water with facility power. Maintenance elements of expense include spare parts, and other consumables. For fourteen stations and two maintenance facilities, these costs are estimated at \$6.5 million on an annual basis.

Additionally, an administrative overhead account will provide for advertising and other incidental expenses, such as the retention of an auditor, and legal counsel. These costs are not included in the cost estimates. No provision is made for vehicle replacement; these are future capital costs.

Fare equipment maintenance contracts, fare collection contracts, cleaning contracts, and snow removal contracts are not included in these estimates. Numbers for similar expenditures in conventional transit systems are available and can be added to the maglev specific costs estimated above. Insurance costs are also not included, since insurance companies will not provide a quote based on preliminary information. Also for transit properties a level of self-insurance can be provided due to the increasing costs of insurance and the rising deductibles. The Denver RTD can provide some basis of insurance costs if this is necessary for establishing a more precise operations and maintenance cost than that provided in this analysis.

Finally, train operating power, in the form of electricity is estimated at \$3 million, per year. It is not possible to predict this value with certainty at the present time, so this estimate is based on the following logic:

Large industrial electricity contracts typically settle in the negotiated region of 6-7 cents per kilowatt-hour. However, these contracts are not of the same scale (200 MW+) as the required consumption for this system, and typically also contain demand clauses permitting the utility to shed industrial load during periods of high demand. This system

cannot tolerate this instability in its power source. Hence, although the quantity consumption is larger, the reliability demanded is greater, also. Furthermore, the system electrical demand is likely to be predictable, due to the stable nature of the service policies. These factors combine to provide the system operators with a relatively strong negotiating position.

Further strengthening this position is the recommendation that the guideway serve in a dual capacity to carry power to the mountain communities through transmission lines placed in the guideway structure. This transmission capacity is a valuable asset, since it is safe, environmentally benign, maintenance-free, and high capacity with low losses. Sale of this capacity to utilities will be a factor in the electric power negotiations, and should substantially lower the cost of power to the system.

With all these factors in the mix, the power cost to the system could amount to something between 3 and 5 cents per kilowatt-hour.

From various analyses, the annual operating hours per consist are known, and an average power consumption per consist can be computed using a typical duty cycle.

In the worst case, a 100 percent duty cycle could be chosen. However, Sandia National Laboratories has computed the average power per car used in traversing the entire route from one end to another under various conditions. The average values used to power an individual vehicle are shown in Table 9.4-2.

**Table 9.4-2: Average Power per Car Traversing Entire System Route**

<i>Energy per car per direction</i>	<i>90 kph headwind</i>	<i>Zero headwind</i>
Westbound	750 kW	491 kW
Eastbound	663 kW	425 kW

The travel time over the entire route is 2.15 hours, so this represents the period over which this energy is consumed. However, each train consists of two cars, so these numbers in the table effectively represent one-fourth of the kilowatt-hours per train to traverse the full route.

Based on projected operating hours for each consist, each could make 1250 of these trips on an annual basis. With 65 trains in the mix, the total consumption is 65 trains x 2 cars per train x 550 kW (an average consumption) x 2.15 hours/ trip x 1250 trips = 192,156,250 kWh. This number can then be multiplied by the chosen electric rate to provide the power cost.

At 4 cents per kWh, this comes to \$7,686,250 on an annual basis. At 7 cents, it amounts to \$13,450,938. As a conservative estimate, \$13,500,000 could be used without undue concern.

Utility companies in Colorado will not quote a price at this stage of project development therefore the conservative estimate is used for projection of operating costs.

These operating cost results are summarized in the following Table 9.4-3:

**Table 9.4-3: Projected Total Annual Operating Costs**

Salaries / Benefits	\$13,437,000
Vehicle Electricity	\$13,451,000
Facility Costs	\$ 6,500,000
Spares	\$ 3,000,000
Other Expenses	\$ 6,610,000
Total Costs	\$42,998,000
Contingency, 10%	\$ 4,300,000
Total Operating Costs	\$46,298,000

#### 9.4.5. **Maintenance Plan**

System maintenance during normal operations consists of scheduled preventive maintenance tasks and unscheduled maintenance tasks. The vehicle has a remote sensing and diagnostic system, which provides status information for maintenance.

The purpose of the preliminary maintenance plan is to establish the approach to the total maintenance of all subsystems and equipment of the CMP. The plan addresses the key aspects of train maintenance, including the following:

- Establishment of maintenance philosophy and procedures
- Maintenance program
- Replacement of equipment
- Data acquisition and reporting
- Spare parts
- Staffing
- Manuals

##### 9.4.5.1. **Establishment of a Maintenance Philosophy**

The maintenance philosophy shall be established as a unitary system encompassing both vehicle and wayside subsystems since they are systematically related. The system maintenance is generally divided into the two following categories:

#### A. Scheduled maintenance

This maintenance will be performed with proper intervals that are programmed to optimize labor, thereby saving money while at the same time attaining the most efficient maintenance. Standard maintenance items for the vehicle and wayside are shown in Table 9.5-1 and 9.5-2. The items listed are arranged to meet the railway maintenance rules of The Ministry of Transport of Japan. Depending on the deployment location in the United States the maintenance rules would need to be modified to meet local, state and US Federal requirements. However, the projected maintenance item schedule shown in Table 9.5-1 represents the best experience of the technology developer, applied consistently with Japanese standards. After careful review, it is the consensus of the CMP team that this proposed schedule represents an effective starting point for maintenance requirements in a US deployment.

This schedule, as put forth in Table 9.4-4, satisfactorily addresses maintenance scheduling issues associated with this new technology, for the following reasons:

- Although the Colorado system is designed for higher speed than current Japanese deployments, the higher design speed does not necessarily affect prospective maintenance scheduling. Component and subsystem designs automatically take the higher performance requirement into account by specifying sturdier designs with materials chosen for the applicable performance regime, and therefore, higher speed does not necessarily imply greater maintenance frequency.
- While higher speed and greater vehicle mileage can increase wear for vehicle consumables, the maintenance item schedule specifically addresses this issue by recognizing that the key factor for maintenance is not speed or mileage, but vehicle operating hours. The time-interval based maintenance item schedule reflects this, since the typical vehicle will generally operate continuously between the scheduled maintenance intervals.

- Specific consideration of prospective failure modes and design issues for the vehicle propulsion lead to the conclusion that, even with somewhat greater component stress levels, correct design procedures will not invalidate the proposed maintenance scheduling. However, during testing of the vehicles prior to delivery and acceptance, the vendor should revisit the maintenance issues, and the proposed schedule should be modified to reflect the information developed by testing.

After deployment, the maintenance items list will need periodic updating and improvement by analyzing the cumulative operation and maintenance history data. The cumulative data will be acquired from the operations log, daily maintenance status report, anomaly report issued during scheduled maintenance and finally with data inputs for diagnosis purposes.

**B. Unscheduled maintenance**

This maintenance is defined as maintenance action which is not specified in the maintenance list, such as corrective action for an anomaly in daily operation, incorporation of system modification and so on. To provide timely corrective maintenance, diagnostic and test equipment will be utilized to isolate a fault in the appropriate subsystem in accordance with the troubleshooting procedures contained in the maintenance manuals.

**Table 9.4-4 Vehicle Maintenance Items List**

<b>Type of Check</b>	<b>Interval</b>	<b>Contents</b>	<b>Example</b>
"P" Check	Every morning	Pre-operation	Emergency brake operation check
Pre-operation check		Maintenance duty	Fluid level check of hydraulic system  Integrity check of on board telecommunication & signalling equipment
"A" check Plain inspection	Every 3 days	General condition of major subsystems	Wear check of power collector, skid and brake shoe
"B" check Extended inspection	Every 3 months	Operation and condition of major subsystems Servicing	Check of battery electrolyte  Check of levitation gap Insulation check of electrical circuit Filter cleaning of air system, air-conditioner and magnet driver
"C" check Detail inspection	Every 3 years	Function and detail of major subsystems	Detailed check of major components, power collector assembly modules, hydraulic brake components, etc.
"M" check Major inspection	Every 6 years	Detail of all subsystems	Detail check of levitation magnet, major structure members, etc.  Major structure  Flaw check of thrust rod, brake rod Change of air suspension unit

This maintenance philosophy is further supported by the CMP design, wherein maintenance personnel are distributed in each station, as well as in centralized facilities. With this approach, the performance of frequently scheduled inspections is facilitated by distribution of the inspection load, leaving the centralized facilities to handle the less frequent cases. The use of computerized

maintenance scheduling, based on vehicle operating hours, will further supplement this capability, and will guarantee that serious operational interruptions due to insufficient maintenance will not arise.

## **9.5. DEPLOYMENT PLANNING**

The central element of deployment planning is the staging approach, formalized in a Staging Plan:

### **9.5.1. Staging Plan**

The Staging Plan describes the following:

- Staging Plan Objective
- Staging Plan Considerations
- First Segment
  - Development
  - Design Considerations
  - Right-of-Way
  - Construction
- Future Segments

#### **9.5.1.1. Staging Plan Objective**

The objective of the Staging Plan for the CMP is to identify the key project milestone(s) and major project activities that are critical to successful implementation of the project. Major emphasis in the development of the plan is on selection of the first segment and then subsequent segments to effectively respond to the growing congestion along the I-70 corridor. Recognition of financial limitations to widening the interstate highway, much less in building a transit system, is a consideration in the staging plan. At this point, however, congestion mitigation will drive the initial decision on the first segment. Subsequent segments will attempt to spread the costs for the completed system to affect a relatively smooth and consistent annual cost basis. This requires the identification of key milestones and activities necessary to achieve a reasonable project schedule for the first segment, while connecting with the significant interrelationships resulting from related activities and external constraints for the entire project deployment.

#### **9.5.1.2. Staging Plan Considerations**

The Staging Plan for the CMP was developed using a number of assumptions and considerations identified during the FTA project as well as the cooperative and coordinated work with the CDOT I-70 PEIS effort. This section addresses those items and provides the rationale upon which the proposed Staging Plan is based.

#### **9.5.1.3. Staging Plan Assumptions and Ground Rules**

The development of a staging plan is based on design and construction activity assumptions prior to the development of details that will be identified during the preliminary and final design phases. Many of these assumptions may later become key pacing milestones in maintaining the progress of the overall project. The approach throughout the staging plan development has been to make preliminary decisions based on qualified assumptions, engineering judgment and such historical information as is available, including discussions with the CDOT I-70 PEIS consultant team.

The staging plan assumptions and ground rules include:

- Timely and complete decisions for all policy and development milestones that specifically define and document and then finalize facility design and construction activities.
- A phased approach to all facility design and construction activities.

- A financial commitment from appropriate mechanisms to assure sufficient cash flow to construct the system based on the staging plan.
- Timely availability of funding and resources (both manpower and material).

The first step of the staging effort was the resolution of basic policy issues through establishment of ground rules that were followed throughout the staging plan analysis for the project. These ground rules reflect the desire for early implementation of the maglev system:

1. The first segment would be capable of operating as a transportation system without the construction of additional or connecting segments.
2. The system would be staged within the ability of the governing entity or entities responsible for construction to generate adequate funds.
3. The first segment would be selected to generate sufficient patronage to justify the decision.
4. The first segment should cause the least residential and business displacement due to ROW acquisition.

In addition to these ground rules, other assumptions were necessary in order to proceed. Available funding was limited in order to permit testing of the economic model for the preliminary funding plan and evaluation of Colorado's ability to generate funds. As a result of competing financial interests, a dollar (\$) limitation by necessity will be defined as the maximum maglev system construction expenditure that could be effectively managed within the Colorado region without seriously impacting local resources and economic patterns. Once the funding restraint is imposed, the overall duration of the construction program will become a function of funding commitment. The physical layout of the system provides the ability to plan for the use of multiple architectural and engineering consultants and construction contractors on various stages of the work, permitting the concurrent construction or overlapping of construction efforts for various system stages or segments. It was assumed that the availability of local and national resources in terms of manpower, skills and material is adequate to support the projected schedule.

A detailed evaluation of available resources will be required during the early stages of preliminary engineering to determine the scheduling and cost impact of any potential shortages. The results of such a study will also provide the basis for final determination of procurement policies with respect to system implementation.

Other factors affecting staging decisions included:

- The identification of an assumed sequence of segments to permit projection of the long-term financial strategy.
- The assumption of an ideal spending curve for all segments.

#### **9.5.1.4. First Segment**

Due to the length of the entire corridor, which is in excess of 240 kilometers (155 miles), it would appear that there are numerous opportunities to identify reasonable first segments. However, due to the composition of the corridor a first segment has proven difficult to identify. A number of options available include:

1. Golden to the Gaming Areas
2. Golden to Silverthorne
3. Golden to EJMT
4. DIA to Downtown
5. Evergreen to the Gaming Areas
6. Eagle County Airport to the Vail/Avon area
7. Frisco to Silverthorne

Typically a first segment needs to be of limited length. The FTA normally strives towards shorter segments due to cost constraints. Further, the first segment should provide an example of the benefits of the maglev system.

However, in the CMP other pertinent factors are present that cause a reconsideration of the first segment approach as traditionally taken. First, the corridor is heavily congested from Idaho Springs to EJMT in the mornings on weekends and on holidays, and then on the west side of the EJMT from Silverthorne to the tunnel and then west of the Twin Tunnels east of Idaho Springs in the afternoon on weekends and on holidays. The major congestion relief, as correctly recognized by CDOT in the PEIS effort, is between Golden and EJMT; this is the segment where CDOT is concentrating its efforts for highway widening. Second, the staging of transportation improvements should logically follow the need to relieve congestion as it occurs or to relieve the reasons for the congestion.

Therefore, the CMP team has taken a similar approach. A number of key assumptions have led to the identification of the first segment. These include:

1. The I-70 mountain corridor congestion is heavily influenced by recreational travel causing the major congestion along I-70 to occur between Friday afternoons and Sunday afternoons as well as on holidays traveling westbound in the mornings and traveling eastbound in the afternoon.
2. Skier travel is extremely schedule sensitive due to the opening times of lifts at the ski resorts, generally at 8:30am to 9:00am on weekends. The ski industry impacts the Colorado economy favorably both directly and far more significantly by the creation of jobs related to the recreational industry. Therefore, it is important to respond to congestion that is affecting access to the mountains.
3. Due to job growth along the I-70 mountain corridor, home to work travel is beginning to show typical urban area peaking patterns with morning and afternoon congestion occurring between resorts where the jobs are and homes typically located out of the resort areas where workers live.
4. Eagle County Airport is expanding with more commercial airline jet traffic occurring with recreational resorts as the final terminus for passengers.
5. Summer travel is less sensitive to schedule due to no beginning or ending time for summer recreational use of the mountains, although summer congestion has distinct peaks in the morning and afternoon on weekends and holidays similar to the winter peaks.
6. During heavy congestion, skiers traveling in the corridor may terminate their trip due to congestion or proceed to the closer ski resorts such as Loveland, Arapaho, Breckenridge and Keystone rather than resorts located further west such as Copper Mountain, Vail or Beaver Creek.
7. Skier visits are not growing as rapidly as in previous years. This could be a result of the skier demographics as well as the continuous congestion on weekends.
8. Transportation systems schedule adherence and predictability could be a major factor in the ski industries and recreational industry's future growth.

Finally, widening the highway will result in a solution that still does not guarantee schedule adherence for auto users due to the uncertainty of both the weather and related congestion caused by accidents or poor driving conditions.

Since the major congestion on weekends and holidays is between Golden and EJMT, a transit system should be directed to provide relief for this congestion. In the Colorado application, this 72-kilometer (45-mile) long transit segment would provide the necessary congestion relief. The Golden to EJMT segment would intercept auto traffic at Golden by guaranteeing schedule dependability and arrival at the EJMT within minutes of the published schedule.

A secondary benefit of this first segment is that access to the Golden area where a major transit station is to be located is excellent for highways with a major parking structure programmed for

construction and will have excellent multimodal transit access with both the regional light rail system and a major bus transit hub.

For the EJMT terminus, it is envisioned that a regional bus service providing individual bus distribution to and from the individual ski resorts would provide the final destination mode required by ski resort visitors until the entirety of the transit system can be built.

Both peak hour and off-peak bus distribution would be provided to the main maglev system transfer terminals at EJMT and Golden. Until the maglev system is lengthened, the bus system would provide final distribution to the resorts from EJMT.

As alternatives to the Golden / EJMT first segment, there is also potential for the first segment to operate between Eagle County Airport and the Vail area as well as intermediate service to Beaver Creek. This line would be approximately 55 kilometers (34 miles) long. Since the Eagle County Airport is in a major expansion process with additional larger commercial jet aircraft utilizing the airport, this segment would provide a convenient mode of transportation to resort visitors. There may be other monies available for the Eagle County Airport to Vail segment such as Federal Aviation Administration money. The Eagle County Airport to Vail segment could be viewed as a second segment or a complimentary first segment if different monies are directed towards the construction of this segment.

Since the availability of financial resources to widen the highway with transit augmentation are currently in question, highway widening alone would also have difficulty generating sufficient financial resources for implementation.

To respond to the financial limitations, shorter segments could be implemented such as the DIA to Downtown Denver link or the Silverthorne to Frisco link, or even the Eagle County Airport to Vail segment. Any of these alternate first segment choices will not provide congestion relief in the critical areas of the I-70 mountain corridor. In this analysis, the technical team is assuming that congestion relief is the over-riding factor and must be a strong determinant in the Staging Plan. Of course the most significant issue is a policy issue dealing with the lack of financial resources to respond to the growing congestion of I-70, and this is beyond the scope of the FTA project. Given these facts, the Staging Plan will deal with the congestion issue and develop segment prioritization based on the facts as stated above.

Throughout the staging effort it was recognized that substantial delays with resulting escalation of estimated cost could result from early program delays due to problems in ROW acquisition and/or negative environmental impacts. Therefore, one of the dominant factors in first segment selection was the requirement for least negative impact resulting from residential and business displacement. The Golden to EJMT segment is considered rural with Idaho Springs having the most significant impacts from transportation capacity demands. The CDOT I-70 Mountain Corridor PEIS document details the environmental issues along the first segment designated for both the highway widening and potential transit system implementation.

#### **9.5.1.5. Next Segments**

Potential segments for follow-on implementation should logically be taken from the interface point with the completed first segment of the system. This is desirable to avoid unnecessary turnarounds that would later become redundant.

After selection of the first segment, the remainder of the I-70 maglev system may be constructed in a logical sequence that public acceptability dictates. Future segments should be contiguous with previously constructed segments in order to provide continuity of service without the requirement for separate supporting facilities (i.e., maintenance, storage and Communications and Control Center facilities).



#### **9.5.1.5.1. EJMT to Frisco**

The next segment following the Golden to EJMT line would be from EJMT to Frisco. This segment would then shorten the length of distribution bus trips between Arapaho Basin, Keystone, Breckenridge and Copper Mountain as well as Vail and Beaver Creek visitors arriving from the east.

#### **9.5.1.5.2. Frisco to Copper Mountain**

The next segment would traverse from Frisco to Copper Mountain providing direct resort visitor travel from Golden to Copper Mountain as well as points in between, including Loveland Ski area directly and Arapaho / Keystone and Breckenridge via bus shuttle distribution systems.

#### **9.5.1.5.3. Copper Mountain to Vail**

The final mountain segment would traverse between Copper Mountain and Vail, assuming the Eagle County Airport to Vail link is operating.

#### **9.5.1.5.4. DIA to Golden**

The final segment of the CMP would be between Golden and DIA, thus providing direct maglev transit service between DIA and the Vail / Beaver Creek resorts with intermediate service to Copper Mountain and Loveland, with no requirement for bus transfer service. Service to Arapaho Basin, Keystone and Breckenridge would still require bus distribution.

### **9.5.2. Systems Operation Plan**

This section describes the plan for operating a maglev system for the entire length between DIA to Eagle County Airport. Naturally, an operations plan would be developed for each segment as policy decisions are made on the overall construction staging plan. The service described in the following sections will be offered after the commencement of operation. No public passenger transportation will be carried out during the construction and commissioning phases.

#### **9.5.2.1. Service and Operations Plan**

The maglev transit service is planned for the transportation of:

- passengers using the system as a continuation of their airline trip (DIA and Eagle County Airport) to reach the final destination along the I-70 mountain corridor;
- passengers using the system from the transit hub station located near Golden;
- resort workers living along the I-70 mountain corridor using the maglev system as a home to work commute line;
- residents along the I-70 mountain corridor using the system for short intermediate trips for multiple purposes;
- Denver metropolitan area home to work commuters who live and work along the line from DIA to Idaho Springs or further west.

#### **9.5.2.2. Capacity of Train Sets**

The system is designed for a maximum of 6,000 persons per hour per direction. The 2-car train, with a capacity of approximately 200 passengers will be operated at a minimum headway of 120 seconds.

#### **9.5.2.3. Change of Train Configuration**

The train configuration of 2-car trains will not change throughout all service patterns. Train coupling during the service is not planned.

#### **9.5.2.4. Operating Crew**

There are no requirements for vehicle operating crew since the system is automated.

#### **9.5.2.5. Turnaround Procedure**

Vehicle train set turnaround procedures differ by type of station. The turnaround procedures are discussed below.

End of Line – DIA and Eagle County Airport

- the disembarking passengers leave the train
- the doors close after all the passengers leave.
- the station attendant inspects the vehicles, collects trash and performs minor adjustments
- the train set is moved by the docking mechanism to the other guideway
- the doors are opened for the boarding of passengers
- the train departs

Intermediate Stations – Through Trips

- the detraining passengers leave the train
- boarding of passengers
- the train departs

Intermediate Stations – Express Trips

- the disembarking passengers leave the train
- the doors close after all the passengers leave.
- the station attendant inspects the vehicles, collects trash and performs minor adjustments
- the train set is moved by the docking mechanism to the other guideway
- the doors are opened for the boarding of passengers
- the train departs

#### **9.5.2.6. Operations Plan**

It is anticipated that the maglev system will operate between the hours of 4:30 am and 10:30 pm. The staffing will normally be handled as three, seven or eight hour, partially overlapping shifts. Staffing may vary seasonally, to accommodate expected peaks in demand.

The potential impact of unions in the operation has been considered carefully, in order to structure a realistic plan. Initially, it is expected that the operation will not be unionized.

Security requirements have also been carefully taken into account, to produce a plan that provides maximum security for the traveling public. All security personnel associated with this system shall be fully trained and armed.

#### **9.5.2.7. System Organizational Structure**

The system organization chart has two major divisions, administrative and operational.

Each branch can be separately described as follows.

The system is governed by a CEO, acting on behalf of a Board of Trustees. The CEO is drawn from the pool of United States corporate executives, and may not have direct transit experience. The salary will range from \$120,000 to \$200,000, depending on experience and benefits.

Reporting to the CEO is the CFO, who, as head of administration, supervises two marketing/public relations personnel, three accountants, two human resources persons and three procurement specialists. A scheduling and planning group comprises three additional persons.

On the operations side, a General Manager with transit experience supervises personnel divided between operations and maintenance. The Operations division is further subdivided into control and security functions. The Chief, Security reports directly to the GM.

Operations will carry the following personnel:

Central control will have both an operations supervisor, and a station supervisor. In addition, system controllers will work in pairs, with responsibility for keeping trains running smoothly on a global basis. A minimum of two controllers will be available on any shift, together with their supervisor. The station supervisor will be available on all shifts.

Large stations will have a station manager and ticket agent. Additionally, two large stations have two ticket agents associated with their large (2500 car) parking garages. Medium stations will have a single ticket agent, while small stations will have none. Garage operating personnel may be outsourced.

Security will be provided by armed security personnel at every station. Large stations will have two, with two additional for parking garages, medium stations will have two, and small stations one. Security personnel will be direct system employees, and will not be outsourced. Central control will be a controlled access facility, with video surveillance, but will not have armed guards.

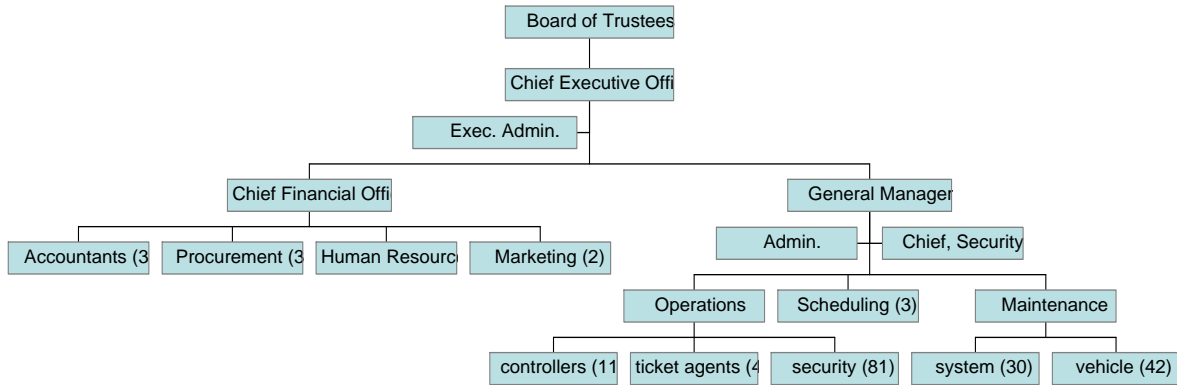
System personnel will be required to handle money only on an incidental basis. All farebox receipts will be transported under bank contracts, and will be electronically reconciled. Every ticket will be serialized and, based on faregate collections, it will be possible to provide full revenue information at any time, including contingent liability on unused farecards.

A maintenance person will be dedicated at each station ready to recover a failed vehicle, replace failed units, or assist with incident management. Additionally, the maintenance facility will be staffed with a supervisor and five maintenance technicians per shift, for two shifts per day.

There are no train operators, but maintenance technicians can operate trains using mobile consoles when necessary.

Two fully equipped maintenance facilities will each be staffed by five service personnel. These facilities will be capable of full disassembly, diagnosis, and reassembly of complete vehicles. Repair shall be carried out by replacement utilizing minimal spares inventory and just-in-time spares delivery. All failed units shall be returned to repair depots, and will not be spared on site unless supported by failure history. To support this method of operation, it is necessary for CHSST to open a repair depot in either the United States or Japan.

The organizational chart depicting this structure is shown in Figure 82.



**Figure 82: System Organizational Chart**

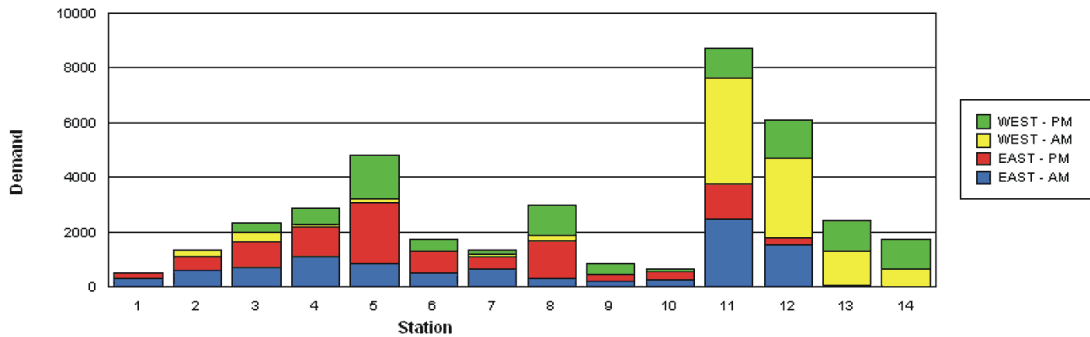
The headcount for system personnel stands at 228, when all shifts are considered. This is a low number for a system of such capacity, and reflects the high degree of automation employed in the system.

**9.5.2.7.1. Service Levels and Policies**

The maglev system is capable of sustained reliable service under nearly all weather conditions, although the performance may change under the most adverse conditions. To reach the highest level of service, a mix of express and local service must be offered. It has been demonstrated that this is possible in theory without compromising a minimum safe brickwall headway of 150 seconds (the system is capable of operating at 120 second headways). To verify the ability of the system to carry the peak loads, a dynamic stochastic simulation was formulated and operated with the following results:

For a winter Saturday, the projected system demand, morning and afternoon, is shown in the following chart, Figure 83:

### Demand by Station



	STATION														Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
EAST - AM	311	573	700	1,068	862	471	649	271	186	234	2,453	1,512			9,290
EAST - PM	202	505	951	1,124	2,216	798	426	1,432	272	312	1,286	267	30		9,821
WEST - AM		249	311	78	116		115	182			3,894	2,931	1,269	635	9,780
WEST - PM			362	605	1,593	471	137	1,081	367	100	1,077	1,387	1,105	1,087	9,372

**Figure 83: Eastbound and Westbound Passenger Demand by Season and Time-of-Day**

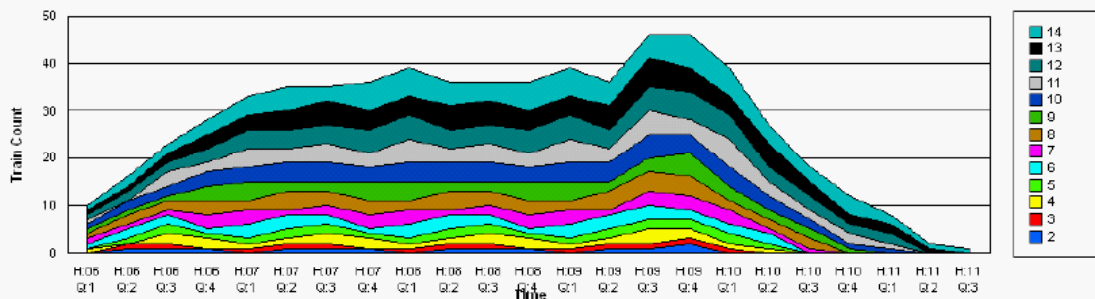
Ridership demand projections provided by the PEIS effort did not quantify eastbound and westbound traffic at each station, instead providing only numbers for arriving and departing passengers at each station without the full origin-destination matrix. Therefore, in the simulation activity, it was first necessary, using operations research techniques, to regenerate the eastbound and westbound components of the flows at each station. This turned out to be surprisingly straightforward, and the solutions found were fully self consistent.

When these flow components were in hand, it was possible to generate ridership stochastically based on these numbers, and load and operate trains.

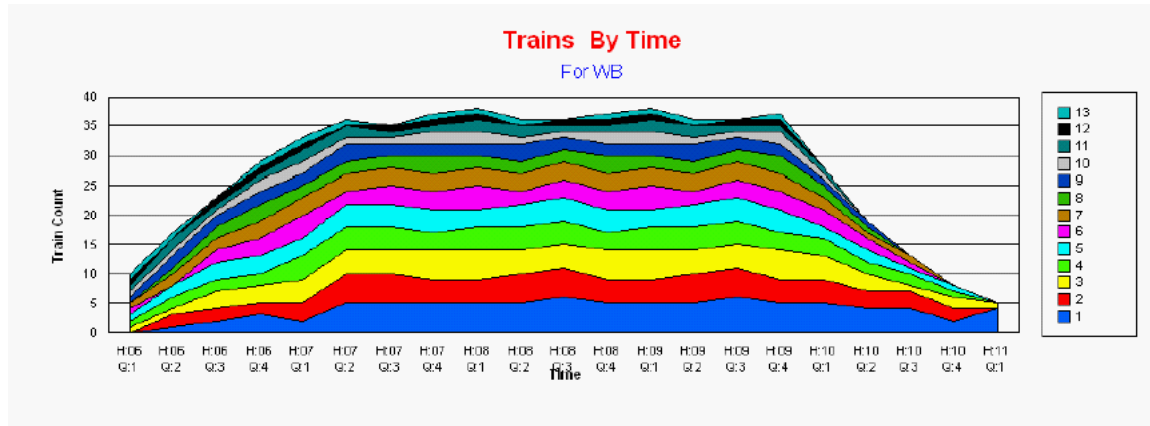
Results from this process are shown in Figures 84 and 85.

### Trains By Time

For EB



**Figure 84: Winter Saturday Eastbound Morning Trains**



**Figure 85: Winter Saturday Westbound Morning Trains**

The operation was very stable when the system was operated as a large conveyor belt, adding trains as necessary as the flow picked up, and stopping at every station. Hence, for purely local service, the system can carry the projected peak loads with the numbers of trains as shown. The figures make clear the incremental demand by station versus time, and clearly show the addition of trains to carry the load. These simulations were carried out with one-minute station dwell times. The general form of the results should hold over a considerable range of dwell times, but the number of trains required may decrease with increasing dwell. Consequently, these simulations set one estimate for the fleet size, while another estimate is set by a full schedule of express trains. Express train schedules are by definition not sensitive to dwell.

This is the most basic level of service that can be provided. Further computer optimization of the flows with a mix of service levels is beyond the scope of the present effort. However, the simulation as operated provides confidence that more complex strategies could be worked out, and that a mix of service levels could indeed be provided with the currently projected fleet of trains. Eventually, this system would be operated much as an airline system is operated, with vehicle staging, maintenance scheduling, and very high service levels for high volume destinations.

#### 9.5.2.8. Ticketing and Passenger Handling

##### 9.5.2.8.1. Ticketing

Each maglev station will be equipped with ticket machines where single or round trip tickets can be purchased. The number of machines and hours of operation will be based upon the projected passenger use of each station and the frequency of service in each station.

##### 9.5.2.8.2. Passenger Handling

Passenger information will be provided through a variety of media and systems:

##### General System Information

Informational brochures will be developed to provide background data, facts, figures, schedule information and photographs of the system. These brochures will be provided to travel agents, system riders and other interested parties as a part of general system marketing activities.

##### Operational Information

Information regarding system operation will be provided through several means:

#### *Station Graphics*

System schedule information can be displayed on information displays designed for the maglev system. Station Graphics will be designed with highly visible international graphics and will be designed to assist passengers boarding and leaving the system. Visual CRT or other high visibility "real time" graphic display systems will be incorporated in station design to display schedule information.

#### *Station Public Address*

Each station will incorporate a public address system to allow passenger communication. Prerecorded announcements will be extensively used to insure consistency of information and audio quality.

#### *Station Attendants*

The Golden, Vail and Frisco stations will have station attendants who, in addition to providing boarding assistance, will be able to answer passenger questions and provide information. The airport stations may need attendants during peak period times. All other system stations would not have attendants.

### **9.5.2.9. Cleaning and Maintenance**

The frequency of train set interior cleaning will be determined during the pre-operational testing period. However, the maintenance of the train is carried out according to a fixed schedule, which is described in the following section. Cleaning of the train's exterior is provided in the maintenance area.

### **9.5.2.10. Train Movements**

All train movements are controlled by the control center with the Head of the Control Center designated as the operation supervisor or delegate (systems operator).

The schedule for revenue operation is planned by the operation supervisor and authorized by the operation manager.

Trains will be requested from the technical department according to this schedule.

The scheduling department plans which train is to be used on what segment of the route, and will program the train into the maintenance area. The scheduling department also determines how long a train stays in service, and when it has to be replaced by a reserved train.

The Command, Control, and Communications subsystem guarantees the safety of the system during operations. In both revenue and non-revenue areas, a train moves only after all switches are set for safe movement. Similarly, once the way for a train has been cleared, no switch can be set that would allow another train to interfere with the cleared way.

### **9.5.2.11. Operating Procedures**

#### *Operating Manual*

The operating procedures for revenue and non-revenue operation will be established in an operating manual. The operating manual can only be prepared after all systems have been defined and designed.

This manual will describe:

- tasks that may be fulfilled by the system (e.g. revenue and non-revenue operations)
- overall system and its components
- configuration of the components
- functions within the system
- proper operation (e.g. substation: voltage and power normally to be delivered)

- possible improper activities to be avoided
- indications and signs of proper functioning, minimum requirements
- possible malfunctions and respective indications of malfunctions
- operational organization and structure
- description of duties and responsibilities
- line and chain of command
- number of required personnel for proper operation
- requirements for personnel, working hours regulations etc.
- standard operation
- handling non-standard situations (according to the failure analysis the non-standard events will be classified and a handling procedure for each will be developed)

#### **9.5.2.12. Handling of Emergency and Failure**

Operational safety measures such as emergency responses may be subject to regulatory acts, government policies and local ordinances. The location on the guideway of the emergency and its nature will also affect the specific responses needed to efficiently and effectively cope with the situation. Therefore, when the system is pre-operational, testing the preparation of a Safety Program as a project deliverable for review by the client and the agencies with jurisdiction for safety will be completed. The Safety Program is in addition to the Safety Certification Plan and will have at least the following elements:

1. Definition of safety policies and guidelines
2. List of emergencies and abnormal situations
3. Design guidelines and procedures for safety
4. Schedule for hazard and failure modes and effects analyses
5. Definition of relevant safety standards and codes
6. Schedule of client safety reviews
7. Program of testing and simulated emergencies
8. Design communication and emergency equipment
9. Coordination of emergency preparedness with local authorities, police, ambulance, and fire department
10. Preparation of Operations Safety Manual

A primary response to an emergency will be to direct the train to the nearest station or to emergency way stations locations, if possible. The intent is that at such locations the provision of assistance will be greatly facilitated by the design and configuration of the guideway relative to other means of access. The automatic train subsystems have the ability to react quickly to any emergency event, to control the movement of the train, and to stop it at the desired location.

Equipment monitoring and diagnostics will be one element of ensuring safety. On-board communications equipment will enable passengers to obtain assistance and to provide personal security. Remote and local manual operation of the train will be included in the options to be examined to facilitate emergency responses. Furthermore, on-board fire protection will be rendered by adherence to National Fire Protection codes for selection of hardware such as cabling, carpets and seating materials.

The following are some general concepts for special procedures for cases of system failure and emergency exit of passengers. The first level of response is to divert the train to the nearest terminal station and arrange for the presence of needed emergency services. The second level would apply if the emergency coincided with a vehicle levitation failure, in which case the



emergency rollers would be deployed and the train would proceed at low speed (48kph/30mph) to the nearest station. Should the propulsion be disabled for whatever reason, then the train could be pulled or towed by another train or recovery vehicle to a station. In the event that the train cannot reach a terminal station, a number of wayside emergency locations will be equipped for emergency evacuation. Although this brief description provides an indication of the types of responses, the safety analyses for the deployed system will include a comprehensive and systematic examination of all hazards as part of the Safety Program. For each abnormal and emergency scenario, the procedures will be formulated and when agreed upon, will be included in the Operations Safety Manual.

### **9.5.3. Maintenance Plan**

System maintenance during normal operations consists of scheduled preventive maintenance tasks and unscheduled maintenance tasks. The vehicle has a remote sensing and diagnostic system, which provides status information for maintenance.

The purpose of the preliminary maintenance plan is to establish the approach to the total maintenance of all subsystems and equipment of the CMP. The plan addresses all aspects of train maintenance, including the following:

- Establishment of maintenance philosophy and procedures
- Maintenance program
- Replacement of equipment
- Data acquisition and reporting
- Spare parts
- Staffing
- Manuals

#### **9.5.3.1. Establishment of a Maintenance Philosophy**

The maintenance philosophy shall be established as a unitary system consisting of vehicle and wayside system since they are related systematically with each other. The system maintenance is generally divided into the two following categories:

##### **A. Scheduled maintenance**

This maintenance will be performed with proper intervals that are programmed to optimize labor, thereby saving money while at the same time attaining the most efficient maintenance. Standard maintenance items for the vehicle and wayside are shown in Table 9,5-1 and 9.5-2. The items list are arranged to meet the railway maintenance rules of The Ministry of Transport of Japan. Depending on the deployment location in the United States the maintenance rules would need to be modified to meet local, state and US Federal requirements.

The maintenance items list will need periodic updating and improvement by analyzing the cumulative operation and maintenance history data. The cumulative data will be acquired from the operations log, daily maintenance status report, anomaly report issued during scheduled maintenance and finally with data inputs for diagnosis purposes.

##### **B. Unscheduled maintenance**

This maintenance is defined as maintenance action which is not specified in the maintenance list, such as corrective action for an anomaly in daily operation, incorporation of system modification and so on. To provide timely corrective maintenance, diagnostic and test equipment will be utilized to isolate a fault in the appropriate subsystem in accordance with the troubleshooting procedures contained in the maintenance manuals.

**Table 9.5-1 Vehicle Maintenance Items List**

<b>Type of Check</b>	<b>Interval</b>	<b>Contents</b>	<b>Example</b>
"P" Check	Every morning	Pre-operation	Emergency brake operation check
Pre-operation check		Maintenance duty	Fluid level check of hydraulic system
			Integrity check of on board telecommunication & signalling equipment
"A" check Plain inspection	3 days	General condition of major subsystems	Wear check of power collector, skid and brake shoe
"B" check Extended inspection	3 months	Operation and condition of major subsystems	Check of battery electrolyte
		Servicing	Check of levitation gap
			Insulation check of electrical circuit
			Filter cleaning of air system, air-conditioner and magnet driver
"C" check Detail inspection	3 years	Function and detail of major subsystems	Detailed check of major components, power collector assembly modules, hydraulic brake components, etc.
"M"check Major inspection	6 years	Detail of all subsystems	Detail check of levitation magnet, major structure members, etc.
			Major structure
			Flaw check of thrust rod, brake rod
			Change of air suspension unit

**Table 9.5-2 Wayside Maintenance Items List**

<i>Item</i>	<i>Type of maintenance</i>	<i>Interval</i>	<i>Contents</i>	
Guideway structure (beams, piers, rails)	Look-around	1 day	View observation of general condition from vehicle	
		1 month	View observation of detail condition from maintenance vehicle	
	Plain	3 months	Check of levitation gap	
	Extended	6 months	Condition check of beams, piers, rails, bolts	
			Visual inspection of safety-related structure including foundation	
Heavy	1 year	Detail inspection of rail: leveling, flatness, etc.		
Guideway equipment -trolley -pattern belt -junction box	Plain	1 year	General condition check of trolley corrosion, fastening of bolt/nut, etc.	
			Tension check of pattern belt	
Telecommunication & signaling - control center - substation - signal houses - wayside equipment	Plain	1 month	Check of general condition	
	Extended	6 months	Measurement of output, input sensitivity, etc	
			Heavy	1 year
Electric power supply -power receiving -power supply for vehicle traction equipment - emergency power generation - emergency batteries	Look Around	1 day	View observation of peripheral around power stations	
		Plain	6 mos	Protection circuit check of power distribution panel
		Extended	1 year	Battery electrolyte level check and full charging
		Heavy	3 years	General condition check of insulator, indicator, contactor, etc. - Insulation check - Gas pressure check of high voltage

**Table 9.5-3 Wayside Maintenance Items List (Continued)**

<i>Item</i>	<i>Type of Maintenance</i>	<i>Interval</i>	<i>Contents</i>
Transformer – switches	Look around	1 day	View for damage & obstacles of sensor surroundings
	Plain	3 months	General condition check of oil leak, corrosion, noise, looseness, etc Grease supply
	Extended	1 year	Insulation & current check of electrical cylinder, motor
			Measurement of switching time
			Leveling check of flapping rail
Heavy	3 years	Grease supply Check of local operation mode Check of structure welding Wear measurement of lock device, roller, etc. Overhaul of electrical cylinder, motor Grease supply	

**9.5.3.2. Maintenance Program**

The maintenance program will start with initial maintenance items to be selected in the standard maintenance items list. It is reasonable that the initial maintenance program will be effective for first two years, and subsequent programs will be improved by diagnosis of daily reports and analysis in conjunction with data acquisition from the reporting system.

*9.5.3.2.1. Replacement of Equipment*

Scheduled and unscheduled maintenance for all elements of the system will be performed by using replaceable pre-tested modules, components and assemblies wherever possible. The Colorado 200 vehicle is designed for ease of maintenance by providing quick access, simple replacement and easier integrity check after replacement of equipment.

*9.5.3.2.2. Data acquisition and reporting*

All data on the maintenance of equipment items comprising the system will undergo centralized control to ensure that the necessary history on repairs and failures can be retrieved promptly. This makes it possible to estimate, on a timely basis, the time of replenishing repair parts or replacing equipment and/or parts. To maintain the accuracy and reliability of maintenance work, all items of work are reported to the supervisory staff providing a clear history of the work and the personnel responsible for the work.

#### **9.5.3.2.3. Spare Parts**

A spare and consumable parts list for the maintenance program will be provided following operational testing, and also parts provision data sheets will be provided to the system owner with the necessary information for the purchase of consumable parts for subsequent periods.

The quantity of the spare equipment will initially be estimated in accordance with respective design Mean Time Between Failures (MTBFs). Following a period of operations, a listing will be made of the equipment repaired in-house and the equipment repaired by vendors for future spare parts planning.

#### **9.5.3.2.4. Staffing**

The staff requirements have been estimated based on the vehicle fleet requirements, the route with its difficult terrain and weather and the initial MTBF calculations.

The maintenance department is supervised by Maintenance Manager and includes the two main functional divisions of Vehicle Maintenance and Wayside Maintenance. Maintenance staff are assigned to various distributed physical locations in the system. For example, a cross-trained maintenance engineer is available on every shift in every station, while the maintenance facilities are also fully staffed.

The vehicle maintenance activities with frequencies of three years and six years have not been taken into account for sizing the maintenance staff since these activities will not start prior to year three. The additional personnel required for these maintenance activities do not need to be hired during the first years of revenue service. Further, it will be possible to adjust the staffing requirements more precisely after two years of operation, which will provide the necessary data to optimize the maintenance staff.

#### **9.5.3.2.5. Manuals**

The total required system of manuals is divided into several separate sections. These are delineated in the following paragraphs.

##### ***Maintenance manual***

The maintenance manual covers all systems related to the vehicle and wayside system consisting of the system description, troubleshooting, removal/installation operation check, function check, inspection procedure and so on.

##### ***Parts catalog***

The parts catalog covers all consumable and material parts.

##### ***Wiring diagram manual***

The wiring diagram manual covers all systems related to the electrical wiring and consists of schematics, wiring diagram, hook-up chart and the items list.

##### ***Component maintenance manual***

The component maintenance manual will be issued for each major repairable part and consists of function/description, assembly/disassembly, testing, troubleshooting, parts catalog and so on.

#### **9.5.4. Operations and Maintenance Costs**

The operations and maintenance (O&M) cost estimates are based on the Operation Plan of this Deployment Guide, the ridership estimates and experience from the previous deployments of CHSST in Japan as well as extended test track test results and other demonstration runs at various exhibits. Table 9.5-4 summarizes the O&M cost estimates.

#### 9.5.4.1. Basis for Operations and Maintenance Cost Estimate

The success of the CMP relies on the system's optimization of costs. Cost effectiveness, using competitive labor rates and minimal labor requirements while providing safety and comfortable service, is one of the critical objectives to achieve deployability.

The following assumptions were used for the estimates:

1. the coverage factor used was 7/5 for a 5 day work week per employee with the system operating 7 days per week;
2. the relief (reserve for vacations of the personnel) accounts for 15% of personnel requirements;
3. the labor rates used match Colorado rates for comparable positions;
4. the wage rates selected reflect 2003 dollars;
5. 19 hour service per day, for Friday, Saturday and Sunday for 365 days per year;
6. 17 hour service per day, Monday through Thursday for 365 days per year;

To derive the O&M costs, the following approach was followed:

- unit costs were multiplied by quantities:
  - the unit cost assumptions for operation personnel were derived from wage rates in Colorado
  - 3% annual wage inflation factor
  - the maintenance work force quantities were derived from the Deployment Guide.

Each cost item comprising the O&M cost is described below:

##### 9.5.4.1.1. Personnel Cost

The maglev operating company is planned to comprise the following divisions:

- administration, and
- operation and maintenance.

The operating company will employ 228 personnel in total: 14 for administration, 142 for train and station operation, and 72 for maintenance.

A. The Administration division incorporates:

1. Chief Executive
2. Administration
  - General management, security, and counsel
  - Marketing/sales
  - Public relations
  - Scheduling & planning
  - Personnel
  - Accounting/procurement

B. Operation & Maintenance division incorporates:

- Operation control
- Train and station operation

**Table 9.5-4 Operation and Maintenance Cost Summary**

Items	Cost 2003\$
<b>1. Personnel Cost</b>	
A. Administration	\$ 960,000
B. Operation & Maintenance	\$ 7,695,000
	Sub-total
	\$ 8,655,000
C. Salary Related Expense(a + b x .35)	\$ 3,029,000
D. Relief Adjustment(c x .15)	\$ 1,753,000
	Total
	\$ 13,437,000
<b>2. Energy Expenses</b>	
A. System	\$ 13,451,000
B. Stations and O&M Facilities	\$ 410,000
<b>3. Maintenance Materials (Parts) Expenses</b>	
A. System	\$ 3,000,000
<b>5. Other Expenses</b>	\$ 12,700,000
A. Station usage fees	
B. Guideway usage fees	
C. Insurance	
D. Taxes	
E. Office rent	
F. Other	
<b>TOTAL O&amp;M COST</b>	<b>\$ 42,998,000</b>
<b>6. Expense Contingency</b> (Up to 10% on the total expenses)	
<b>TOTAL O&amp;M COST PLUS CONTINGENCY</b>	<b>\$ 47,298,000</b>

**Table 9.5-5 Administration Personnel Requirement**

	President	VP	Director	Staff	Admin	Total
Chief Executive	1				1	2
Chief Financial Officer		1				1
Scheduling & Planning			1	2		3
General management, security			2		1	3
Marketing/sales/PR			1	1		2
Personnel			1	1		2
Accounting/procurement			2	4		6
<b>Total</b>	<b>1</b>	<b>1</b>	<b>7</b>	<b>8</b>	<b>2</b>	<b>19</b>

**Table 9.5-6 Administrative Personnel Cost**

<b>Position</b>	<b>No.</b>	<b>Wage(2003\$/Person)</b>	<b>Cost (2003)</b>
Chief Executive	1	100,000	100,000
Chief Financial Officer	1	80,000	80,000
Director	7	60,000	420,000
Staff	8	40,000	320,000
Admin	2	20,000	40,000
<b>TOTAL</b>	<b>19</b>		<b>960,000</b>

The operation control will require:

1) Director of operation

The director of operation is responsible for the overall operation of the system and the quality of service offered to the public. The director is in charge of managing the operating personnel and setting up the organization for the operation department.

2) Operation Supervisor

An operation supervisor is in the control center during the operation; at least 18 hours/day plus special demand operation 365 days/year. An operation supervisor participates in planning and scheduling activities and is responsible for implementing all features of the system in operation in accordance with the operational program. The operations supervisor reports to the director of operation. When the director of operation is absent, the operation supervisor is acting Director of Operations.

3) System operators

System operators work in pairs in the control center. The system operators are under control of the on-duty operation supervisor. In the control center, system operators are in charge of operating the system by means of consoles and communication equipment.

They are responsible for immediate intervention when any kind of difficulty cannot be solved from the control center. In those circumstances they contact the maintenance department to perform the technical actions that are needed to restore the service within a minimum delay.

Train and Station Operations will require the following personnel:

1) Station personnel: Station managers and ticket agents control the station activities, providing passenger assistance and information as well as inspecting train sets when in station.

2) Security: Armed security personnel are provided at every station. Large stations have multiple security personnel, and parking garages are policed.



**Table 9.5-7 Operation Control Personnel Requirement**

Position	Peak	Non-Peak	Total
Requirement			
1. Operation Manager	1	1	2
2. Operation Supervisor	1 per shift	1 per shift	3
3. System Operator	2 per shift	2 per shift	6
4. Maintenance	4 per shift	2 per shift	10
<b>TOTAL</b>			<b>21</b>

(Note): When a Director is not on duty during fringe hours or takes holidays, a supervisor covers the responsibility.

**Table 9.5-8 Operation Control Personnel Cost**

Position	No.	Wage (2003\$/Person)	Cost (\$2003)
1. Operation Manager	2	65,000	130,000
2. Operation Supervisor	3	40,000	120,000
3. System Operator	6	30,000	180,000
4. Maintenance	10	45,000	450,000
<b>TOTAL</b>	<b>21</b>		<b>885,000</b>

**Table 9.5-9 Station Operation Personnel Requirement**

Position	Peak	Non-Peak	Total
Large Station			
			Four Stations
1. Manager	1 per shift		8
2. Ticket Agent	1 per shift	1 per shift	12
3. Security	3 per shift	3 per shift	36
4. Maintenance	1 per shift	1 per shift	12
			Five Stations
Medium Station			
1 Ticket Agent	2 per shift	1 per shift	25
2. Security	2 per shift	2 per shift	30
3. Maintenance	1 per shift	1 per shift	15
			Five Stations
Small Station			
1. Security	1 per shift	1 per shift	15
2. Maintenance	1 per shift	1 per shift	15
<b>TOTAL STATIONS HEADCOUNT</b>			<b>168</b>

(Note): When a Director is not on duty during fringe hours or takes holidays, a supervisor covers the responsibility.

**Table 9.5-9 Station Operation Personnel Cost**

<b>Position</b>	<b>No.</b>	<b>Wage (2003\$/Person)</b>	<b>Cost (\$2003)</b>
1. Station Manager	8	45,000	360,000
2. Ticket Agent	37	35,000	1,295,000
3. Security	81	30,000	2,430,000
4. Maintenance	42	45,000	1,890,000
<b>TOTAL</b>	<b>168</b>		<b>5,975,000</b>

**9.5.4.2. Maintenance Program and Staffing**

The initially developed maintenance program will be used and presumed effective for the first two years with the subsequent maintenance programs improved upon by diagnosis of daily reports, and analysis in conjunction with data acquisition and the operations and maintenance reporting system.

**Staffing**

The maintenance department is supervised by the Maintenance Manager and includes the main functional divisions of Vehicle Maintenance and Wayside Maintenance. The staffing level is shown in Table 9.5-10.

**Table 9.5-10 Maintenance Personnel Requirements**

SectionName	Staff Title	Working Pattern	Peak	Total <sup>16</sup>
Maintenance Department	Maintenance Manager	Normal	1	1
	Maintenance Supervisor	Shift	1	3
Vehicle Maintenance	Engineer (Mechanical)	Shift	2	4
	Mechanic (Mechanical)	Shift	2	4
	Engineer (Electrical)	Shift	2	4
	Mechanic (Electrical)	Shift	2	4
	Engineering Mechanic	Shift	1 per station	42
Wayside Maintenance	Mechanic (Trackway/Switch)	Shift	1	2
	Mechanic (Power Supply)	Shift	2	4
	Mechanic (Telecom and switches)	Shift	1	4
<b>Total</b>				<b>72</b>

Portions of these personnel have been accounted above in other functions. The remaining costs are estimated as:

**Table 9.5-11 Maintenance Personnel Cost**

Position	No.	Wage (2003\$/Person)	Cost (\$2003)
1. Maintenance Manager	1	60,000	60,000
2. Supervisor	3	45,000	135,000
3. Mechanical Engineer	4	45,000	180,000
4. Electrical Engineer	4	45,000	180,000
5. Mechanic	8	35,000	280,000
<b>TOTAL</b>	<b>20</b>		<b>835,000</b>

<sup>16</sup> The working pattern of a "shift" is constructed by a four day rotation incorporating day, night, night/morning and off. This shift would cover an entire (24 hour) maintenance day.

This staffing includes the technical work force required for the system and does not include the following personnel:

- administrative
- security
- general management
- cleaning staff

**Table 9.5-12 Total Personnel Cost**

<b>Position</b>	<b>No.</b>	<b>Cost (\$2003)</b>
Administration	19	960,000
Operations	21	885,000
Stations	168	5,975,000
Maintenance	20	835,000
<b>TOTAL</b>	<b>228</b>	<b>8,655,000</b>

Employee Benefits

\$8,655,000 x 35% = \$3,029,000

Total Personnel Related Cost

\$8,655,000 + \$3,029,000 = \$11,684,000

Vacation or sick time coverage will require additional personnel payments, whether to additional employees or to overtime. Accordingly, the adjustment for this relief coverage must be added to the total:

Adjusted Total Personnel Related Cost

\$11,684,000 x 1.15 = \$13,437,000

**9.5.4.3. Energy Expenses**

Energy consumption is classified into the following two categories based on the usage:

- Operations (Operation and O&M Facility) and
- Stations.

These two categories are described below.

**9.5.4.3.1. System Operations**

Consumption of electric energy has been calculated based on the present route, curves, gradient, and speed for the Colorado operation and is shown in Table 9.5-13.

**9.5.4.3.2. Stations**

The energy requirement for stations includes: lighting, HVAC, elevators and escalators and other uses. Total power consumption for the stations is summarized in Table 9.5-13.

**Table 9.5-13 Energy Consumption and Cost**

SYSTEM OPERATIONS		
	Consumption	<b>\$0.07/kWh, \$2003</b>
<b>System</b>	192,156 MWh	\$ 13,451,000
<b>O&amp;M Facility</b>	1,350 MWh	\$ 95,000
<b>Stations</b>	4,500/MWh	\$ 315,000
<b>TOTAL</b>		<b>\$ 13,861,000</b>

## 9.6. CRITICAL DEPLOYMENT ELEMENTS

Several elements of the deployment process are critical to a successful completion. Specifically, there is a particular sequence of actions which must be initiated according to the Project Master Schedule, the procurement approach must be well planned and executed, and the long and complex process of certification and approval by all cognizant entities must be carefully adhered to. Additionally, the opportunities for commercial participation in the system's success require exploration. The following sections outline the framework for these elements, however, this section makes no attempt to advocate in policy matters, such as contract forms or other elements of the procurement approach, which will be established by the responsible officials as appropriate to the time and circumstances.

### 9.6.1. *Deployment Action Sequences*

The following actions should be taken in a deployment setting:

#### **Phase 1 Finalize Detailed Design and Cost**

1. Public outreach
2. Identify first segment of maglev
3. Prepare detailed drawings and specifications of the maglev system
4. Identify and select vendors
5. Obtain quotes and prepare construction cost breakdown
6. Finalize operational and maintenance plan and costs
7. Estimate ROI for a few plausible scenarios
8. Finalize environmental impact considerations

#### **Phase 2 Create Financing Plans and Arrangements**

1. State (direct funds, loans, bonds)
2. Federal (direct funds, loans)
3. Local Counties
4. Industries (Colorado and national level)
5. Banks (loans)

#### **Phase 3 Scheduling**

1. Construct general schedule and deployment sequence
2. Initiate procurement of test vehicles
3. Construct test guideway—identify location and length

#### **Phase 4 Develop Qualification and Acceptance Criteria**

1. Vehicle/guideway qualification tests
2. Vehicle acceptance/design modifications
3. Guideway acceptance/design modifications
4. Controls and other equipment acceptance

**Phase 5 First Stage Deployment**

1. Guideway construction contract award
2. Vehicle manufacturing contract awards
3. Other equipment contracts
4. Station and parking construction contract
5. Electrification and substation contract
6. Maintenance depot construction contract

**Phase 6 Conduct Field Trials and Training**

1. Safety tests and certification
2. Train operators/controllers training
3. Other operations personnel training
4. Maintenance depot staff training

**Phase 7 Project Completion and Transfer**

1. Public rides
2. Final system check
3. Approval by state and federal governments
4. Transfer to transit operator, owners, or management

**9.6.2. Colorado Maglev Project Procurement Template**

The following outline presents a preliminary CMP Request for Proposals for the construction and implementation of the project. This is preliminary in nature and will be modified as work continues on the project. The Request for Proposal/Bids will specify that the project will be specifically a maglev system deployment. The Request for Proposal/Bids will have the following major sections:

- |             |   |
|-------------|---|
| 1. Volume 1 | Invitation to Propose / Instructions to Proposers                   |
| 2. Volume 2 | General Conditions, Supplementary Conditions and Special Provisions |
| 3. Volume 3 | Technical Provisions  |
| 4. Volume 4 | Delivery Approach   |
| 5. Volume 5 | Operations and Maintenance  |
| 6. Volume 6 | Contract Drawings   |

**9.6.2.1. Volume 1 Invitation to Propose**

**REQUEST FOR PROPOSALS  
INSTRUCTION TO PROPOSERS TABLE OF CONTENTS  
COLORADO MAGLEV PROJECT**

**TABLE OF CONTENTS**

**INTRODUCTION AND GENERAL INFORMATION**

- Introduction
- Definitions
- Summary of Work
  - Estimated Cost of the Project
- Overview of Procurement Process
  - Process
  - Anticipated Procurement Schedule
- Proposal Documents and Correspondence

- Proposal Documents
- Other Proposal Correspondence
- Legal, Contractual, and Miscellaneous Matters
  - Owner Controlled Insurance Program (OCIP)
    - Coverage Under OCIP
      - Automobile, Equipment, and Bonding Coverage
    - Changes
    - Insurance Costs
  - Legal Basis of Procurement
  - Labor Compliance Program
  - Colorado Contractor's License
  - Certifications
    - Debarment, Suspension, Ineligibility and Voluntary Exclusion, Lower Tier
    - Covered Transactions
    - Lobbying
    - Buy America
    - Financial Contribution Limitations
    - Conflict of Interest
  - Protests
    - Address
    - Pre-Proposal Protests
    - Protests of Recommended Award
    - Federal Transit Administration Review
  - Public Records Act
  - Environmental Requirements
  - Partners and Funding
  - Federal Requirements
  - Disadvantaged Business Enterprise Representation/Non-Discrimination Programs
    - Disadvantaged Business Enterprise Policy
    - Transit Vehicle Manufacturers
    - DBE Participation Goals
    - O&M Non-Discrimination Program
  - Proposer's Bond
  - Contract Bonds
  - Changes to the DB Entity Team
  - Escrow Proposal Documents
    - Submittal
    - Escrowed Proposal Documentation Certification

## **PROPOSAL CONDITIONS AND REQUIREMENTS**

- Contents of Proposal Documents
- Contracting Approach
- Preparation of Proposals
- Acceptance or Rejection of Proposals
- Disqualification of Proposers
- Alternate Proposals
- Withdrawal or Revision of Proposal
- Supporting Data
- Stipends
- Proposals from Joint Ventures
- Authorized Representatives
- Proposal Validity
- Language and Units
- Conditions of Proposal
- Clarification and Interpretation of the Proposal Documents

Correspondence During the Proposal Period  
Requested Proposal Clarification  
Proposal Conditions and Exceptions

## **CONTENTS OF THE PROPOSAL**

Organization of Proposals  
Contents of Parcels  
    Parcel 1 Proposed Documents and Price Proposal  
    Parcel 2 Commercial Proposal  
    Parcel 3 Technical Proposal  
    Parcel 4 Management Proposal  
    Parcel 5 Operations and Maintenance Proposal  
    Parcel 6 Executive Summary  
    Parcel 7 Public Records Proposal  
Preparation of Price Proposal  
    Total Lump Sum Fixed Price Forms  
    Economic Price Adjustment  
    Life Cycle Costs  
Commercial Proposal (Parcel 2)  
    Financial Capability  
    Project Financing  
    Exceptions and Conditions  
Technical Proposal (Parcel 3)  
    System Description  
    Fixed Facilities  
Management Proposal (Parcel 4)  
    Management Program and Organization  
    Agency Coordination  
    Quality Assurance and Quality Control  
    Direct Experience with Proposed System Technology  
    Record of Past Performance on Similar Project  
Operations and Maintenance Proposal (Parcel 5)  
    Experience in Operations and Maintenance  
    System Operating Plan  
    Maintenance Plan  
    O&M Management Plan  
    Operations and Maintenance Manuals  
    Training Program  
    Capital Asset Replacement Plan  
Restriction on Disclosure and Use of Data

## **PROPOSAL EVALUATION AND CRITERIA**

Confidentiality of Proposals  
Evaluation of Proposals  
    Proposal Responsiveness  
    Minimum Requirements  
        Technical Requirements  
        Price Requirements  
    Acceptability of Conditions  
    Evaluation Criteria  
    Best Value Determination

## **APPENDICES**

Proposal Form  
Form for Questions  
Form for Conditions of Proposal



- Form 1, Joint Venture
- Form 2, Company Profile
- Form 3, Financial Statement
- Build Pricing Forms
- O&M Pricing Forms
- Expansion Pricing Forms
- Life Cycle Pricing Form
- Certification Forms
- Contracts

Volume 1 will contain Formal Offer forms that comprise the entirety of the Project. Each subsystem such as Guideway, Vehicle, Stations, etc. will be submitted on separate Formal Offer forms which will be summarized on a Formal Offer Summary Form.

**9.6.2.2. Volume 2 GC, SC, SP**

General Conditions, Supplementary Conditions and Special Provisions are specific to properties in which deployments are undertaken. These conditions and provisions are developed formally by the governmental jurisdictions that have the primary deployment responsibility.

**9.6.2.3. Volume 3 Technical Provisions**

The Technical Proposals will require substantial information. The following Table of Contents provides an outline of the requirements for the Colorado Maglev Project.

**TABLE OF CONTENTS TECHNICAL PROVISIONS**

**SYSTEM DESCRIPTION**

- Project Overview
- System Configuration
  - First Segment
  - Ultimate System
- Project Phases
- Stations
- Operations and Maintenance
- Service Proven System Technology and Technical Resources
  - Service-Proven System Technology
    - Use of Technology Modifications
    - Exceptions
    - Evaluation of Technology Modifications
  - Successful Passenger Service Operation
  - Operation and Maintenance
  - Manufacturing Facilities
- System Facilities, Equipment, and Operations
- System Expansion Requirements
  - Expansion of System Line Capacity
  - Vehicles
  - Power Distribution
  - Command, Control, and Communications
  - Guideway and Guideway Equipment
  - Stations and Station Equipment
  - Maintenance and Storage Facility and Equipment
  - Operations
- Accessibility
- Design Lives

**SYSTEM OPERATING CRITERIA**

- Passenger Service Characteristics
  - System Operating Hours
  - Headway
  - Station Dwell Times
  - Travel and Round Trip Times
  - Line Capacity
  - Fleet Size, Train Length and Spare Vehicles
    - Peak Period Operating Fleet for First Segment
    - Spare Vehicles for First Segment
    - Fleet Size for Ultimate Line Capacity
    - Other Requirements
  - System Performance and Failure Management Analysis
  - Design Requirements for Subsystems
- System Operating Modes
  - Normal Operating Modes
  - Failure Operating Modes
    - Short Turnback Mode
    - Single-Tracking Mode
    - Contractor-Proposed Modes
  - Operational Overrides and Adjustments
- Failure Management
  - Recovery of Stalled Trains
- System Startup and Shutdown, Mode Transition and Restart
  - Startup and Shutdown
  - Mode Transition and Train Adjustments
  - System Restart

**SYSTEM ENVIRONMENTAL DESIGN REQUIREMENTS**

- Temperature and Humidity
- Electromagnetic Compatibility
  - General
  - Electromagnetic Compatibility Control Plan
- Airborne Noise
  - Exterior Noise
  - Interior Noise
- Structure-Borne Noise and Vibration
- Air Pollution
- Water Pollution
- Wind
- Precipitation
- Lightning Protection
- Other Site Specific Environmental Conditions

**SAFETY AND SECURITY TECHNICAL REQUIREMENTS**

- Safety Technical Requirements
  - Safety Principles
  - ATC System Fail-Safe Design
- Verification and Validation
- Fire Safety
  - Fire on Board a Train
  - Fire on Guideway (Tunnel)
  - Fire in Station
  - Facility Fire Detection Subsystem
  - Fire Management Panels
  - Fire in Vehicle Storage Area

- Electrical Safety
- Emergency Evacuation
- Operations and Maintenance Personnel Safety
- Non-User Safety
- Departure Test
- Fire Extinguishers and personal Safety Equipment
- System Security
  - Intrusion Alarm Subsystem
  - Vehicle Security
  - Facilities' Security
  - Wayside Enclosures
  - Security Wiring
  - Guideway
  - Restricted Access Subsystem
  - Closed Circuit Television System
  - Communications
- Construction Safety and Security

#### **SYSTEM SERVICE AVAILABILITY**

- General
- Service Mode Availability
- Fleet Availability
- Station Platform Availability
- Elevator, Escalator Availability
- System Service Availability Requirements
  - System Service Availability Levels
  - Service Mode Downtime Limits
  - Corrective Actions

#### **VEHICLE**

- Dynamic Outline and Clearances
  - Dynamic Outline
  - Clearance Requirements
- Vehicle Weights
- Vehicle Capacity
- Vehicle Structure
  - Structural Design Criteria
    - Design Loads
    - Materials Properties
    - Paints, Coating, and Protection of Metals
    - Allowable Stress
    - Deformation
    - Vehicle Connections
    - Equipment
    - Vibration
  - Structural Analysis
  - Tipping Stability
  - Jacking Pads and Hoists
  - Crashworthy Design
    - Vehicle/Vehicle Collision
    - Vehicle/Buffer Collision
      - Collisions with Buffers within the Passenger Carrying System
      - Collisions with Buffers within the Non-passenger Carrying System
  - Bolts, Nuts, Fasteners, Welding and Bonding Standards
- Vehicle Design Life

- Passenger Comfort
  - Heating, Ventilation, and Air Conditioning
  - Interior Noise level
  - Ride Comfort
  - Mobility Impaired and Disabled Considerations
- Propulsion and Braking System
  - Propulsion/Braking Control
  - Duty Cycle
  - Service Brakes
  - Emergency Brakes
  - Design Stopping Distances
    - Guideway Conditions
    - Out-of-Tolerance Conditions
    - Wind Loads
  - Parking Brake
  - Propulsion and Braking System Component Design
    - Design Requirements
    - Service Requirements
  - Installation and Protection
  - Controls and Interlocks
  - Brake Testing
- Electrical Subsystem
  - Vehicle Primary Power Subsystem
  - Vehicle Auxiliary Power Subsystem
    - Low Voltage Power
    - Emergency Power Subsystem
  - Power Collection
  - Circuit Breakers and Interrupters
  - Wiring
    - General
    - High Temperature Wire and Cable
    - Communication Wire and Cable
    - Conduit and Raceways
    - Junction Boxes
    - Undercar Wiring
    - Connections, Connectors and Splices
  - Grounding
  - Lighting
    - Interior
    - Exterior
  - 120-Vac Power Supply
  - Maintenance Power Connection
- Suspension and Guidance Subsystems
  - Clearance of Obstacles
  - Loss of Levitation
  - Loss of Load Leveling
  - Mileage Recording Equipment
  - Vehicle Weight Overload
  - Turning Radius
- Doors
  - Features and Dimensions
  - Door Operation
  - Door Safety
  - Door Alignment
  - Emergency Exits
- Watertight Construction

- Interior Design
  - Interior Materials
  - Access Panels
  - Fire Barriers
  - Floor and Floor Covering
    - Floor Structure
    - Floor Covering
  - Seats
  - Windows
  - Insulation
  - Stanchions, Handrails and Ceiling Grips
  - Passenger Information
    - Audio Announcements
    - Graphics
  - Resistance to Vandalism
- Flammability and Smoke Emission
  - Electrical Wire Insulation
- Fire Protection
- Vehicle Coupling
  - Mechanical Couplers
- Train Interaction
- Switching
- Communications
- Vehicle Control
  - Automated Mode
  - Manual Operations
    - Manual Control Panel
- On-Board Diagnostics
  - Malfunction Annunciation
  - Malfunction Classifications
  - Microprocessor Diagnostics and Validation

## **POWER DISTRIBUTION SYSTEM AND BACKUP POWER SUPPLIES**

- Power Distribution System
  - Metering, Alarms, and Data
  - Power Factor and Harmonics
  - Switchgear
  - Power Collection System
    - Contact Rail System
    - Negative Return System
    - Power Rails Design Data
    - Rail Connections
    - Rail Heating
  - Electrical System Protection and Grounding
    - Protection
    - Grounding
    - Stray Current and Corrosion Control
    - Cathodic Protection
  - Substation Transformers and Rectifier Units
  - Negative Drainage Equipment
- System Equipment Backup Power Supply
  - Uninterruptible Power Supply
- Housekeeping Power
- PDS Data Communications Delay
- Substation Design
- Infrastructure

Umbilical Stinger / Power Leads and Mounting Hardware  
Uniformity  
Special Design Considerations

## COMMAND, CONTROL, AND COMMUNICATIONS

### Automatic Train Protection

#### Presence Detection

- Safe Train Separation Assurance
- Unauthorized Motion Prevention
- Overspeed Protection
- Parted Train Protection
- Signal Transmission and Detection
- Unscheduled Door Opening Protection
- Vehicle/Station Alignment and Door Interlocks
- Departure Interlocks
- Reverse Operation Interlocks
- Merge/Diverge Safety Function
- Service Brake Failure Protection
- Zero Speed Detection
- End of Track Protection
- Facility Door Detection and Response

### Automatic Train Operation

- Programmed Station Stop
- Door Operation
- Train Movement Control
- Loss of Propulsion Power
- Operating Modes
- ATO Manual Control Functions
- Loss of Ventilation and/or Facilities Power in Tunnel Section

### Automatic Train Supervision

- Safety Constraints on ATS
- Performance Monitoring
  - System Schematic Display
  - Power Schematic Display
  - Other Displays
- Performance Control, Override and Adjustments
  - Automatic Train Management Control Functions
  - CCO Control Functions
- Alarms and Malfunction Reporting
  - System Alarms
  - Facility Fire and Security Alarms
- Communications
- Data Recording and Reporting
  - System Availability and Operations Reports
- System Simulator
- Weather Station and Monitors

### Audio and Visual Communications

- Audio Communication
  - Wayside Public Address
  - Emergency and Passenger Service Telephones
  - Vehicle Vice Communications
  - Recorded Audio Announcements, Messages and Music
  - Operations and Maintenance Radio Communications
  - Internal Telephone Communications
  - Transmission Equipment for Audio Communications Subsystems
  - Recording of Audio Transmissions

- Intelligibility Requirements for Audio Communications Subsystems
- Video Surveillance
  - Central Control Equipment
  - Passenger Station and Tunnel Equipment
  - Transmission Equipment for Video Communications Subsystems
  - Guideway and Emergency Walkway Equipment
  - Vehicle Equipment
  - Cameras

- ATC System Reliability
  - Redundancy
  - Software Requirements
- Data Communications Delay
- Communications Systems Redundancy
- Signal Rail Connections
- Software/Hardware Calendar Considerations
- Wayside Intrusion Detection

### **GUIDEWAY EQUIPMENT**

- Running and Guidance Surfaces
  - Construction Tolerances
  - Running and Guidance Surface Conditions
  - Superelevation
- Guideway Mounted Propulsion and Suspension Elements
- Overtravel Buffers
- Wayside Equipment
- Barriers and Fences
- Switching
  - General Requirements
  - Basic Principles of Switching
  - Mechanisms
  - Manual Operation
  - Switching Safety
- Aesthetics, Protection, and Drainage
- Emergency Evacuation
  - Tunnel Guideway
  - Surface Guideway
  - Elevated Guideway
  - Emergency Walkway
- Signage

### **STATIONS AND STATION EQUIPMENT**

- System Components
  - Station Safety Components
    - Platform Edge Safety Protection
    - Platform Nosing
    - Station Emergency Walkway Doors or Gates
    - Emergency Guideway Power Shut-Off Switch
    - Door Alarms and Security Equipment
    - Fire/Smoke Detectors and Alarms
  - Station Passenger Information
    - Station Dynamic Signs
    - Station Static Signs
    - Station Arrival/Departure Announcements
  - Public Address System
  - CCTV System
  - Passenger Station Communications

- Station UPS Equipment
- Equipment Room and Enclosure Criteria
- Communications Rooms
- Owner-Supplied Housekeeping Power
  - Distribution Panels, Conduits, and Junction Boxes
- UPS and Battery Rooms
- Wayside Control Rooms and Enclosures
- Fire Protection
- Electrical and Lighting Components
  - Lighting
  - Emergency Lighting and Ventilation
  - Housekeeping Electrical Power
  - Conduits, Ducts and Cable Trays
- Mechanical Components
  - Storm Drainage
  - Water Supply
  - Stand Pipes
  - Mechanical Ventilation and Air Conditioning
  - Sprinklers
- Station Facilities
  - Aesthetics
  - Safety/Security
  - Entrance Components
    - Pedestrian Pavements
    - Landscaping
    - Information and Advertisement Kiosks
    - Newspaper/Vending Equipment and Enclosures
    - Passenger Information Graphics
    - Public Telephones
    - Emergency Telephones
    - Trash/Cigarette Receptacles
    - Escalator
    - Elevators
    - Stairs
    - Entrance Canopy
    - Security Fence/Grill
    - Baggage Cart Barriers

## **MAINTENANCE FACILITIES AND EQUIPMENT**

- Functional Requirements
  - Passenger Operations
  - Vehicle Storage
  - Vehicle Washing
  - Train Receiving Guideway
  - Train Ready Guideway
  - Maintenance Bays
  - Maintenance Functions
- Location, Design, and Finishing
- M&SF Guideway and Related Equipment
- Maintenance Tools and Equipment
- Spare parts, Expendables, and Consumables
- System Support Vehicles
  - On-Guideway Maintenance and Recovery Vehicle
  - Other Operations and Maintenance Vehicles
- Maintenance Management Information System
- Architectural and Engineering Requirements



- General Characteristics
- Building Exterior
- Building Interior
- Vertical Circulation
- Lighting
- Structural
- Electrical
- Mechanical Equipment
- Utilities
- Safety
  - Overhead Hoist
  - Signage
  - Paint Codes
- Emergency Systems
  - M&SF Fire Protection System
  - Emergency Power
- Central Control Facility
- Administrative Offices

### **CORROSION CONTROL AND GROUNDING**

- Purpose and Scope
- Interfaces
  - Expansion Capability
- Soil and Water Corrosion Prevention
  - Stray Current Corrosion Prevention Systems
  - Electrical Bonding
  - Drainage Facilities and Equipment
  - Test Facilities
  - Special Design Provision
- Atmospheric Corrosion Prevention
  - Atmospheric Corrosion Prevention Systems
    - Materials
    - Coatings
- Grounding
  - Power Substations
  - Passenger Stations and Facilities
  - Aerial Structures

### **GUIDEWAY ALIGNMENT AND STRUCTURAL CRITERIA**

- Scope and General Requirements
  - General Design Considerations
    - Environmental Design
    - Graffiti Control
  - Traffic Control Lights and Street Lights
- Clearance Requirements
- Guideway Alignment
  - Horizontal Alignment
  - Vertical Alignment
  - Alignment Aesthetics
  - Pier Placement
  - Fencing
- Tunnel and Facilities
- Structural Design Criteria
  - General
    - Purpose and Scope
    - Design Codes and Specifications

State and Local Laws  
Minimum Basis of Design Criteria

Structural Loading Criteria  
Loads and Forces  
Foundations  
Passenger Stations and Buildings  
    Scope  
    Design Codes  
    Loads and Forces  
Support and Underpinning and Separation of Existing Structures  
Other Minimum Requirements  
    Bridges  
    Earth Retaining Structures  
    Lateral Earth Pressure  
    Buildings  
    Design of Pile Foundations  
    Combinations of Loads  
        General  
        Load Factor Design  
        Service Load Design  
        Live Load

**CIVIL WORKS AND UTILITIES**

Scope and General Requirements  
Design Factors  
Sight Distance Criteria  
Traffic Control  
    General Design Criteria  
    Codes, Standards, and References  
    Traffic Lane Widths  
    Traffic Control Devices  
    Monitoring Equipment  
Roadway Modifications and Restorations  
Utilities  
    Responsibility for Utility Work  
        Utility Design, Construction and Coordination  
        Specific Utilities  
    Public Utility Requirements  
        Sanitary Sewers  
        Water  
        Restoration of Paving  
        Landscape Areas and Trees  
        Relocation and Restoration of Signage  
        Drainage  
    Private Utilities

**MATERIALS AND WORKMANSHIP**

General  
    Compliance  
    Working Environment  
    Submittals  
    Interface Coordination  
    Pre-Installation Activities  
    Damage  
    Fixed Facility Installations  
    Equipment Mounting

- Identification
- Spare Provisions
- Architectural Finishes
- Sitework
  - Earthwork
  - Trenching and Backfilling for Utilities
  - Aggregate Subbase
  - Aggregate Base
  - Aggregate Drainage Fill
  - Slope Protection
  - Piling
  - Asphalt Concrete Paving
  - Portland Cement Concrete Paving
  - Concrete Curbs, Gutters, and Walks
  - Pavement Marking
  - Utility Structures
  - Water Distribution System
  - Subsurface Drainage System
  - Site Drainage System
  - Site Sanitary Sewerage System
  - Landscape Irrigation System
  - Fences and Gates
  - Pre-cast Parking Bumpers
  - Wayside Signage and Graphics
  - Traffic Barriers
  - Landscape Planting
- Concrete
  - Concrete Formwork
  - Concrete Falsework
  - Concrete Reinforcement
  - Joint Seals
  - Waterstops
  - Elastomeric Bearing Pads
  - Cast-in-Place Concrete
  - Portland Cement Concrete
    - General
    - Materials
      - Portland Cement
      - Aggregates
      - Special Aggregates for Reducing Shrinkage and Creep
      - Concrete Admixtures and Cementitious Materials
      - Water
    - Mix Designs
  - Lightweight Concrete
  - Concrete Finishing
  - Shotcrete
  - Prestressed Concrete
  - Precast Concrete
  - Nonshrink Grout
- Masonry and Stone
  - Concrete Unit masonry
  - Crystallized Glass Panels
- Metals
  - Welding
  - Structural Steel
    - Structural Steel for Bridges

- Structural Steel for Buildings
  - Structural Steel Tubing
  - Pipe
  - Anchors and Fasteners
  - Painting Structural Steel
- Steel Joists
- Metal Decking
- Cold-Form Metal Framing
- Metal Fabrications
- Metal Stairs
- Handrails and Railings
- Woods and Plastics
  - Finish Carpentry
  - Casework
- Thermal and Moisture Protection
  - Elastomeric Sheet Waterproofing and Flashing
  - Bentonite Waterproofing
  - Batt and blanket Insulation
  - Aluminum Wall Panels
  - Built-up Asphalt Roofing
  - Standing Seam Metal Roof
  - Sheet Metal Flashing and Trim
  - Firestopping
  - Joint Sealers
- Doors and Windows
  - Standard Steel Doors and Frames
  - Access Doors
  - Overhead Coiling Door
  - Overhead Coiling Grille
  - Aluminum Entrances and Storefronts
  - Aluminum Windows
  - Door Hardware
  - Manual Assist Door Equipment
  - Glass and Glazing
  - Translucent Wall Assemblies
- Finishes
  - Metal Support Systems
  - Gypsum Board Systems
  - Ceramic Tile
  - Suspended Acoustical Ceilings
  - Metal Ceilings
  - Tactile Warning Surface
  - Resilient Flooring
  - Seamless Epoxy Flooring
  - Painting
  - Graffiti-Resistant Coating
- Specialties
  - Plastic Toilet Compartments
  - Fixed Metal Wall Louvers
  - Access Flooring
  - Plastic and Metal Signs
  - Metal Lockers
  - Fire Extinguishers and Cabinets
  - Toilet and Bath Accessories
- Equipment
  - Loading Dock Equipment

- Conveying Systems
  - Hydraulic Elevators
- Mechanical
- Electrical
  - Cabinets and Consoles
  - Raceway, Conduits, Ducts, Cable Tray Systems and Boxes
  - Cables, Wires, Fiber Strands and Cords
  - Terminations
  - Pull Wires
  - Grounding and Bonding
  - Light Fixtures

#### **CODES AND STANDARDS**

- Specific Requirements
- Other Codes and Standards
- Building and Relater Permits

#### **CONSTRUCTION REQUIREMENTS**

- Scope and General Requirements
- Access and Protection of Property
- Protection and Underpinning of Structures
- Dewatering
- Detection of Movement/Preconstruction Survey
- Temporary Utility Services
- Construction Sequence Considerations
- Construction Schedule Factors
- Preconstruction Meetings
- Noise and Vibration
  - Construction Noise Mitigation
  - Use of Noise Buffers and Sound Barriers
  - Pile Driving Noise Reduction
  - Construction Vibration Mitigation
- Temporary Facilities
  - Project Office
  - Other Project Field Offices
  - Storage and Parking Areas
  - Enclosed Storage and Shops
  - Security
- Project Identification Signs
- Site Access-Vehicles and Equipment
- Field Engineering and Surveys
- Field Samples and Mockups
- Traffic Management
  - General
  - Traffic Management Plan
  - Construction Management Plans for Vehicular Circulation
  - Temporary Walkways
  - Temporary Replacement Parking for Affected Businesses
  - Priority of Guidelines, Criteria, Standards, or Specifications
  - Application of Standards
  - Traffic Control Devices
  - Portable Changeable Message Sign
- Temporary Controls
  - Reference Standards
  - Pollution Abatement
  - Erosion and Sediment Control

- Dust Control
- Mud Control
- Noise Control
- Air Quality During Construction
- Waste and Water Pollution
- Salvage of Materials
- Historical and Scientific Specimens Found During Construction
- Removal, Treatment and Disposal of Materials

**LANDSCAPING**

- Introduction
- Planting Survey
- Planting Basic Goals
- Planting Considerations
- Planting Areas
- Keyed Planting Areas Shown on Civil Plans
- Plant Types
- Plant Sizes
- Planting Near Utilities
- Irrigation
- Landscape Lighting

**9.6.2.4. Volume 4 Delivery Approach**

The delivery approach such as Design Build (DB) will be specified for delivery of the system. Volume 4 will contain the following documents:

- a. Contract Data Requirements List (Specifies format for drawings, spreadsheets and word documents)
- b. Operating System Compliance Verification Matrix
- c. Operating System Verification / Acceptance Plan
- d. Military Standards Excerpts (Develops the System Safety Program Plan and the Hazard Analysis)
- e. Safety and Security Certification Plan
- f. Construction Safety Plan
- g. List of Referenced Documents
- h. Project Insurance Manual

**9.6.2.5. Volume 5 Operations and Maintenance**

The Operations and Maintenance Contract provisions (if necessary) will have the following:

**Table of Contents for General Provisions**

**GENERAL**

- O&M Contract Documents
- Exercise of Contract Responsibilities
- Certification of Funds, Budget and Fiscal Provisions and Termination in the Event of Non-Appropriation
- Guaranteed Maximum Costs

**THE TRANSIT JURISDICTION**

- Obligations to the Contractor
- Specific Representative Responsibilities
- Right to Carry Out the Work
- Right to Stop or Suspend the Work
- Offices and Equipment Furnished to the Jurisdiction

**JURISDICTION'S PROVISION OF THE PROJECT**

Project's Operating System and Fixed Facilities  
Control of Premises

**COMPENSATION**

**PAYMENT DOES NOT IMPLY ACCEPTANCE OF WORK**

**CONTRACTOR'S WARRANTIES AND GUARANTEES**

**RESPONSIBILITY FOR EQUIPMENT, PROPERTY AND RELATED CLAIMS**

**LIQUIDATED DAMAGES FOR DELAYS TO JURISDICTION**

**INCIDENTAL AND CONSEQUENTIAL DAMAGES**

**NO THIRD PARTY BENEFICIARIES**

**CONFLICT OF INTEREST**

**OWNERSHIP OF RESULTS AND TITLES TO MATERIALS**

**WORKS FOR HIRE**

**NON-DISCRIMINATION PROGRAM FOR SUBCONTRACTING**

**ALCOHOL AND DRUG DETECTION AND DETERRENCE**

**HAZARDOUS MATERIALS AND SUBSTANCES**

**PUBLIC RELATIONS AND ADVERTISING**

Site Tours  
Advertising on the System

**OTHER RESTRICTIONS**

Other Agreement Requirements

**SAFETY AND SECURITY**

Safety of Persons and Property  
Project System Safety Program  
Security

**INSPECTION**

**FINAL O&M CONTRACT PAYMENT**

**Table of Contents for Operations and Maintenance General Requirements**

GENERAL

STATEMENT OF WORK

TERM OF THE CONTRACT

PAYMENT

- Economic Price Adjustment
- Monthly Payments
- Invoices
- Final Contract Payment for O&M Work

CONTRACT MODIFICATIONS

SYSTEM AVAILABILITY

- System Service Availability
- Downtime Event Limits
- Corrective Action
- Alternate System Service Availability Report

REPAIR AND REPLACEMENT OF DAMAGED PARTS, COMPONENTS OR MATERIALS

- Repairs and Replacements
- Replacement of Materials
- Compensation for Repair and Replacement
- Payment Procedures

REPORTING OF ACCIDENTS

CAPITAL ASSET REPLACEMENT

**Table of Contents for Operations and Maintenance Appendices**

OBLIGATIONS OF THE CONTRACTOR

O&M ADMINISTRATION AND MANAGEMENT

- Training of Contractor's Personnel
- Option to Train Transit Jurisdiction Personnel
- Inventory Control
- Management Reports and Records
- Contractor Performance
- Limits of the O&M Work Area
- System Design and Configuration
- Drawings and Documents
- Testing and Acceptance of Upgrades and Expansion Work
  - Testing and Acceptance of Upgrades
  - Accommodation of Expansion Work
- Safety
  - Safety Program
- Security
  - General
  - Security Services Plan
  - Coverage
  - Scope of Work
  - Administrative Activities
  - Scheduling and Operations
  - Personnel Qualifications and Requirements
- Operations Requirements
  - General
  - System Assurance Monitoring
  - Special Services
  - Operational Readiness Testing



- Objective of Readiness Testing
- Frequency of Readiness Testing
- Testing of Operations Personnel
- Testing of Maintenance Personnel
- System-Wide Readiness Drill
- Maintenance Requirements
  - General
  - Maintenance Duties
    - Subsystem Maintenance
    - Cleaning and Janitorial Services
    - Treatment of Effluents
    - Spare Parts and Equipment, Expendables and Consumables
    - Maintenance Tools and Equipment
    - Elevator and Escalator Maintenance
- Determination of Monthly Payments
  - Monthly Payments
  - System Service Performance Adjustments
  - Adjustments for Elevator and Escalator Service Levels
  - Adjustments for System Cleanliness Failures
- O&M Contract Prices
- O&M Agreement and Release of any and all Claims

**9.6.2.6. Volume 6 Contract Drawings**

All contract drawings for Proposal submittal shall be included in Volume 6.

Each specific project will require additions and deletions to the system requirements necessitating modifications to the proposal requirements. The previous detail for the Request for Proposal provides sufficient outline information to allow the reader the understanding of the extent of the proposals and its contents.

### **9.6.3. Government Certification/Approval Program**

The deployment of the CMP involves federal, state and county certification and approval processes and local governmental coordination. For the CMP this process involves: the State of Colorado, RTD, USDOT (FTA, FRA and FHWA), the Federal permitting process, Environmental Agencies including EPA, and the counties through which the system traverses. The Deployment Guide summarizes the various certification requirements and approval processes necessary for system deployment. It is assumed that the certification and approval documents would essentially be the same as for the LRT system.

It will be necessary to complete a federal environmental assessment for purposes of the National Environmental Protection Act (NEPA). Much of the PEIS work performed by CDOT for the I-70 Mountain Corridor will be applicable to the CMP.

It may be required to complete a detailed analysis of electric and magnetic fields for the CMP for potential environmental impacts. If required this assessment will be completed for the environmental certifications.

The CMP will be subject to FRA safety jurisdiction.

The Railroad Safety Act of 1970 includes the following declaration of purpose: "promote safety in all areas of railroad operations..." In the Act, the Secretary of the U.S. Department of Transportation is charged to "prescribe, as necessary, appropriate rules, regulations, orders and standards for all areas of railroad safety..."

The Rail Safety Improvement Act of 1988 made clear the jurisdiction of the FRA by defining the term railroad to include: "all forms of non-highway ground transportation that run on rails or electromagnetic guideways, including (1) commuter or other short-haul passenger service in a metropolitan or suburban area and (2) high speed ground transportation systems that connect metropolitan areas without regard to whether they use new technologies not associated with traditional railroads."

Pursuant to this authority, the Office of Research and Development of FRA will need to conduct a safety review of the CMP system. This review will identify safety issues presumed to exist at the time of this review and the hazards that potentially lead to them.

The following sections describe the certification process for the CMP.

#### **9.6.3.1. System Safety Program Plan (SSPP)**

The responsible maglev system operating agency ("agency") will oversee activities that affect safety including the planning, design, construction, procurement, testing and startup of the maglev system. The agency will be assisted by consultants and contractors, as appropriate.

The agency will implement this System Safety Program Plan (SSPP) to ensure that project safety criteria are designed into the Project, subsystems and facilities. Safety provided will include provisions to enable safe and timely evacuation of patrons and personnel from all fixed structures, disabled vehicles and facilities. The provisions will include the necessary safeguards to protect patrons, system personnel and emergency personnel during evacuation, and will minimize exposure to all hazards, including moving vehicles and potential falls.

#### **9.6.3.2. Policy**

The maglev project has established safety as a primary consideration through the planning, design, construction, procurement, testing, startup and operation of the system. The agency and contractors will adhere to all applicable codes, regulations, standards, and industry safety

practices to achieve a level of safety equal to or better than that of other modern transportation systems.

The agency and contractors will eliminate, minimize or otherwise control hazards during the pre-operational phase of the Project through performance of safety hazard analyses, safety reviews, and design selection.

All provisions of the Federal Transit Administration, US Department of Transportation, 49 CFR, Part 659, State Safety Oversight of Rail Fixed Guideway Systems, will be followed. The agency will establish a close working relationship with the Colorado Public Utilities Commission, the agency designated by the State of Colorado as being responsible for State Safety Oversight of Rail Fixed Guideway Systems.

Responsibility for implementation of the Project SSPP, and for coordination with the Rail State Safety Oversight agency, has been delegated to the agency's Safety and Security Manager.

#### **9.6.3.3. Revisions**

The SSPP will be reviewed as the Project progresses towards revenue operations. The reviews are the responsibility of the Project Safety and Security Manager and Safety Review Committee (SRC). Inputs to the SSPP review will be gathered from Project management staff, consultants and contractors. Proposed revisions to the SSPP will be approved by the SRC and Safety and Security Manager.

#### **9.6.3.4. Purpose**

The purpose of the SSPP is to establish requirements for identification, evaluation and minimization of safety risks throughout all phases of the Project. Requirements are defined in the following areas:

- Implementation of established safety criteria;
- Processes for identification and assessment of safety hazards early in the design phase; and
- Methods to eliminate minimize or control the identification of critical and catastrophic hazards.

#### **9.6.3.5. Goal and Objectives**

The goal of the SSPP is to provide a level of safety compliant with all applicable codes, guidelines, regulations and standards; and to establish a safety philosophy that emphasizes preventive measures to eliminate unsafe conditions.

The objectives of the SSPP are to identify design and management controls, plans and processes to:

- Perform all necessary safety analyses to identify and assess safety hazards;
- Analyze historical data from other similar transportation systems;
- Develop and implement a safety certification program to document that safety requirements are incorporated into the design of the Project, safety items have been properly installed in the field, materials have been provided to train operations personnel, and integrated tests and emergency drills have been conducted to ensure that all systems and equipment function as designed;
- Develop document controls that attest to safety throughout the design, construction, procurement and testing of the Project; and
- Coordinate safety initiatives with quality, reliability and maintainability activities.

#### **9.6.3.6. Scope**

The scope of the SSPP includes the management and technical safety activities that are performed during the: design, construction, procurement, testing, and startup phases of the Project. Operations phase safety activities will be added to this document during final design of the Project.

#### **9.6.3.7. Applicable Documents**

The following documents were used as guidance or reference for this SSPP.

Compliance Guidelines for States with New Starts Projects, DOT-FTA-MA-5006-00-1, U.S. Department of Transportation, Federal Transit Administration, June 2000.

Manual for the Development of Rail Transit System Safety Program Plans. American Public Transit Association, September 1991.

MIL-STD 882D, System Safety Program Requirements, U.S. Department of Defense, January 19, 1993.

FTA Regulations, 49CFR, Part 659, State Safety Oversight of Rail Fixed Guideway Systems, Federal Transit Administration, December 1995.

Hazard Analysis Guidelines for Transit Project, DOT-FTA-MA-26-5005-00-01, U.S. Department of Transportation Federal Transit Administration, January 2000.

#### **9.6.3.8. Safety and Security Committee**

##### **9.6.3.8.1. Fire/Life Safety Committee**

The purpose of the FLSC is to serve as a liaison between the Project, fire and police jurisdictions, and emergency response agencies. The FLSC is composed of representatives from local fire and police jurisdictions, local emergency response agencies, and Project system safety and security, engineering and construction management staff.

The system safety and security manager will chair the Fire/Life Safety Committee (FLSC) and other staff will participate as needed.

##### **9.6.3.8.2. Safety Review Committee**

The Safety Review Committee (SRC) will be responsible for assessing hazards and overseeing compliance with the Safety Certification Program. The SRC is responsible for:

- Reviewing documentation (evidence of conformance to safety requirements), assigning responsibilities for open safety issues and approval of certification documentation, conducting site visits and defining safety-related tests and analyses, as required;
- The specific method to mitigate the conditions or potential hazard; and
- Determining whether to accept specific conditions or require corrective action, including providing recommendations to the designers regarding certification and noncompliance of system elements.

The SRC is composed of senior management personnel, or designees, who represent the following areas: engineering, system safety and security, vehicle, construction, operations and maintenance, fixed facilities, system integration, and startup. The system safety and security manager will chair the SRC.

#### 9.6.3.8.3. Security Committee

The Safety Review Committee will also function to review security design issues during the design and construction phases of the Project. Security criteria will be incorporated into the Safety Certification process.

#### 9.6.3.9. Hazard Identification, Analysis and Resolution

Hazard identification, analysis and resolution is the formal process to identify, evaluate and mitigate hazards associated with the design, construction, testing, startup and operation of the system for patrons, employees and the general public. All known hazards identified are categorized by severity and probability of occurrence, analyzed for potential impact and resolved by design, procedures, warning devices or other methods so that they fall within the prescribed level of risk acceptable to the Project. A Hazard Identification, Analysis and Resolution Plan will be developed for the Project; guidelines listed below will be followed.

##### 9.6.3.9.1. Hazard Identification

Hazard identification defines conditions and faults, which have the potential for causing an accident.

The physical and functional characteristics of the Project will be defined. These characteristics include the equipment, procedures, people and environment. An essential part of the hazard identification process is to understand the systems interfaces.

Hazards can be identified in a variety of ways:

- Formal hazard analyses using the inductive process. They analyze system components to identify failure modes and effects on the total system or a part thereof, as well as personnel actions. Failure modes include conditions such as: fails to open; fails to close; opens or closes when not required; fails to act; acts improperly or inadequately or at the wrong time; or any combination. Examples of formal hazard analyses include Preliminary Hazard Analysis (PHA), Failure Modes and Effects Analysis (FMEA), and Operating Hazard Analysis (OHA).
- Formal hazard analysis using the deductive process, which identifies sequential and concurrent states that are causally or conditionally required to support a specific effect. An example of this type of analysis is the Fault Tree Analysis (FTA).
- Definition of the Safety Critical Items List (SCIL).
- Data from previous accidents or operating experience on existing similar transportation systems.
- Scenario development.
- Generic hazard checklists.
- Design data and drawings.

##### 9.6.3.9.2. Hazard Categorization

Hazards are rated in terms of their effects on employees and/or the Project. Hazard severity is a subjective measure of the worst possible mishap that results from design inadequacies, personnel error, environmental conditions, or procedural efficiencies for systems, subsystems or component failure or malfunction.

Severity categories are:

Category I – Catastrophic; Death or System Loss.

Category II – Critical; Severe injury, severe occupational illness, or major system damage.

Category III – Marginal; Minor injury, minor occupational illness, or minor system damage.

Category IV – Negligible; Less than minor injury, occupational illness, or system damage.

**9.6.3.9.3. Hazard Probability**

The probability that a hazard will occur can be described in potential occurrences per unit of time, events, population items or activity. A qualitative hazard probability may be derived from research, analysis, and evaluation of safety data from the operating experience of similar transportation systems. A depiction of the hazard probability rating system is described below.

<b>DESCRIPTIVE WORD</b>	<b>LEVEL</b>	<b>SPECIFIC INDIVIDUAL ITEM</b>	<b>FLEET OR INVENTORY</b>
Frequent	A	Likely to occur frequently	Continuously experienced
Reasonably Probable	B	Will occur several times in life of an item	Will occur frequently
Occasional	C	Likely to occur sometime in life of an item	Will occur several times
Remote	D	Unlikely, but possible to occur in life of an item	Unlikely, but can reasonably be expected to occur
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced	Unlikely to occur, but possible

**9.6.3.9.4. Risk Assessment**

Risk assessment facilitates the acceptability of assuming a risk associated with a hazard, the necessity of implementing corrective measures to eliminate or reduce the hazard, or a combination of both. Hazard risk assessment involves categorization of hazard severity and probability of occurrence.

A Risk Assessment Index, or Hazard Rating Table, is shown below.

<b>HAZARD FREQUENCY</b>	<b>CATEGORY I</b>	<b>CATEGORY II</b>	<b>CATEGORY III</b>	<b>CATEGORY IV</b>
Frequent (A)	1A	2A	3A	4A
Probable (B)	1B	2B	3B	4B
Occasional (C)	1C	2C	3C	4C
Remote (D)	1D	2D	3D	4D
Improbable (E)	1E	2E	3E	4E

Hazard Risk Index	Criteria by Index
1A, 1B, 1C, 2A, 2B, 3A	Unacceptable
1D, 2C, 2D, 3B, 3C	Undesirable – Management decision
1E, 2E, 3D, 3E, 4A, 4B	Acceptable with SRC review
4C, 4D, 4E	Acceptable without review

- Unacceptable means the hazard cannot remain as is but must be mitigated.
- Undesirable means that the hazard should be mitigated, if at all possible within fiscal constraints. However, this level of risk must involve a documented decision by executive management, and it may be mitigated at a later time.
- Acceptable with review means the Safety Review Committee must determine if the hazard can remain.
- Acceptable without review means that the hazard can remain.

Managers can use the Hazard Rating Table to prioritize hazardous conditions and focus available resources on the most serious hazards requiring resolution while effectively managing the available resources.

**9.6.3.9.5. Hazard Resolution**

Resolution of hazards involves defining acceptance criteria for hazards, based on severity and probability of occurrence. The objectives of the hazard resolution process are to:

- Identify areas where hazard resolution requires a change in the system design or development of special procedures;
- Verify that hazards involving interfaces between two or more systems have been resolved; and
- Verify that the resolution of a hazard in one system does not create a new hazard in another system.

The agency and contractors will use the following methodology to assure that system safety objectives are implemented throughout design, construction procurement, testing, and startup and that hazards are eliminated or controlled:

1. Design out or design to minimize hazard severity. To the extent permitted by cost and practicality, identified hazards will be eliminated or controlled by the design of equipment and facilities.
2. Hazards that cannot reasonably be eliminated or controlled through design shall be controlled to the extent practicable to an acceptable level through the use of fixed, automatic, or other protective safety design features or devices. Provision shall be made for periodic functional checks of safety devices.
3. When neither design nor safety devices can reasonably effectively eliminate or control an identified hazard, devices shall be used to the extent practicable to detect the hazard and to generate a warning signal to provide for operating personnel/public reaction. Warning signals and their application shall be designed to minimize the probability of incorrect operating personnel/public reaction to the signals.
4. Where it is impossible to reasonably eliminate or adequately control a hazard through design or the use of safety and warning devices, procedures and training shall be used to control the hazard. Precautionary notation shall be standardized and certain safety-critical tests shall require certification of personnel.

No single point failure shall result in a Category I or Category II hazard. Multiple latent, undetected failure modes shall be considered as a single point failure. Equipment/system design shall include component interlocks wherever an out-of-sequence operation can cause a Category I or II hazard. Emergency equipment for public use will be clearly identified and accessible.

#### **9.6.3.9.6. Hazard Tracking**

During the performance of the hazard analyses, the agency will identify Category I and II hazards. These hazards will be compiled on the Safety Critical Items List to provide management visibility of these issues, and to ensure monitoring and control. The agency will continually update the SCIL to reflect the status of Category I and II hazards. The list will be published and managed until all Category I and II hazards have been eliminated, reduced or controlled to acceptable levels.

#### **9.6.3.10. Design and Construction Safety**

The agency will provide safety support as part of the design and construction processes for the Project.

##### **9.6.3.10.1. Design Support**

Safety-related design support provided includes:

- Providing information and analysis pertinent to system design;
- Conducting design reviews;
- Identification of contractor or supplier for pertinent data on safety related analyses, tests and other submittals that form part of the plans and specifications;
- Participating in the change review process to assess the impact of design changes to facilities, systems and equipment;
- Assisting in the development and implementation of safety activities related to the Project including passenger safety, occupational safety, construction safety, and property loss control initiatives;
- Conducting safety meetings with equipment suppliers, facilities contractors and subcontractors on an as needed basis to discuss submittals, designs and change requests; and
- Reviewing operating, maintenance and training manuals and procedures that are safety related including operator rulebooks, maintenance safety checklists, standard and emergency operating procedures, and warnings in maintenance manuals.

##### **9.6.3.10.2. Construction Support**

Construction contractors working on the Project will be required to prepare a Construction Safety Plan, which emphasizes prevention of injuries to persons and damage to property and equipment during construction activities for the Project. These Plans will be approved and periodically audited.

#### **9.6.3.11. Safety Documentation**

Safety and security-related documentation for the project will be maintained in the system safety and security files. The system safety and security manager will prepare procedures to review, comment on and track changes to safety and security criteria, changes notices and other related documentation, including:

- The internal and contractor-provided system safety and security related analyses;
- The resolution of all hazards identified in the Safety Critical Items Lists;
- Accident/incident reports of all construction, test, startup and operational anomalies;



- Status reports of all contractor safety and security related analyses;
- Test and safety certification documents; and
- Status of safety and security training programs for operators, maintenance personnel, and other staff as required.

#### **9.6.3.12. Rules and Procedures Development**

The agency will develop operating rules and procedures for the Project. Operating rules provide specific directives for conducting operations, and maintenance procedures identify the maintenance requirements for the complete system.

#### **9.6.3.13. Accident/Incident Investigation**

The agency will develop procedures for investigating accidents and incidents that may occur during the design, construction, testing, and pre-revenue operations phase of the project. The Safety Review Committee will review these procedures. The system safety and security manager is responsible for investigating all incidents/accidents and issuing a report to prevent a recurrence. Notification will be made to the CPUC, as appropriate.

#### **9.6.3.14. Fire Hazard and Toxic Materials List**

The agency will develop a list of potentially hazardous chemicals and materials employed in the operation and maintenance of the system. This list will be prepared as part of the design review process and will be used to evaluate fire/life safety implications of chemical and materials. The list will identify potentially hazardous effects of solvents, insulation, finishes, sealants, coatings, adhesives, cleaning chemicals, etc.

#### **9.6.3.15. Operating and Maintenance Manuals and Procedures**

The agency will provide operations and maintenance manuals for system and equipment for the Project. The Safety Review Committee will review the manuals that are safety related, such as maintenance safety checklists, and standard operating procedures and warnings in maintenance manuals.

#### **9.6.3.16. Emergency Preparedness Plans and Procedures**

The agency will plan for emergency conditions by developing emergency procedures during the pre-operational phases of the Project. An Emergency Response Plan and Procedures will be developed during final design and revised/updated during startup and pre-revenue phases. The FLSC, the Security Committee, the SRC, and the agency management, will review these procedures.

#### **9.6.3.17. Safety-Related Testing, Inspection, Training and Drills**

##### **9.6.3.17.1. Safety Related Testing**

The agency will oversee the conduct of contractual tests, and support integrated tests, which will validate proper operation of equipment being furnished for the project. Integrated test plans and procedures for system verification and demonstration will be prepared.

Safety-critical tests, and walk-through inspections, are part of the safety certification process. Prior to testing, all safety-related test procedures will be reviewed by the Safety Review Committee. Designated safety representatives and the SRC will witness all safety-related tests. Appropriate contractors will support these tests as needed.

##### **9.6.3.17.2. Safety Related Inspections and Audits**

The agency will conduct contractor and manufacturer audits, inspections and tests where the system safety and security of passengers and/or employees, equipment or facilities could be

affected by the improper construction or manufacture of system elements. The audits, inspections and tests cover facilities and systems elements. The agency and the SRC will participate in all major contractor and manufacturer audits, inspections and tests that involve system safety and security.

#### **9.6.3.17.3. Safety-Related Training**

Safety training is conducted to ensure that operations and maintenance personnel are adequately trained to perform their duties safely. The agency will develop training programs for train operators, operations control center personnel, maintenance personnel, and, police/fire services personnel.

All safety-related elements of training involving new equipment and facilities are part of the safety certification process. Contractors will support training by providing necessary systems and equipment documents that relate to training, such as maintenance manuals.

#### **9.6.3.17.4. Drills**

Emergency drills will verify that all parties can respond to system emergencies, in accordance with approved emergency response plans and procedures. Prior to revenue service, simulated disaster drills will be conducted along the line.

The agency will prepare plans for these emergency drills, including definition of roles and responsibilities of participants, and will conduct the drills.

#### **9.6.3.17.5. System Safety Program Audits**

The agency will periodically audit the System Safety Program, as defined in the SSPP. The audits will be performed to verify compliance against pre-selected requirements. Safety certification program audits are included in these audits.

Audit objectives include:

- Verify compliance with the SSPP;
- Verify compliance with contract requirements;
- Verify compliance with procedures, rules, codes and regulations;
- Verify that safety processes have been properly implemented;
- Verify that corrective action has been taken from identified audit findings.

### **9.6.4. Safety Certification Plan**

The proposed CMP is being constructed to widely accepted transportation construction practices. Safety Certification is a key part of the process. The Federal Transit Administration (FTA) requires the development of a *Safety Certification Plan*, which identifies the processes, procedures, roles and responsibilities for safety certification of fixed guideway systems. This *Plan* applies to the design, construction, testing, start-up, and operational readiness of the Maglev project.

The safety certification process is subject to approval of the Colorado Public Utilities Commission (CPUC), the Safety Oversight Agency for the State of Colorado.

#### **9.6.4.1. Goal**

The goal of the Safety Certification Program is to verify that the CMP is safe for public conveyance prior to revenue operations and to provide documentary certification of that level of safety.

#### 9.6.4.2. Objectives

To accomplish the stated goals, the following safety objectives have been identified:

- To eliminate or control hazards to passengers and employees
- To eliminate or control hazards leading to damage to facilities and equipment to the extent that is practical and cost effective
- To maintain inherent levels of safety through effective operating and maintenance procedures
- To assure application of system safety concepts.

#### 9.6.4.3. Scope

The Safety Certification Program includes the following project elements:

<u>Fixed Facilities:</u>	Passenger stations, guideway (tunnels, at-grade, aerial), storage yards, and others, as appropriate.
<u>System-wide Elements:</u>	Operating systems equipment such as, passenger vehicles, wayside and vehicle mounted propulsion equipment, power, train control, and communications. It also includes system-wide elements such as trackwork, ventilation equipment, escalators and elevators.

Safety Certification comprises the following areas:

- Facility and systems design
- Facility construction and systems equipment installation
- Integrated testing
- Contractual vendor training for operations and maintenance staff regarding equipment operations and maintenance
- Fire/life safety
- Security design and systems components
- Emergency response training drills
- Training of outside agencies – fire and police services

The safety requirements for facilities and systems are documented in the project criteria documents. The verification that safety requirements included in the Project are documented in the *Safety Certification Verification Report*.

Note: It is important to distinguish between contractual acceptance and safety certification. Contractual acceptance and safety certification involve separate processes and actions. Acceptance does not constitute certification, and certification need not imply acceptance. Contractual acceptance verifies the entire contract whereas safety certification verifies subsets of the contract.

#### 9.6.4.4. Responsibility and Authority

Authority for implementing the Safety Certification Program will be delegated to the responsible operating agency. Final Safety Certification authority will rest with the agency's designated Project Manager, System Safety.

The Safety Review Committee (SRC), composed of a group of senior level personnel from relevant disciplines, supports the Project Manager, System Safety. Disciplines represented on the SRC may include, but are not limited to:

- Safety
- Systems Engineering
- System Activation
- Construction
- System Transportation
- Security
- Design

The function of the SRC is safety review, compliance assessment, and recommendations regarding safety certification. The Project Manager, System Safety, or other designee, serves as the chair of the SRC.

Members of the SRC will conduct periodic audits of the safety certification documentation and operations and maintenance related safety items.

#### **9.6.4.5. Safety Certification Process**

The Safety Certification process flow is shown in Figure 86. Safety Certification activities are identified on the left side and project life cycle phases are shown on the right side of the figure.

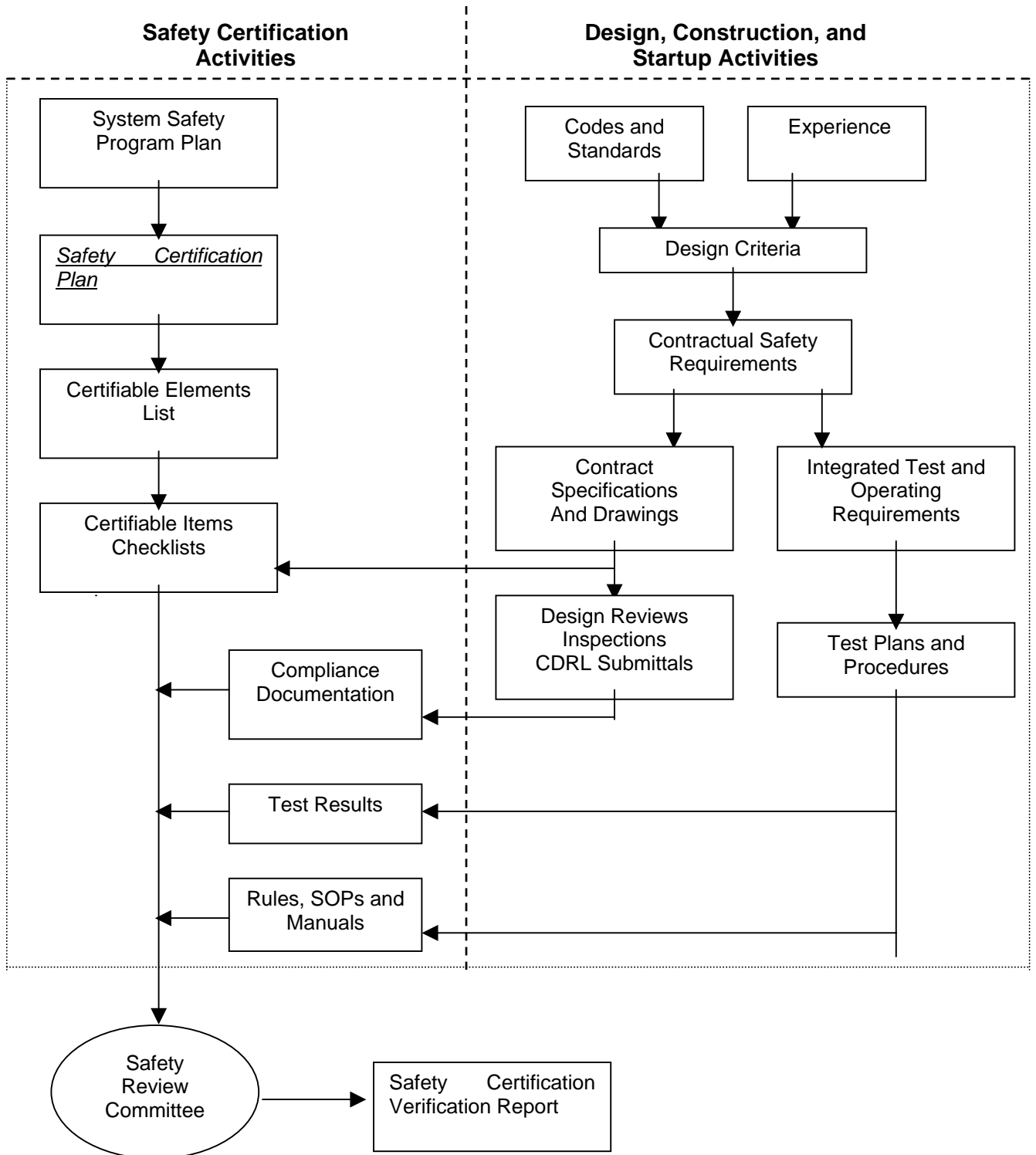


Figure 86: Safety Certification Process

The Safety Certification Program verifies that:

- A certifiable elements list is developed for each certifiable system contract.
- A design checklist is developed to verify that Safety Criteria are included in developing designs.
- Construction checklists are developed to verify that facility and systems equipment installation have been installed according to design.
- Integrated tests are identified that need to be monitored for safety.
- Contractual training classes are provided to operations and maintenance staff.
- Contractual operations and maintenance manuals are provided to operations and maintenance staff.
- System hazard identification and resolution is monitored via the Safety Review Committee.
- Occupancy/Test Permits and/or Certificates of Compliance have been issued to allow or document the process.
- The Certificate of Systems Safety is issued to verify that the entire Project is safe for revenue service.
- The results are presented to the CPUC.

In addition, the SRC will support:

- Operations and maintenance staff training on rules and procedures.
- Outside agency personnel, i.e. fire and police training in operations.
- Conducting emergency drills for identified system emergencies.

If there are exceptions to the safety certification documents, they must be noted on the appropriate safety certification forms. These exceptions must be accompanied by operational or maintenance workarounds, if the item is critical for revenue operations.

Workarounds proscribe policies and procedures that assure safe system operations, even though all safety certification requirements are not approved.

The responsible operating agency will process contractor safety certification submittals. The agency will also send these submittals to the appropriate parties for review and approval.

#### **9.6.4.6. Design and Construction Checklists**

System Design Criteria and standards are required for the Project. In addition, applicable requirements from codes and standards, such as NFPA (National Fire Protection Association) are to be verified. Safety criteria are a subset of the System Design criteria.

The Project Safety Criteria from the contract are the basis for judging compliance with safety requirements. The responsible agency will derive the Safety Criteria checklists for each certifiable element from the design criteria. The designer is then responsible for performing verification of the checklist items. The purposes of the checklists include:

1. Identification of applicable safety-related design criteria and tracing to a contract or system, and verification that the provisions comply with the safety requirements.
2. Verification that safety-related contract specification requirements are constructed and installed correctly.

The first part of the verification process is to crosscheck the safety checklists against contract specifications. Once this verification is complete, the signed forms are submitted to the construction manager for use in the field. The design contractor may also be required to verify that submittals meet requirements.

The Construction Manager verifies that the certifiable elements have been constructed in accordance with specifications. This field verification includes measurement, test or visual inspection.

#### **9.6.4.7. Issuance of Permits and Certificates**

If the SRC determines that the relevant safety requirements have been fulfilled, it recommends to management that the appropriate Occupancy/Test Permit or Certificate of Compliance be issued (see blank forms and Instructions for Completing Design and Construction Checklists in sections 9.6.10.6).

The purpose of issuing these documents is listed below.

- Occupancy/Test Permits are issued to document that it is safe to test and evaluate the equipment or occupy the facility in question, prior to public use.
- Certificates of Compliance are issued to document that the portion of the system complies with applicable system safety criteria for public use.
- Certificate of System Safety is issued to say that the complete system is safe for passenger service.

#### **9.6.4.8. Integrated Tests**

Integrated tests verify the compatibility and coordination of different systems elements, equipment and facilities. For integrated tests, a Test Program Plan will be developed which identifies tests and training drills that are required to verify the project requirements, and a subset of which verify safety.

The Manager, Systems Integration oversees the *Test Program Plan* implementation, including management of all integrated testing. The construction manager and operating personnel (transportation and maintenance) are responsible for supporting the integrated tests.

Test/Occupancy Permits will be requested before testing, and a test certificate issued when finished.

#### **9.6.4.9. Contractual Training**

Systems contractors are required to provide training to operations and maintenance personnel as defined in the contract specifications. The SRC will verify that contractual training is completed.

##### **9.6.4.9.1. Contractual Operations and Maintenance Manuals**

Contractors are required to provide manuals showing how to safely operate and maintain systems equipment and facilities.

##### **9.6.4.9.2. Operations and Maintenance Training**

A vital part of the Safety Certification Process is training of operations and maintenance personnel in accordance with written rules and procedures. The agency will develop training programs and operations and maintenance rules and procedures for the new and combined lines. In order to safety certify the project, all train operators and maintenance personnel must receive formal training. Managers within operations and maintenance will verify this training and report progress to the SRC.

#### **9.6.5. Outside Agency Personnel Training**

The proposed project alignment falls within numerous fire and police jurisdictions. Fire and police will be an integral part of emergency operations for the project. Their personnel must become knowledgeable in how to work safely around project systems and equipment. In addition, security

personnel must complete the same training. This activity is the responsibility of the agency, and coordinated through the SRC.

#### **9.6.6. Emergency Drills**

Emergency drills test the project readiness for potential emergency conditions. These drills are designed to simulate a possible system emergency. Objectives are:

- To familiarize and train response personnel in emergency procedures
- To validate response procedures
- To identify improvements to response procedures before a real emergency occurs
- To sustain an adequate level of preparation for a possible emergency.

These drills are evaluated upon completion to identify action items for improvements to emergency procedures. After-action reports will be reviewed by the SRC.

#### **9.6.7. Hazard Identification and Resolution**

Hazards are continually identified during the development of the project. The hazard identification and resolution process is described in the *Hazard Identification, Analysis, and Resolution Procedure* and the *System Safety Program Plan*.

Project safety hazards must be eliminated or controlled prior to completion of safety certification. The Safety Review Committee will track these safety hazards to resolution.

#### **9.6.8. Audits**

Members of the Safety Review Committee will conduct periodic audits of the safety certification documentation. The audit team will review the backup documentation for the safety certifiable elements and will generate a written report.

#### **9.6.9. Safety Certification Verification Report**

Prior to revenue operations for the project, the Manager, System Safety will prepare a Safety Certification Verification Report. This report summarizes the safety readiness of the Project for revenue service.

The report includes a status of safety criteria elements checklists, system testing activities, operations, maintenance and training activities, and hazard identification and resolution.

The Safety Certification Verification Report will address the following elements:

1. Executive Summary
2. Design and Construction Checklists
3. Contractual Vendor Testing
4. Integrated Testing
5. Emergency Drills
6. Contractually Required Operations and Maintenance Manuals
7. Contractually Required Training
8. Certificate of System Safety.

This report will be submitted to the agency's project managers.

Before revenue service begins, all safety certifiable elements must be certified, or workarounds documented and communicated in writing to all affected parties. The project is likely to be safe for revenue service prior to all safety certifiable elements being completed. Workarounds define



engineering modifications, rules or procedures that must be in place to assure safe operations until the certifiable element can be completed.

#### **9.6.10. Documentation**

##### **9.6.10.1. Backup Documentation**

Backup documentation is critical to the success of the Safety Certification Program. This documentation provides a detailed audit trail of activities accomplished to safety certify certifiable elements.

The documentation system must promote accountability, timeliness and accessibility. Accountability ensures that all permits and certificates are accurately completed, signed by the appropriate levels of authority, verified by the Safety Review Committee, and maintained in a secure manner. Timeliness assures that each certifiable element is certified as safe prior to use. Accessibility allows quick verification that permits and certificates are in place, and provides any other information required to support the permit or certificate.

##### **9.6.10.2. Configuration Control**

Changes may occur in design or construction of certifiable elements. The agency design manager and system safety manager must review these changes for technical evaluation and assessment of impact to the certification effort. If a significant change is made subsequent to the completion of a certification task, safety requirements must be re-verified. This may be in the form of an addendum to a safety certification checklist or other documentation.

##### **9.6.10.3. File Structure**

The safety certification documentation consists of stored files, system safety, and files stored within each functional department.

The safety office files contain the following:

- A copy of the certifiable elements list
- A summary sheet showing the certification status for each major item on the certifiable items list

The Document Control Office files contain the following:

- The original of each safety certificate that has been issued
- The original of the Safety Certification Verification Report.

The functional departments also need to maintain safety certification files. These files should contain documents pertaining to the functional area safety certification; a copy of each safety certificate that has been issued; selected documents pertaining to the function, such as test results and submittals; and a list of other documents or files which reference or otherwise impact the function. Original documents are filed in the Document Control Office.

##### **9.6.10.4. Periodic Reporting Requirements**

An important part of the safety certification process is keeping all interested parties informed of the status of the program, including the CPUC. To accomplish this, periodic reports are prepared. The period may change from time to time, dependent upon activity levels.

The reports advise of the following information:

- a) Permits and certificates completed during the reporting period
- b) Problems encountered
- c) Permits and certificates expected to be issued in the next reporting period
- d) Certification progress to date (schedule to be updated at least monthly).

The Manager, System Safety is responsible for collecting all data and maintaining the required safety certification documentation. The Manager, System Safety prepares and presents all documentation for transmittal to and/or approval and will assist in preparation of the Safety Certification Verification Report.

The Manager, System Safety prepares the required periodic safety certification periodic reports, monitors all relevant documentation and activities, tracks progress against a pre-determined schedule, and recommends actions as necessary to assure program success.

#### **9.6.10.5. Certifiable Elements List**

The following table lists the certifiable elements list.

#### **Dynamic Systems**

##### **VEHICLES**

- Car body
- Coupler and Draft Gear
- Doors, Door Operators and Controls
- Propulsion and levitation equipment
- Communication Equipment
- Lighting
- HVAC
- Fire/Flammability/Smoke Emissions

##### **SIGNALS**

- Mainline Interlocking Circuits
- Mainline Controls and Indications
- Mainline Interlocking Equipment
- Yard/Mainline Interface

##### **COMMUNICATIONS**

- Supervisory Control and Data Acquisition Systems (SCADA)
- Radio System
- Control Center
- Fire Department Communications
- Security Communications
- Security Systems
- Fire Systems
- Public Address System
- Variable Message Signs

##### **PROPULSION SYSTEMS**

- Propulsion Equipment
- Levitation Equipment

## TRACTION POWER SYSTEMS

- Enclosures
- High Voltage Switchgear
- AC to DC Conversion
- DC Switchgear
- Batteries and Accessories
- Stray Current Protection

## Civil Installations

### TRACK AND STRUCTURES

- Right of Way/Guideway
- Tunnels
- Aerial Structures
- Barriers and Warnings

### YARD

- Electrical Safety Provisions
- Vehicle Movement Provisions
- Guideway

### STATIONS/PARKING LOTS

- Platforms
- Handicapped Access Provisions
- Elevators and Escalators
- Illumination
- Electrical Grounding
- Fencing
- Art Works
- Ticket Vending Machines

## PLANS AND PROCEDURES

### TEST PLANS AND PROCEDURES

- Integrated Tests
- Pre-Revenue Tests
- Emergency Drills
- Training
  - Contractor
  - Operations
  - Maintenance
  - Fire/Life Safety
  - Security

#### 9.6.10.6. Safety Certification Compliance Forms

q Design q Construction	SAFETY CERTIFICATION DESIGN/CONSTRUCTION COMPLETION CERTIFICATE	Certifiable Element: _____ Contract # _____
----------------------------	--	--

Status <b>C</b> = Compliance <b>N</b> = Noncompliance <b>P</b> = Partial Compliance	Means of Verification – Design <b>PS</b> = Plans & Specifications <b>S</b> = Submittal <b>CN/CO</b> = Change Notice/Order	Means of Verification - Construction <b>M</b> = Measurement <b>T</b> = Test <b>V</b> = Visual Inspection	LOCATION: _____
--	--	---	-----------------

Reference	Description	Design Cross Reference	Design		Means of Verification	Construction		Means of Verification
			Status	Initial Date		Status	Initial Date	

<b>Final Design Verification</b>  _____  <b>Name</b> _____ <b>Date</b> _____  <b>Signature</b> _____  Organization _____ <b>Comments:</b>	<b>Final Construction Verification</b>  _____  <b>Name</b> _____ <b>Date</b> _____  <b>Signature</b> _____  Organization _____
---	---

**CERTIFICATE NUMBER**  
\_\_\_\_\_

**Safety Certification Program  
CERTIFICATE OF COMPLIANCE**

**COMPLETION OF THIS CERTIFICATE INDICATES THAT THE PORTION OF THE SYSTEM  
DESCRIBED BELOW COMPLIES WITH APPLICABLE SYSTEM SAFETY CRITERIA**

**CERTIFIABLE ELEMENT:** \_\_\_\_\_

**DATE OF CERTIFICATE:** \_\_\_\_\_

**NUMBER OF  
RESTRICTIONS:** \_\_\_\_\_

**VERIFICATION**

Manager,  
System Safety

Date

\_\_\_\_\_  
Manager, Design

\_\_\_\_\_  
Date

\_\_\_\_\_  
Manager, Construction

\_\_\_\_\_  
Date

**THIS CERTIFICATE OF COMPLIANCE APPLIES ONLY TO THE SYSTEM OR SUBSYSTEMS  
DESCRIBED BELOW:**

<b>CERTIFICATE NUMBER</b> _____
------------------------------------

**Safety Certification Program  
RESTRICTIONS TO CERTIFICATE OF COMPLIANCE**

**THE FOLLOWING \_\_\_\_\_ RESTRICTIONS APPLY TO  
CERTIFICATE NUMBER \_\_\_\_\_**

<b>DESCRIPTION</b>	<b>RESOLUTION</b>	<b>DATE</b>

<b>VERIFICATION</b>	
Manager, System Safety	Date

<b>PERMIT NUMBER</b> _____
-------------------------------

**Safety Certification Program  
OCCUPANCY / TEST PERMIT**

**COMPLETION OF THIS CERTIFICATE INDICATES THAT IT IS SAFE TO TEST AND EVALUATE THE EQUIPMENT OR OCCUPY THE FACILITY IN QUESTION, PRIOR TO PUBLIC USE**

**CERTIFIABLE ELEMENT:**

**DATE OF PERMIT:** \_\_\_\_\_  
**PERMIT EXPIRES:** \_\_\_\_\_  
**NUMBER OF**  
**RESTRICTIONS:** \_\_\_\_\_

<b>VERIFICATION</b>	
Manager System Safety	Date

\_\_\_\_\_  
Manager, Design Date \_\_\_\_\_

\_\_\_\_\_  
Manager, Construction Date \_\_\_\_\_

**THIS OCCUPANCY/TEST PERMIT APPLIES ONLY TO THE SYSTEM OR SUBSYSTEMS DESCRIBED BELOW:**



**PERMIT NUMBER**  
\_\_\_\_\_

**Safety Certification Program  
OCCUPANCY / TEST PERMIT**

**RESTRICTIONS AND CONTINGENCIES**

**THE FOLLOWING \_\_\_\_\_ RESTRICTIONS APPLY TO  
PERMIT NUMBER \_\_\_\_\_**

DESCRIPTION	RESOLUTION	DATE

**VERIFICATION**

Manager,  
System Safety

Date

**CERTIFICATE NUMBER**

---

**Safety Certification Program  
CERTIFICATE OF SYSTEM SAFETY**

**COMPLETION OF THIS CERTIFICATE INDICATES THAT THE PROJECT COMPLIES WITH  
APPLICABLE SYSTEM SAFETY CRITERIA AND IS RECOMMENDED FOR REVENUE  
SERVICE**

**DATE OF CERTIFICATE:** \_\_\_\_\_

**NUMBER OF  
RESTRICTIONS:** \_\_\_\_\_

**VERIFICATION**

Manager,  
System Safety

\_\_\_\_\_  
Date

\_\_\_\_\_  
Project Manager

\_\_\_\_\_  
Date

**CERTIFICATE NUMBER**

---

**Safety Certification Program  
OCCUPANCY / TEST PERMIT**

**RESTRICTIONS AND CONTINGENCIES**

THE FOLLOWING \_\_\_\_\_ RESTRICTIONS APPLY TO  
CERTIFICATE NUMBER \_\_\_\_\_

DESCRIPTION	RESOLUTION	DATE

**VERIFICATION**

Manager,  
System Safety

Date

### 9.6.11. System Security

“Terrorism is the use of force against persons or property in violation of the criminal laws of the United States for intimidation, coercion or ransom.” This FBI definition is general, broad and easy to understand. Unfortunately, terrorist acts are specific, narrowly focused, and very difficult to understand. Since 9/11, many new initiatives have been put into place to help insure homeland security. The following discussion is a generalized discussion related to transit security that can be applied to the CMP. Specific security documents have been provided to the FTA concerning security actions identified for the CMP. These documents are not available to the general public.

In response to September 11, 2001, FTA launched an aggressive initiative to enhance the security of the nation’s transportation systems. This initiative has shown that large transit operations that already had emergency response plans needed to re-evaluate, and that operations without plans needed to develop comprehensive approaches and formulate plans. FTA is deploying Technical Assistance Teams to assist all agencies at required levels of assistance necessary to accomplish these tasks. As part of this effort, FTA offers planning that emphasizes the importance of taking the following steps:

1. Notify authorities of the incident
2. Evacuate passengers
3. Protect personnel and equipment
4. Activate a unified communications systems among transit security personnel, police, fire fighter and emergency medical units
5. Restore system to normal operations as soon as practical.

FTA has a Safety and Security Tool Kit for transit system use. The kit includes:

- An inventory of FTA Services and Publications
- [Practical Security and Emergency Response Advice from New York and Washington](#)
- An Overview of FTA’s Security Assessment Services
- Key Transit Security Publications
  - [Transit System Security Program Planning Guide](#)
  - [Transit Security Procedures Guide](#)
  - [Transit Security Handbook](#)
  - [Critical Incident Management Guidelines](#)
- TCRP Synthesis Reports
  - TCRP Synthesis 21: Improving Transit Security
  - TCRP Synthesis 27: Emergency Preparedness for Transit Terrorism
- Sample Materials to Increase Public Awareness about Safety and Security
- Resource Guides
  - Transit Safety Institute [Courses and Seminars](#) Catalog, October 2001-September 2002
  - [FTA Office of Safety and Security Publication Resource Guide](#), September 2001
  - Contact List of Organizations
- Key Intelligent Transportation System Publications
  - [Advanced Public Transportation Systems: The State of the Art Update 2000](#)
- [ITS Resource Guide](#) 2001

As both the recent Moscow subway and Madrid regional train bombings have shown, weapons of choice for targeting innocent civilians are bombs, placed in areas where maximum bodily harm can be inflicted. Mass transit systems are easy targets for this approach, since security precautions are minimal and passenger convenience still remains the paramount goal.

The ease with which bombs can be placed on trains, in restaurants, in movie theaters, etc. and the potential ease of using simple triggering devices such as cellular telephones or timers deserve urgent attention. Specifically cellular telephones were used as the trigger devices in Madrid and have historically been used by the IRA for commission of acts of terrorism and the Israelis to eliminate terrorists from activity in Israel. All techniques which can prevent planting and detonation of bombs should be carefully considered; not nearly enough has been done to deal with this deadly threat.

Our goals in developing security plans for the CMP included:

1. Prevention of acts of violence
2. Preservation of human life
3. Containment of the hazard
4. Preservation of the transit facility
5. Preservation of public confidence in the transit system

#### **9.6.11.1. THE CMP SECURITY APPROACH**

The three major design aspects of the CMP system security are produced by linked subsystem designs that provide:

1. detection
2. delay, and
3. response.

Each of these design aspects must be balanced to provide effective and affordable security. Detection components include video surveillance and imaging systems; intrusion detection; explosives, chemical, biological, and radiation detectors; secure data links for high-data rate imaging; and information surety.

If an intrusion event is detected, then the second aspect of security is activated to delay the intruder sufficiently to allow security forces to arrive on-scene. These access delay methods may include passive architectural design and layouts, and may also include active methods, such as remote activation of barriers, foams, and other delaying techniques.

The final aspect of security is active response from security forces.

Transit systems are intended to be customer friendly and are designed to minimize any delay or discomfort to the passenger. As a result of the growing incidence of terrorist attacks against transit systems a fundamental change is required to secure passengers from injury and possible death.

However, because of the various system-wide interactions, safety, security and operability features of the overall system must be assessed together. That is to say, what is done in the name of security may degrade (or in some cases enhance) safety and/or operability. Because these three system dimensions draw ultimately from the same fixed system resources, expenditures for mitigation will necessarily be limited.

Security strategies and implementations are tightly coupled to system vulnerabilities and consequences of system stresses arising from safety and operability considerations. For this

reason, it is extremely important that the impacts of safety, security, and operability decisions be simultaneously reflected in all aspects of creating, realizing, and operating the system, so that an optimal result may be achieved. Additionally, what is affordable must be determined not only for development and implementation costs but also for operating costs. Each cost category has a safety/security component and because of limitations in the overall budget, the safety/security requirements and implementations cannot be mandated independently without regard for the maintenance of a workable system. For this reason, *hard choices must eventually be made about which safety/security threats will be countered, and how aggressively they will be countered.* There will be residual risks, for every dollar spent on safety or security potentially reduces expenditures for operational convenience or rider comfort, and not every safety/security risk can be addressed.

**9.6.11.2. CONCEPTS FOR ACHIEVING SECURITY**

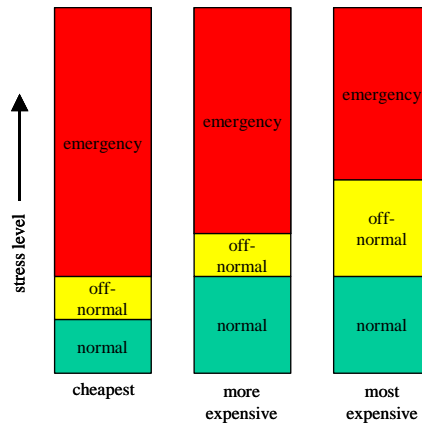
No system is capable of performing its intended function under arbitrarily high levels of stress. A key question is what threshold of stress is selected beyond which it is acceptable for the system to fail? This is more than just a theoretical question. Suppose for example that the transit system operates in an area easily accessible from multiple roads and access-ways. However each roadway or access-way has varying degrees of security applied currently. These may then fall into the classes of small, large, and very large degrees of risk with these descriptions needing to be agreed to by management. It could then be agreed that impacts on transit operations would be as follows: small—no impact; large—continued operation at reduced speed; very large—vehicles stop and passenger evacuation triggered. This is an example of graceful degradation. It provides two major benefits: predictable protection of passengers and equipment; and an explicit link between defined levels of stress and what is expected of the system under those stresses. Table 9.6-1 provides an overview of a three-level stress-response paradigm.

Table 9.6-1. System response versus stress

<b>Environment</b>	<b>Stress Level</b>	<b>System Response</b>
Normal	low	full operations
off-normal	medium	degraded operations
Emergency	high	minimal or no operation; emergency response

**9.6.11.2.1. Link Between Stress Levels and the System Requirements**

There is a link between stress levels and system requirements. The highest level allowed for a particular level of stress, the greater the expense and difficulty of dealing with this stress will be, as illustrated in Figure 87. To understand this figure, assume the stress is wind speed. As the wind speed increases, the system will protect itself by advancing from normal to off-normal, and eventually to emergency conditions. However the speeds at which the advances occur are a function of protective measures. Note that expending more money on such measures may raise the boundary between normal and off-normal, or even between off-normal and emergency environments. The reason for the expenditures is not necessarily to improve safety or security but rather to improve margins under which normal or off-normal operations may continue. Thus we see that operating conditions, safety and security can be tightly linked.



**Figure 87. Link between stress levels and the system requirements**

This linkage is formally and explicitly recognized in the risk management process discussed below.

**9.6.11.3. Residual Risk**

The term “residual risk” implies that in spite of our best efforts to deal with safety/security threats, there may be some circumstances under which the system can suffer harm. Such risk can arise in two separate ways. First, the highest level of stress may be open-ended. Second, for the lower levels of stress that we expect to fully cover with positive measures of one sort or another, there is some chance that these measures may fail to be effective and the associated loss occurs anyway. Whether or not the nature and magnitude of such risks is ultimately accepted is a business decision to be made by management. In general, increasing amounts of money—if wisely spent—will reduce the residual risk. However, because total project expenditures are limited, there will always be some amount of risk (even if imprecisely known) to be accepted. Such risks should be formally recognized.

**9.6.11.4. Strategy-driven Threat Reduction**

When safety/security threats are chosen for control/elimination, there is a tendency for many to immediately offer specific solutions or technologies (example: install rope ladders in vehicles to allow for evacuation off the elevated guideway). Such a process is premature and sub-optimal because it forecloses consideration of other alternatives that may be preferable. Instead the question of “what” (a strategy) should be put before “how”(a specific implementation). There are a number of advantages to using strategies to guide choices for implementation. Primary of these is that one has the best chance of covering the majority of implementation alternatives. This is so because by following the logic of strategy-begets-implementation because the simple, high-level strategy statement connects more clearly to the objective than more intricate, detailed “how-to” descriptions. Secondly, the use of strategies promotes “out-of-the-box” thinking that can lead to innovative solutions that might not otherwise become apparent.

Table 9.6-2 includes some guidewords that may aid in developing threat reduction strategies.

Table 9/6-2. Guidewords for developing threat reduction strategies

Deflection	diversion	reflection	release	Decontamination
Detection	Delay	defeat	impairment	Absorption
Dispersion	discouragement	diversity	multiplicity	Synergy
ability to replace	Ability to repair	situational awareness	compartmentalization	Inoperability
Incompatibility				

## 9.6.11.5. RISK MANAGEMENT PROCESS

### 9.6.11.5.1. Process overview

The risk management process is described in Figure 88. The process' major tasks are denoted by letters (in circles in the figure); these become the major elements of the security assessment. Because the process is cyclic, it will be applied at intervals throughout the life of the system. The process is discussed twice—below in a general sense and later as it might apply to a transit application.

- A. Determine External Requirements—these are supplied by others and cannot be changed. Such requirements may include DOT/FTA standards, construction codes and EPA requirements
- B. Determine Potential Negative Consequences—these must reflect all stakeholders including workers, customers, neighbors and interveners. In general, categories include loss of business opportunity, loss of or damage to materials or equipment, death, injury, and despoilment of the environment
- C. Determine Threats to Business—broadly, threats of increasing intensity fall into three categories:
  - Normal condition:** recurrent or continuing low threat conditions of natural insult, wear-and-tear, inadvertent human error, or malevolent human action;
  - Off-normal condition:** occasional occurrence of moderate threats, including natural insult, inadvertent human error, or malevolent human action; and
  - Emergency condition:** rare occurrence of high threats, including natural insult, inadvertent human error, or malevolent human action
- D. Determine Internally Driven Requirements—the business objectives define levels of performance the system must achieve given limited threats of the various types defined above. The limitations reflect the finite resources (e.g., budget, personnel, time and technologies) available for the conduct and protection of the target system. For higher-level threats we assume a business decision has been made to either rely on external assets to mitigate undesired consequences (e.g., police or National Guard response) or simply to accept the residual risk of not internally addressing various open-ended threats.
- E. Determine Strategies to Meet Requirements—the overall strategy is to address normal and off-normal threats internally through system design features or procedures, and to address emergency threats with a mix of internal and external (emergency response) measures
- F. Formulate Designs to Implement Strategies—at this stage “requirements” are derivative, because they reflect choices that have been made by management about how to implement strategies.
- G. Determine Impacts by Analysis & Testing—this step determines efficacy of proposed implementations, and consequences should the implementations fail, and other business impacts of cost, schedule, availability, etc. These are the primary feasibility considerations for deciding whether to proceed with the implementations or modify requirements and cycle again through the overall process herein. Efficacy assesses the level of confidence that the proposed implementations will meet requirements (security, safety, functional) and the level of residual risk. The tools used are analysis (and possibly testing) to determine two things: whether an implementation a) does what it is supposed to do, and b) can pose an interference somewhere else in the system. The first task is relatively straightforward, involving the implementation's roles and interfaces (intentional interactions) within the overall system. The second task is more difficult because it seeks out unintentional interactions that might occur between components or subsystems—we call them *interferences*. Interferences are unwanted energy or information passing between components or subsystems enabled by sharing of volume or functional aspects. Often interferences become apparent only when the system is analyzed under off-normal or emergency conditions. An example is the placement of the gas tank in the Ford Pinto—not a problem in normal conditions, but devastating in certain



rear-end collisions. Most often interferences are cross-coupled, that is, security/functionality, security/safety, or safety/functionality faults. Residual risk is the expectation of undesired consequences, should the implementation fail to thwart the defined threat. Other business impacts are assessments of cost, schedule, and availability effects that may enhance or detract from the feasibility of an implementation.

- H. Relax Requirements Or Reduce Threat Definitions—if reached, this step assumes that the first (or previous) pass-through of the process yielded an unaffordable or otherwise unacceptable business impact.

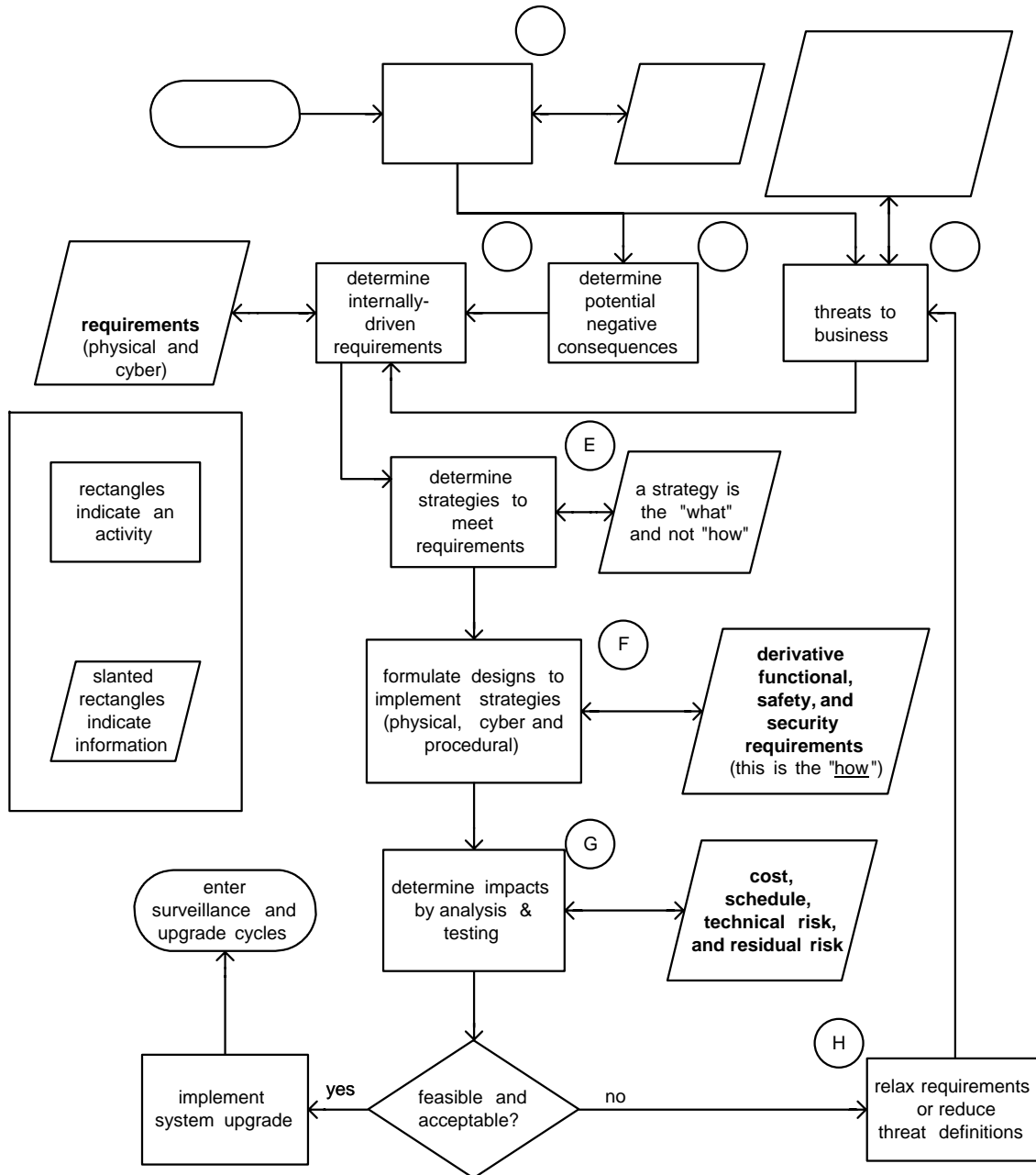


Figure 88. Risk Management Process

The identification of threats is objective, based on what has happened, and knowledge of capabilities. The events of September 11, 2001 have shown that even extreme threats are not to be ignored or dismissed out of hand.

However, the assessment of risk is subjective. Value judgments must be made, and it is difficult to know if a potential terrorist would follow the same logic. With these limitations in mind, one can craft a straightforward system to assess risk from each category of identified threats. A completed assessment provides a prioritized guide to design requirements to be imposed on any potential system deployment.

Just as the threat system has been taken to a five level approach characterized by a color scale, a straightforward system for risk assessment can be developed around the familiar one to ten ranking with one being least likely, and ten most likely. In practice, many other factors come into these decisions, and a comprehensive risk assessment performed with adequate resources will provide a multidimensional system of factors affecting the final decisions.

#### **9.6.11.6. Process Applied to CMP**

To show how the risk management process applies to the CMP, consider the key elements illustrated in Figure 89. The CMP runs in parallel to I-70. The operational subsystems are the transit vehicle itself and its guideway or roadway; the communications and control system; the stations; the maintenance depot; and the power system. The operational system is subject to safety and security stresses (red arrows) which are addressed in part with security and emergency services. Some services (emergency, FBI intelligence) can be viewed as backups that are outside the transit system however are still important when considering strengths and weaknesses.

The top-down view treats these subsystems in a nested fashion with increasing amounts of detail available. Of special interest at the top are interactions (both positive and negative) between subsystems. Positive interactions include successful interfaces; negative interactions include interferences and failed interfaces.

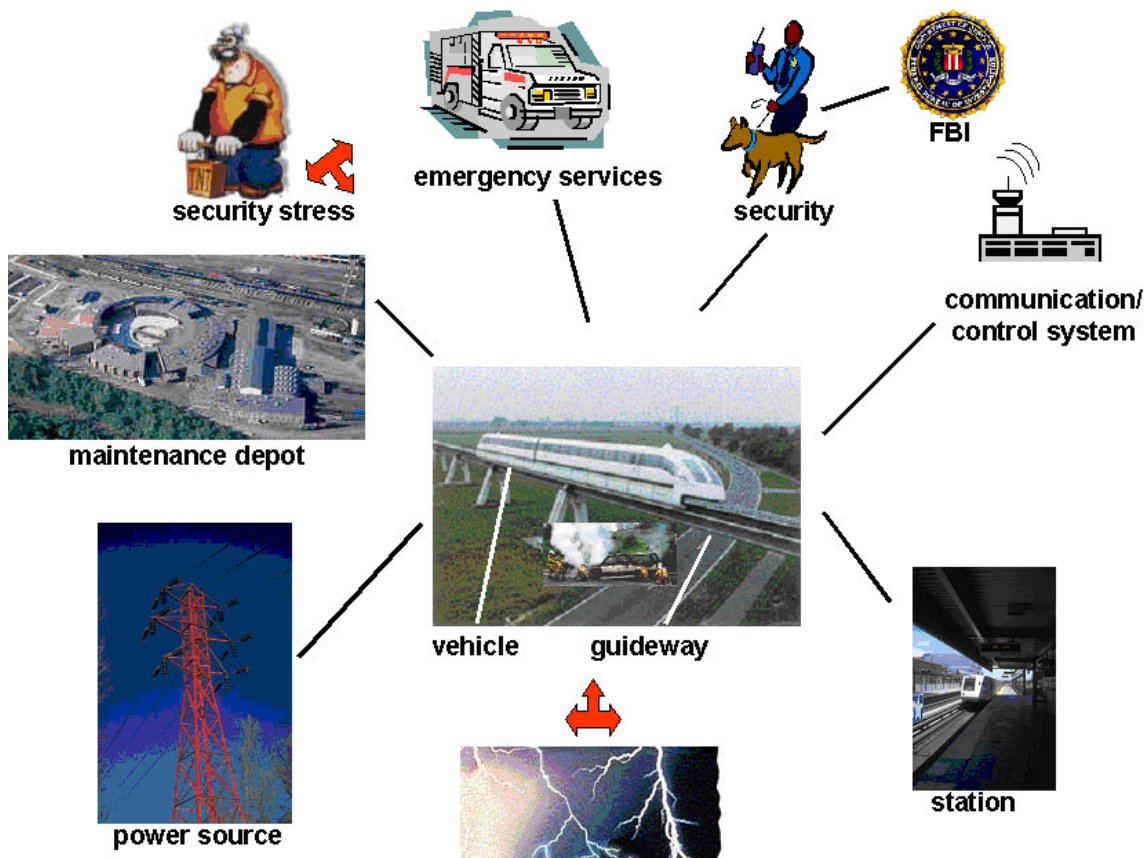


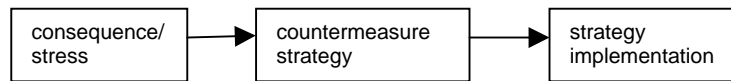
Figure 89. Target System

For the target system, we notionally describe a cycle of the process:

- A. Determine External Requirements—DOT/FTA standards, construction codes, plumbing and fire codes, and NEPA requirements are illustrative of external standards, many of them prescriptive.
- B. Determine Potential Negative Consequences—included are train stoppage, freeway blockage, equipment/facilities destruction, and human injury or fatality.
- C. Determine Threats to Business—**Normal condition:** materials corrosion or wear-and-tear, inclement weather, inadvertent operator or maintenance error, and vandalism. **Off-normal condition:** minor flooding, small arms fire on moving train or vehicle by a single attacker, equipment sabotage by disgruntled employee. **Emergency condition:** 100 year flood, major terrorist attack, uncontrolled forest fire adjacent to guideway or roadway.
- D. Determine Internally Driven Requirements—**Normal condition:** meet external requirements and maintain system throughput of 100,000 passenger-miles/day; limit vandalism damage to \$50K/yr. **Off-normal condition:** limit system downtime to one day, limit damage to facility to \$2M. **Emergency condition:** given a credible attack, limit fatalities/injuries to 1/20, limit equipment damage to \$20M, and limit system downtime to 1 week. *These requirements are not prescriptive, but rather performance-based.*

- E. Determine Strategies to Meet Requirements—**Normal condition:** control access to critical facilities (e.g., maintenance depot); protect Supervisory Control and Data Acquisition (SCADA) elements and employ redundant data pathways. **Off-normal condition:** design a simplified backup control system that operates trains at less-than-design capacity, predict and prevent attacks by gathering intelligence data. **Emergency condition:** design crashworthiness and fire protection into vehicles; train and drill regular passengers on emergency egress procedures; automatically alert emergency response authorities.
- F. Formulate Designs to Implement Strategies— design crumple zones into vehicles, install bullet-resistant windows; bury critical data cables or armor them when exposure is necessary; procure escape chutes for egress from guideways, increase communication with outside security agencies.
- G. Determine Impacts By Analysis & Testing—do scenario-based modeling of proposed subsystem designs under normal, off-normal and emergency conditions to evaluate whether proposed requirements are met. Perform cost, technical risk and operational impact analyses. [Let us assume deficiencies are identified associated with subsystem-to-subsystem interferences, or expense; this will activate step H, below.]
- H. Relax Requirements Or Reduce Threat Definitions—because of the results for step G above we must reduce our aspirations in steps C or D to allow a less expensive design in step F. This increases residual risk. For example, regarding off-normal requirements, authorities may choose to accept more downtime or greater equipment damage for some threats.

As an aid to correlating targets, stresses, consequences, and countermeasures an organizational paradigm is presented that is broadly inclusive yet allows tabulation of details in a useful manner. The paradigm follows roughly the sequence



Thus within each consequence class (8 of these classes have been identified—see below) a determination is made to assess which credible stress could cause a particular consequence. Within each consequence class created numerous stress/consequence pairs have been identified. For each consequence/stress pair there may be one or more countermeasure strategies. Each strategy can spawn perhaps many strategy implementations. As one moves from left to right in the figure, more and more detail enters, especially in the context of the large and complex systems. The following table formats are an attempt to capture, at a relatively high level, the flow of information from consequence to strategy to implementation.

The consequence classes we have identified include (in no particular order):

- fear/loss of confidence
- property destruction
- property corruption/contamination
- property diversion/theft
- information diversion/theft
- information corruption/contamination
- injury to or death of persons
- delay or denial of service

The term “property” includes hardware, land, etc.; “information” includes data for vehicle control, accounting, emergency communications, etc.; and “persons” includes passengers, workers, and bystanders. “Stresses” refers to attack mode.

Because the stresses and associated countermeasure strategies are a function of stress environment (normal, off-normal, and emergency), these distinctions are broken out within two sets of tables. This first set of tables, the **consequence/strategy tables**, takes the form:

**consequence class**

target	Normal		off-normal		emergency	
	stress	countermeasure strategy	stress	countermeasure strategy	Stress	countermeasure strategy

The term “target” includes the major system elements illustrated Figure 89 as well as sub-elements such as the public relations website.

A straightforward progression to implementation tables would be to connect each countermeasure strategy with reasonable implementation alternatives. Because this would be unwieldy, we have chosen a shorthand method—guidewords—to aggregate like strategies. Thus the second set of tables, the **implementation tables**, are subdivided according to these guidewords and take the form:

**countermeasure strategy guideword:**

implementation method	subsystem where used	applicable stress environment (n, o-n, e)	up-front cost (l, m, h)	operating cost (l, m, h)	technical risk (l, m, h)	operational interference?	safety interference?	security impact

(n=normal, o-n=off-normal, e=emergency), (l=low, m=medium, h=high)

The list below includes the countermeasure strategy guidewords used in building the second set of tables. This list of guidewords is not necessarily complete.

access control	surveillance	detection (screening)	deflection/reflection	decontamination
rapid replacement	bypass capability	situational awareness	compartmentalization	defeat
discouragement	release	ability to repair	Delay	inoperability
impairment	absorption	Dispersion	incompatibility	diversity
Multiplicity	synergy			

#### 9.6.11.7. SECURITY RISK ASSESSMENT

The security approach for the CMP depends on the following considerations:

1. Structures and facilities that are designed and built to present a “hard target” to as many threats as practical, within cost constraints.
2. Limitation of access to the facilities by fences, gates, and guard searches, dogs, sophisticated sniffers and chemical detectors.
3. Latest surveillance technologies in telephones, emergency communications, cameras, lights, motion detectors, smoke detectors, chemical detectors, and other threat devices as they become available.
4. A well-trained security force that uses guards, guard dogs, surveillance devices, local police, local rescue squads, local emergency medical teams and other personnel.
5. A riding public that has been educated to be aware of potential hazards, and motivated to report any suspicious objects or activities.

A number of examples have been developed for the report delivered to the FTA. These examples provide an indication of various scenarios and approaches to mitigate attacks on the CMP.

## 10.0 CONCLUSION

A number of key findings and conclusions have resulted from the CMP. The pertinent conclusions and findings are as follows:

- The Colorado maglev technology system introduces a new urban/suburban/rural transit system into the United States with *comparable or* (in some applications such as the San Diego light rail line extension known as the Mission Valley East Line) *lower costs* than existing transit systems by employing new state-of-the-art subsystems.
- The CHSST vehicle, from which the Colorado 200 Car is derived, is a mature maglev technology with over 30 years of development and deployment experience. The technology is *deployable now* in the United States.
- The CMP provides for *schedule dependability* to offset the growing congestion on the I-70 Mountain Corridor. The schedule dependability provided by the maglev system may induce additional transit use due to the variable impacts and delays of highway congestion.
- The CMP can be staged in such a fashion as to provide transportation *capacity relief* jointly with the highway widening from Golden to EJMT that is the first priority of the CDOT in this corridor.
- The cost per mile of deploying the CMP on the I-70 corridor from DIA to Eagle County Airport is approximately *\$38 million per mile* (these estimates do not include additional engineering design, environmental studies, construction management costs, work zone traffic control, right of way and environmental mitigation costs – this cost can be further optimized with additional constructability assessment).
- The cost estimate for operations and maintenance cost for the full 250-kilometer (155-mile) system is *\$43 million per year or \$47 million per year with contingency*.
- The transit system guideway can be used to carry a high capacity, safe, and economical *transmission line* for needed additional electric capacity for the I-70 Mountain Corridor. The system operating cost for electricity can be reduced by providing such a transmission line capability to the utility companies, earning additional revenue for the transit operation.
- The Colorado 200 Car, with modification to the standard CHSST propulsion motor, is capable of sustained operation at speed for 7% grades and can operate easily under a degraded speed for 12% grades. The maximum grade potential is 18%. With this grade climbing capability the EJMT tunnel can be avoided and a new shorter tunnel of 701 meters (2300 feet) is possible north of the EJMT existing bore, producing a substantial cost SAVINGS of over \$200 million compared to a new EJMT transit tunnel. This cost savings has been taken into account in the cost per mile of \$38 Million.
- The CHSST can also use the new moving block control system developed by BART providing future expandability by reducing headway and adding trains.
- The CMP system is automated with no operating personnel on trains, although maintenance personnel will be assigned to each station allowing for virtually immediate response to situations at stations and in-between stations.
- Introduction of the CMP will also allow the *development of lower-cost security measures* to respond to the perceived vulnerability of public transit systems in the United States. Many of the security measures recommended for the CMP are transferable to existing transit operations.

The CMP brings to the United States renewed competition in the urban/suburban/rural transit market with the potential to lower the costs of future transit deployments in the country.