U. S. Department of
Transportation

**Federal Transit
Administration**

Urban Maglev Technology Development Program

COLORADO MAGLEV PROJECT
EXECUTIVE SUMMARY
OF
FINAL REPORT

JUNE 2004

Federal Transit
Administration

OFFICE OF RESEARCH, DEMONSTRATION, AND INNOVATION

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13. ABSTRACT *(Maximum 200 words)*

The overall objective of the urban maglev transit technology development program is to develop magnetic levitation technology that is a cost effective, reliable, and environmentally sound transit option for urban mass transportation in the United States. This project will include the design of an urban maglev system and the development and demonstration of advanced hardware subsystems to verify advanced technology aspects of proposed system concepts. The system design may be derived from integrating existing subsystem technologies (to create a new system) or by improving an existing system using advanced technologies. The Colorado Maglev Project represents the prototype system design for a full-scale maglev system in the U. S.

As part of its findings the Colorado Maglev Project has determined that with minor modifications an existing system, CHSST, based on linear induction motors (LIMs), can feasibly be deployed in the Colorado I-70 corridor. The project reports fully evaluate and present the modified CHSST technology's capability to accommodate the terrain and service levels of the I-70 corridor. The full report is presented in three parts. Part I is this Executive Summary. Part II is the Final Report. Part III is provided in CD format only upon request from the FTA and provides additional technical detail and support to the Part I and Part II reports.

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1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
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				=	1.1 short tons
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1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
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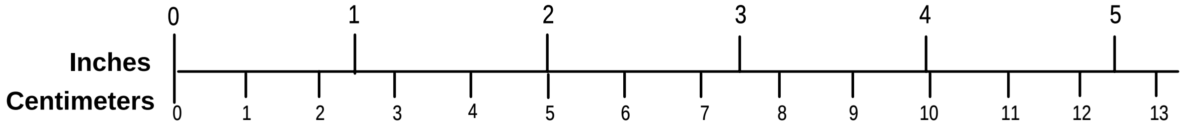

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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

Urban Maglev Technology Development Program

COLORADO MAGLEV PROJECT PART 1: EXECUTIVE SUMMARY OF FINAL REPORT

June 2004

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A.0 *INTRODUCTION*

The Colorado Maglev Project (CMP) is an effort between the Federal Transit Administration (FTA), through the Urban Magnetic Levitation Transit Technology Development Program, and the Colorado Department of Transportation (CDOT), coordinated with the Interstate-70 (I-70) Programmatic Environmental Impact Statement (PEIS) effort. Although coordinated, the two efforts have differing origins, requirements, and objectives, and may produce differing conclusions. The findings of the FTA CMP are presented in this Executive Summary and detailed in the Final Report. In addition, a Comprehensive Technical Memorandum is also provided detailing specific technical issues and results referred to in both the Executive Summary and the Final Report (the Comprehensive Technical Memorandum is available in CD format only).

The FTA created the Urban Magnetic Levitation Transit Technology Development Program in 1999 to “support further development of magnetic levitation technologies for potential application in the U.S. mass transit industry” (Federal Register Vol. 64, No.19). The objective of the program is to “develop magnetic levitation technology that is cost effective, reliable and environmentally sound transit option for urban mass transportation in the United States” (Federal Register Vol. 64, No.19).

Through the I-70 PEIS, the CDOT is currently assessing methods to increase transportation capacity and relieve congestion along the I-70 corridor from Denver to Glenwood Springs.

The FTA CMP, in cooperation with the CDOT, is assessing the viability of deploying a magnetically levitated (maglev) transit system from Denver International Airport (DIA) to the Eagle County Airport, generally following the I-70 freeway alignment. The magnetically levitated system may or may not be an alternative in subsequent studies to be conducted by the CDOT. The CMP team began work in early 2002 with the ultimate goal of developing a maglev system deployable in the I-70 corridor with cost containment identified as the key ingredient to the ultimate deployment and success of the project.

Although CDOT and the FTA are working cooperatively by sharing data, the goals of the two projects are somewhat different. The CMP team is only assessing maglev technology as a method to increase corridor capacity while the CDOT PEIS team is evaluating multiple transit technologies as well as highway widening. Therefore, the CMP team has focused its efforts only on magnetic levitation technology to be deployed in the I-70 corridor. CDOT, on the other hand, is independently assessing overall project issues and goals and not just one option. Due to the larger scope of this latter project, it has been necessary for CDOT to factor additional issues into the PEIS analysis that are not relevant to the more specific FTA project.

Magnetic levitation is a cutting edge technology employing the use of magnetic fields to create a gap between the vehicle and guideway. The magnetic levitation force transmitted across the gap creates a smooth, comfortable, quiet ride for passengers and allows for a frictionless environment for mechanical parts, minimizing failure rates. Levitation of the vehicle over the guideway is attained in one of two ways: ElectroDynamic Suspension (EDS) in which a vehicle is levitated magnetically by repulsive force and ElectroMagnetic Suspension (EMS), using the attractive force of magnets. The vehicles are propelled along the guideway using electric motors located on the vehicle, on the guideway, or in combination. Linear Induction Motors (LIMs) are located on the vehicle and are generally less expensive than Linear Synchronous Motors (LSMs). LIMs are used in several transportation applications and have been proven in use. The LSM motors are usually located on the guideway. They have not been applied in the traditional transit industry to date.

Although no maglev system has yet been successfully deployed in the United States (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, China and Germany.

Of all the systems developed worldwide, only two fully developed technologies were likely candidates to match the requirements of the Colorado Project: the Japanese CHSST systems and the German Transrapid.

A.1. MAGLEV TECHNOLOGY COMPARISON

A.1.1. *low speed/local, Figure A-1*

(The low speed systems are well suited for shuttle and local transit applications where the average distance between stops is significantly smaller than the end-to-end trip distance. The speed range of the low-speed systems is between 60 to 120 kph (37-75 mph).)

Figure A-1: CHSST Linimo Maglev Vehicles (Low Speed) for the Tobu Kyuryo Line in Nagoya, Japan

The Japanese Chubu CHSST system is also a fully developed maglev system that has successfully carried over 3 million passengers since the mid 1970s. Additionally, new generations of equipment are currently being developed. The CHSST system uses a Linear Induction Motor (LIM) for propulsion that is located on the vehicle rather than on the guideway, providing lower costs. The CHSST is an urban/regional system currently being deployed in Nagoya, Japan.

A.1.2. ***high speed/ inter-city,*** *Figure* ***A-2.***

(High-speed maglev systems have the capabilities of reaching maximum speeds upwards of 500 kph (310 mph). Systems in this speed range are specifically targeted to applications with a travel distance of many hundreds of miles.)

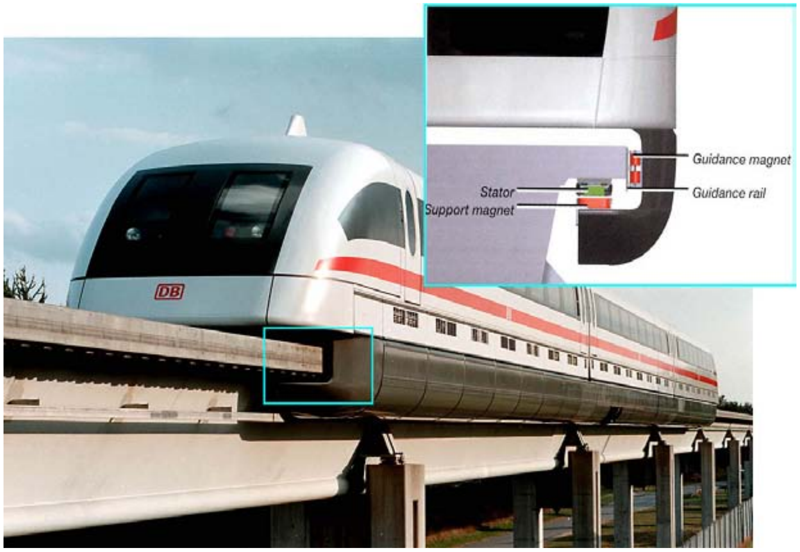

Figure A-2: Transrapid TR08 High Speed Vehicle

The German Transrapid is a fully developed test track maglev system that has successfully carried a large number of passengers. The system is being deployed and is in pre-operational testing for the Shanghai Pudong Airport connection to city-center. This system uses a Linear Synchronous Motor (LSM), which is a highly efficient motor, although it requires an active guideway (e.g. propulsion motors are physically located in the guideway rather than on the vehicle), thus significantly increasing the system costs. The Transrapid is a high-speed system that can attain speeds upwards of 480 kph (300 mph) with a grade climbing capability of 10% grade. The Transrapid system would require a number of modifications to operate in the Colorado Rocky Mountains.

The CMP is evaluating maglev technology for potential use in the I-70 corridor due to the unequaled performance capabilities of maglev technology based systems. The propulsion motors used in the maglev systems allow a superior grade-climbing capability unmatched by steel-wheel train technology; maglev has the capability of climbing grades of 7% without degradation of performance and grades of up to 18% with degraded performance. Maglev systems can also brake safely under adverse environmental conditions, since they do not depend on friction for braking efficacy, unlike wheel-based technologies. Additionally, maglev systems have the capability of maneuvering through tight horizontal curves, at degraded speeds.

In keeping with the project goal of deploying a maglev system in the U.S., with cost containment being the key to success, the CMP team gathered technical information for maglev systems in development worldwide. From the information gathered, it was possible to identify maglev systems that have been developed to a level supporting vehicle operations, and these could be considered for selection as the baseline system for application in the Colorado Project. It was understood by the CMP team that selection of a system already in development would most likely need some modification for use in Colorado, but such selection would significantly reduce the costs associated with deploying this cutting-edge technology in a timely manner.

For the Colorado application, operational simulations determined that speeds of 160 kph (100 mph) proved adequate for the terrain and patronage demand. Although the Japanese system is capable of speeds approaching 250 kph (155 mph), this speed capability was not advantageous in the Colorado application and the higher speed capability of the German Transrapid was not necessary.

In order to operate in the challenging terrain of the Colorado Rocky Mountains, the CHSST system requires additional vehicle power that can be provided by increasing the size and number of LIMs on the vehicle. To that end a third maglev vehicle system has been identified, the intermediate speed vehicle that will provide significantly increased flexibility and efficiency on potential maglev routes.

A.1.3. *intermediate speed/urban-suburban-rural, Figure A-3*

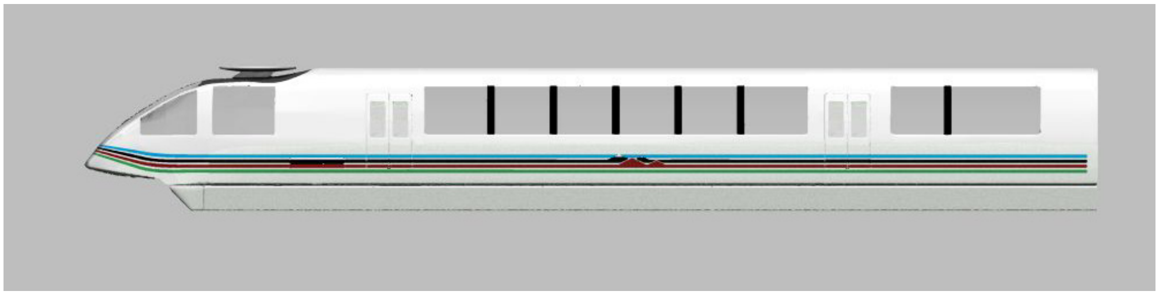

Figure A-3: Intermediate Speed Colorado 200 Vehicle

The Colorado 200 vehicle is optimally designed for the Colorado I-70 corridor and provides for an intermediate speed maglev system in the speed range of 100-200 kph. This intermediate speed maglev system will also be applicable to travel between population centers where the distance between one or more stops is a significant fraction of the end-to-end trip distance.

A.2. THE I-70 MOUNTAIN CORRIDOR PEIS

The I-70 PEIS is being conducted by the CDOT Region 1 consultants, J.F. Sato and Associates (JFSA). The underlying needs of increasing the I-70 corridor capacity, resolving congestion, and improving accessibility and mobility for users of the corridor were identified by CDOT and the study effort was initiated. The PEIS is a Tier I policy document intended to provide pertinent information to aid in the choosing of a preferred alternative that will meet the project needs and goals. Subsequent environmental studies will be required to complete NEPA requirements before implementation of the preferred alternative from the PEIS.

The PEIS has analyzed 13 different improvement alternatives including no action and minimal action alternatives, three highway alternatives, four transit alternatives and four combination highway/transit alternatives that could be taken to meet the project needs. Alternative impacts relative to resources are identified as direct, indirect and cumulative. The degree of impact though, is presented relative to all the alternatives under study; an alternative creates more or less of an impact to individual resources as compared to the impacts created by the other alternatives. This methodology of creating a scale of lesser to greater impact was employed to enhance the goal of the PEIS as a decision making tool.

The method of improvement is intended to meet four primary purposes (to the degree possible) while meeting the underlying need to increase capacity, address the congestion issue, and improve accessibility and mobility for I-70 Mountain Corridor users. These purposes are: 1) environmental sensitivity, 2) adherence to community values, 3) safety, and 4) implementation of the preferred alternative.

The PEIS effort and the FTA's CMP are cooperative efforts, with the results of the FTA project to be incorporated into the PEIS document as appropriate. Although the projects are cooperative efforts, the Automated Guideway System (AGS) alternative considered by PEIS is not identical to the maglev technology studied by the FTA project. The differences are attributable to the more detailed and technically explicit maglev information developed during the FTA project, and to the difference in project schedules. The AGS alternative was defined earlier with lesser technical accuracy than that developed for the FTA project, and consequently had performance characteristics different from those of the real-life system studied in the FTA project. Additionally, the lengths of the two systems are different. The FTA project extends from DIA to Eagle County Airport while the PEIS extends from C-470/I-70 at the western edge of the greater Denver metropolitan area to Glenwood Springs. Additional environmental study will be required if a maglev transit system is planned for the entire length from DIA to Eagle County Airport.

A.3. I-70 CORRIDOR REVIEW

Significant traffic congestion is occurring along the I-70Corridor in the mountainous portions of Colorado. Summer and winter recreational opportunities in the Rocky Mountains west of Denver cause heavy traffic and delays for visitors, commuters and local residents, mainly on the weekends and during holidays. The heavy traffic is further exacerbated by severe weather conditions during the winter months. Additionally, commuter-type (e.g. peak hour, peak direction) congestion is also occurring in the I-70 Mountain Corridor, especially in Eagle County, during the weekdays as the population expands further west from the Denver metropolitan area.

The travel demand in the corridor continues to grow in both the summer and winter seasons due to the popularity of the mountain areas. The trends of urbanization, increased purchases of second homes and an increase in population due to the recreational opportunities in the area are contributing to the area's growth. Historical growth trends show an increase of traffic along the I-70 corridor averaging 3-5% per year. Over the next twenty years, this travel growth trend is forecasted to continue.

The Corridor economy is largely driven by tourism and recreation due to the world-class ski resorts and national forest destinations. Tourism is the second largest industry in Colorado, after manufacturing and before agriculture, and contributes approximately 12 to 14 percent to Colorado's economy ($7 billion in 2000). The high rates of tourism in the I-70 corridor result in employment for nearly 125,000 persons and the generation of $4.8 billion in annual personal income. Due to this significant economic benefit to the State of Colorado, the continued accessibility of the recreational areas along the corridor to both visitors and residents alike is important to the future economic health of the State. Existing congestion levels during the ski and recreation seasons is already thought to be suppressing the number of skier visits, and the Corridor's economy.

Figure A-4: Denver International Airport

Figure A-5: Denver Union Terminal

Work performed by CDOT and used in the CMP effort has shown that the most congested segment of I-70 is between Golden and the Eisenhower-Johnson Memorial Tunnel (EJMT), a distance of approximately 72 kilometers (45 miles). The congestion occurring is a recreation-based seasonal peaking problem.

The CMP team, working under the Urban Magnetic Levitation Transit Technology Development Program, proposed to the FTA the evaluation of a maglev system deployment in the I-70 corridor to assist in resolving the congestion problems occurring in the peak seasons. The I-70 corridor that winds through the Colorado Rocky Mountains presents one of the most challenging alignments for deployment of a transit system anywhere in the world with its steep grades, tight horizontal curves and severe winter weather conditions.

Figure A-6: Floyd Hill Toward West (Golden to Eisenhower Tunnel Section)

Figure A-7: Vail Pass – Summer

Figure A-8: Vail Pass - Winter

The CMP team undertook this challenge with the realization that if a maglev transit system could be designed for deployment in the I-70 corridor, then it could be designed for deployment in any location in the U.S.

The CMP team and the CDOT Region 1 consultants performing the PEIS have worked cooperatively to ensure accuracy and efficiency for both efforts. This does not imply, however, that there is absolute technical agreement on all issues. The FTA project is evaluating the ultimate deployment of a maglev system while the CDOT PEIS effort is assessing the capacity requirements of the I-70 corridor, including assessment of both highway and transit alternatives.

As previously stated, the CMP team performed research into currently existing maglev systems in order to choose a baseline system to be used as the basis of all maglev research and development in this corridor. Subsequently, the maglev route was specifically defined and analyzed in order to define the transit system corridor requirements. Other work performed as part of the Project effort included vehicle definition, guideway and switch design, station layouts, definition of power supply and system impact on greenhouse gases, systems integration and development of a final system specification. In addition, winterization and propulsion motor (LIM and LSM) trade studies were performed in support of the effort , and system security and safety certification plans were developed.

A.4. TECHNICAL FINDINGS SUMMARY

The crucial findings resulting from the CMP effort are summarized below.

A.4.1. *Vehicle*

The results of the CMP have shown that the Colorado 200 Car will successfully operate in the I-70 corridor. This system would provide transit service from DIA to Eagle County Airport, thereby serving the many recreational opportunities on and near the corridor as well as providing transit service for the commuting needs of residents of the mountain counties. The system operational simulation efforts have concluded that the system can operate without conflict under headways of 120 to 150 seconds. Further, route level simulations have concluded that the optimum speed of operation need not exceed 160kph (99.4mph), while also showing that enhanced propulsion motors are required to handle the grades and curvatures of the alignment.

One of the key issues in selecting the baseline maglev system was the capability of the propulsion motor to operate effectively in the I-70 Mountain Corridor with the inherent grades and horizontal curves as well as severe winter conditions.

Sandia National Laboratories completed a trade study comparing the LIM powered maglev systems and the LSM powered maglev systems, which is summarized below, and explored in detail in subsequent sections. The full trade study comparing LIM and LSM is found in the Comprehensive Technical Memorandum.

The trade study determined that for applications up to approximately 250kph (155mph), a LIM powered system provided advantage over an LSM system. This conclusion is based largely on guideway cost; the LSM system requires a powered guideway, which implies substantial additional cost when compared to the LIM powered systems utilizing powered vehicles rather than powered guideways.

Based on the analysis of available information, the CMP team selected the CHSST system technology as the baseline system to be used in the I-70 corridor. This technology is used as the basis for all research, development and design work in the research effort.

One of the more interesting findings of the systems analysis addressed the maglev system’s controls. Fortunately, the CHSST system is control-neutral. Until this study effort, systems had always been put forward with fixed block controls and manually operated trains. For the Colorado Project a recommendation has been made to use more modern controls incorporating the approach developed by the Bay Area Rapid Transit District (BART). This approach employs a moving block control system that 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.

A.4.2. *Guideway*

Extensive integration efforts were undertaken relative to the guideway construction since the guideway costs typically comprise approximately 60 percent of the overall cost of guideway transit systems. Three alternative guideway concepts (Concept A Figure A-9, Concept B Figure A-10 and Concept C Figure A-11) were evaluated in depth during the course of the analysis.

Figure A-9: Concept A: Rendering of Concrete U-Girder Guideway

Figure A-10: Concept B: Rendering of Steel Box Girder Guideway

Figure A-11: Concept C: Rendering of Steel Truss Guideway

The guideway analysis has shown that there are a number of opportunities to optimize the costs of the guideway through fabrication methods when utilizing steel trusses. In addition, various options in automating the welding requirements for the guideway and options for final rail alignment procedures have been assessed.

In the Nagoya, Japan TKL deployment the largely manual initial construction alignment has been conducted with traditional surveying instruments, basically transits and tapes and is labor intensive and time consuming. This approach is also challenging in complex curves. The manual approach will be replaced on the Colorado project with more modern, electro-optical techniques. The use of these new techniques will improve accuracy and reduce costs.

It was also concluded that the use of large prefabricated, pre-aligned guideway sections is feasible in the Colorado application since transporting these sections to the construction sites would not cause undue difficulty. (See the Final Report for detailed discussion on use of prefabricated guideway sections.)

A.4.3. *Stations*

The station evaluation has found that the weather patterns along the I-70 corridor dictate enclosed stations with platforms protected with elevator-type doors to provide the shelter and safety required for passengers. Figure A-12 shows an architect's rendering of a generic maglev station. The rendering shows I-70 adjacent to the station structure with the elevated maglev guideway near I-70. There are two platforms which are secured from the lobby area and the automobile, taxi or bus arrival and departure are on the streetside. Each station will be given its own unique architectural treatment depending on the station's location.

Figure A-12: Prototype Maglev System Station

Further, due to the length of the Colorado Project alignment together with the number of stations, specific requirements for reliability, availability, and serviceability are imposed on the overall system. Based on examination of these requirements, the integration effort established an approach of distributed maintenance that would be effective in meeting system availability goals. As a result of these requirements, a recommendation has been made that maintenance activities will be supported at each station, where replacement of failed vehicle elements will be possible.

A.4.4. *Electrification*

The electrification analysis has determined that there are inadequate transmission line resources available within the I-70 Mountain Corridor for operation of the proposed maglev system and that additional transmission line capacity is necessary. The electrification analysis concluded 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. The findings of the research have concluded that if this were not done, it would be easier to build new power generation plants in the corridor than to build conventional transmission lines necessary to carry the power.

A.4.5. *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.

As both the recent Moscow and Madrid 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 bombs, since security precautions are minimal and passenger convenience still remains the paramount goal.

The Colorado Project analysis addressed the security issues inherent in any public infrastructure project that deals with many people. As both the Moscow and Madrid bombings have shown, actions are required now to reduce the risks. 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 terrorist acts, and the Israelis for targeting terrorists operating within Israel. All techniques which can prevent planting and detonation of bombs should be carefully considered.

In producing the security documents for the Colorado Project a need has been identified to closely scrutinize the processes used by terrorists and assess countermeasures to mitigate, if not eliminate, the threats to transit systems.

Our goal in developing the security plans for the Colorado Project are:

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

The three major design aspects of system security for the Colorado Project 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 a fundamental change is required to secure passengers from injury and possible death.

Two reports were prepared for the Colorado Project with one being unclassified while the other was made available only to the USDOT. Both reports have pointed out approaches to limit death and destruction from terrorist incidents targeting transit.

Fundamentally, transit systems in the U.S. will need to be modified to eliminate the ease of access to passengers with more use of controlled access. Uncontrolled access simply provides the opportunity to perpetuate the cycle of violence. The CMP will be designed with the appropriate protective measures in place including detection and constant scrutiny to mitigate potential threats as much as possible.

A.4.6. *System Costs*

The system costs are critical in establishing the deployability of the CMP. Extensive effort was applied to the costing exercise, encompassing both the capital costs and the operations and maintenance costs as summarized below.

The CMP team was determined to produce the best possible estimates for system capital cost, with contingencies clearly displayed to accommodate unforeseen local conditions and circumstances.

There is 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 Executive Summary and are presented in more detail in the 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. 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 its own experience with Colorado projects as well as recent bridge construction projects performed in Colorado for CDOT.

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. A contingency of 25% was used by T. Y. Lin for the Colorado project. This contingency was determined as proper for this stage of development by T. Y. Lin professional bridge designers, who have substantial bridge design and costing experience.

To collect cost data for estimation of other portions of the system, the CMP 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.

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. There was no need to use similar or dissimilar vehicle cost estimates or averages from other rail projects.

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 CMP team also 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 results of this effort show a transit system cost that is competitive with other familiar fixed guideway transit systems including LRT Guideway and Heavy Rail systems. In certain projects, such as the San Diego LRT Mission Valley East extension, the cost of the projected maglev system deployment is less than the per mile cost of the San Diego LRT extension (the current cost to complete for the 6 mile LRT is over $500 million).

The aggregated capital systems costs calculations show an estimate of $4.674 billion or $30 million per mile for the 250-kilometer (155-mile) long system. A twenty five percent general contingency has been added making the total cost $5.842 billion or $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.

The operations and maintenance cost has been calculated to be approximately $43 million per year ($47 million with contingency), based on a particular operating model chosen for the Colorado Maglev System capable of transporting 40,000 trips per day.

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 manufacuturing 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.

B.0 COLORADO MAGLEV PROJECT TECHNICAL FINDINGS AND CONCLUSIONS

The following sections provide additional detail related to each of the key conclusions reached in the analysis.

B.1. ROUTE

The CMP stretches from the Denver International Airport (DIA), through the Denver urban area, and into the Rocky Mountains to the Eagle County Airport, a distance of over 250 kilometers (155 miles). This corridor is one of the challenging corridors under consideration worldwide. It 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.

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

- Denver International Airport 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.

The following figure shows the Golden to Idaho Springs segment with a possible alternative alignment avoiding the Twin Tunnels just east of Idaho Springs.

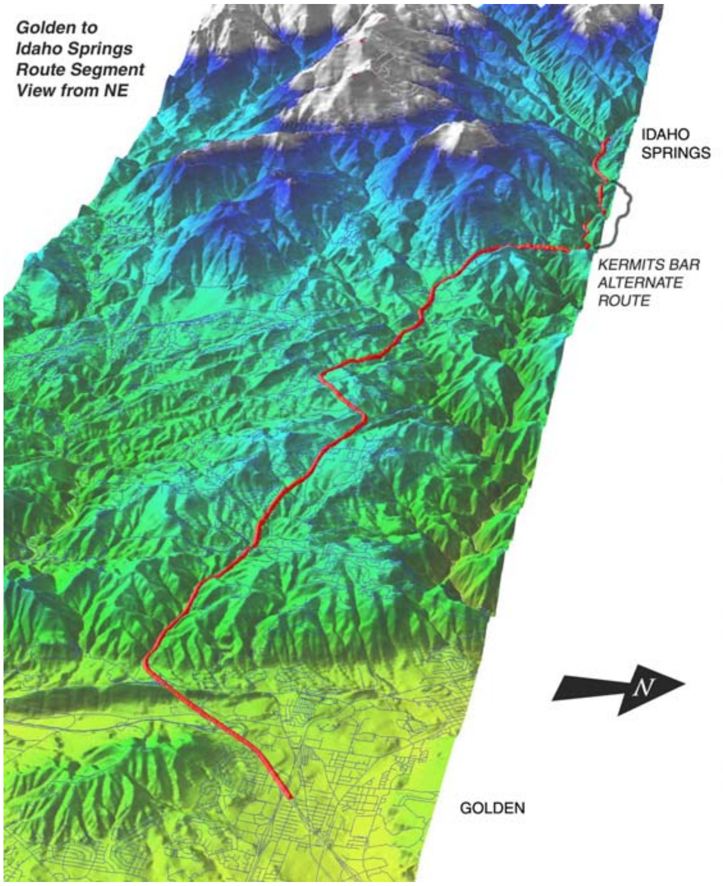

Figure B-13: Golden to Idaho Springs with Alternative Alignment

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. Topographically, the ground surface above the tunnels consists of steep mountain terrain leading up to the Continental Divide and forms 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 B-14 illustrates the landslide area in 1965 and the severity of the slopes up to the Continental Divide; the photo is looking north.

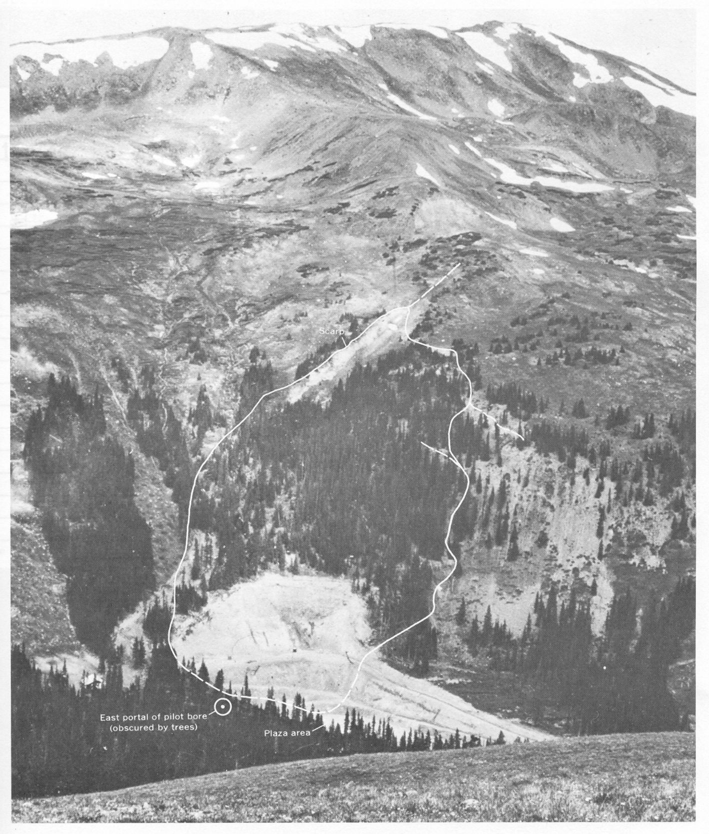

Figure B-14: Loveland Basin Landslide, 1965

An additional new EJMT tunnel for the maglev system might be avoidable, since the proposed maglev transit system has the unique capability to traverse grades up to 18% with degraded train operation. The maglev system's grade climbing capability provides potential cost relief, by reducing or completely eliminating the need for a new transit system tunnel adjacent to the new proposed highway tunnel bore near the EJMT.

The FTA project dictated that significant consideration must be provided to alternative alignments in order to avoid costly tunnels. This evaluation resulted in definition of an alternative to the long EJMT transit tunnel as depicted in Figure B-15. Pictures are shown on the following pages with the EJMT alignment alternative from the east side of the Continental Divide to the west side in Figures B-16, B-17 and B-18. The alternative alignments did not take into consideration environmental impacts or hazards. Avalanche and rockfall can be mitigated by snow sheds and/or fenders specifically designed for both avalanche and rockfall and positioned around guideway structures as required. Also the alternative alignments are within the boundaries of the

Arapaho National Forest and will require extensive negotiations for use permits. The National Forest Service is at times receptive to allowing for fixed transit system use over forest lands. Other alignment alternatives were also considered, and may be feasible.

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 3.93miles) 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 0.65miles) 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 Maglev Project costs for guideway.

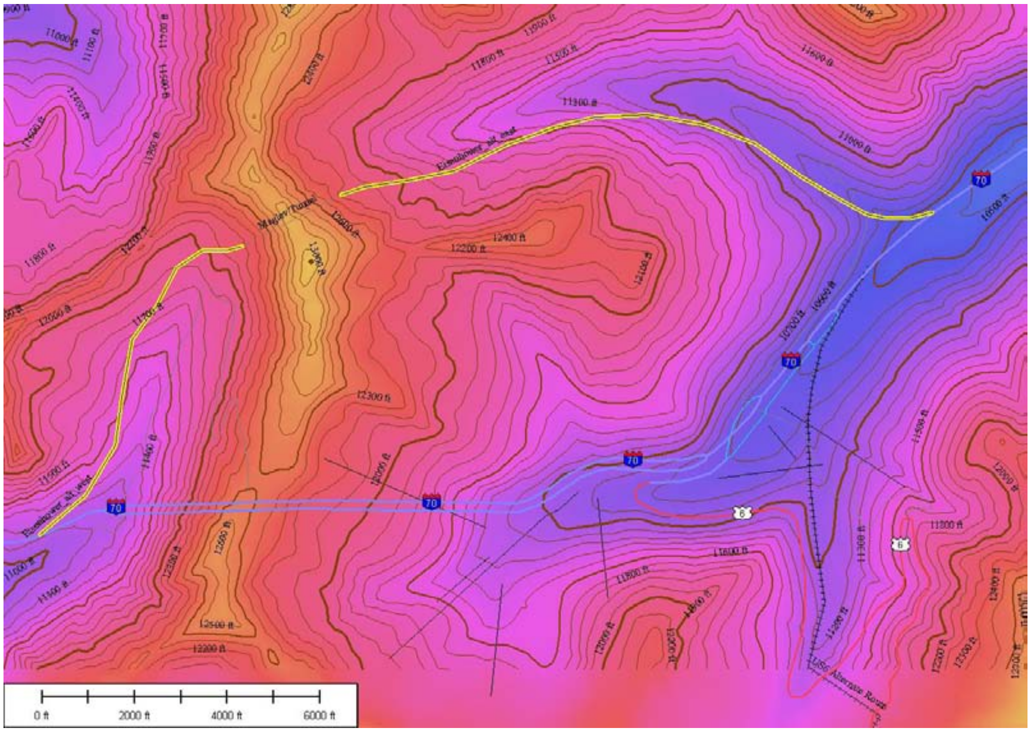

Figure B-15: EJMT Alternative Alignment, with Short Tunnel

Figure B-16: Westbound View Showing Approximate Eastern Location of Alternative Alignment to EJMT

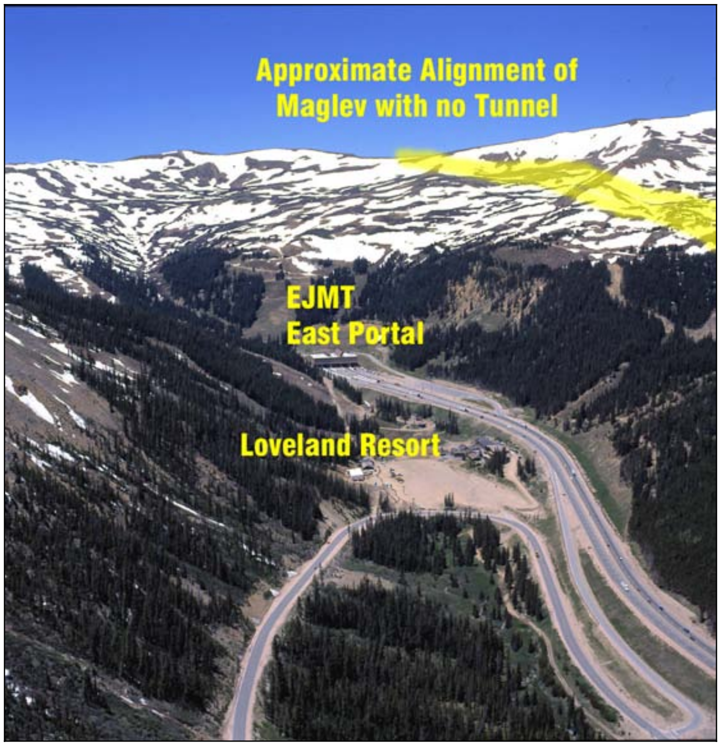

Figure B-18: Westbound View of Alternative Alignment with No Tunnel Over Continental Divide

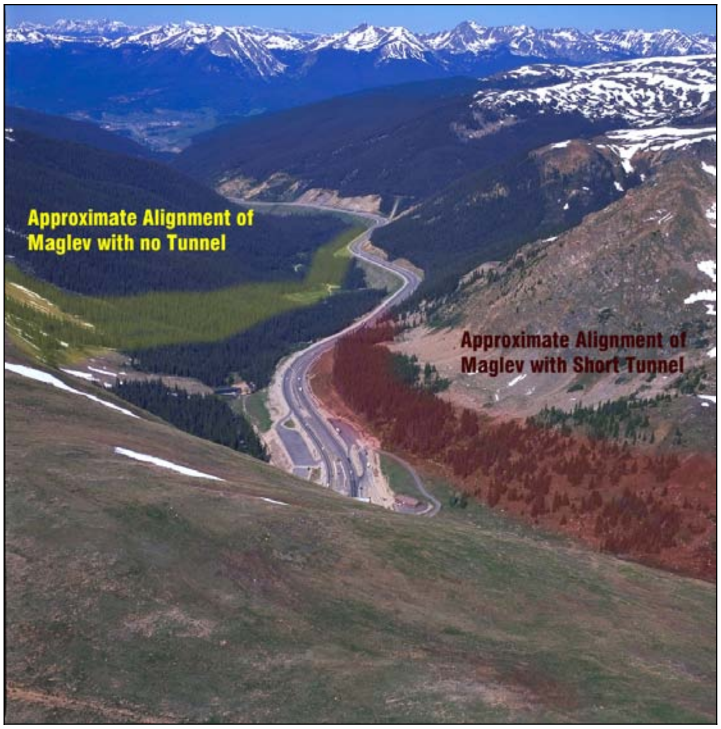

Figure B-19 Westbound View Above EJMT West Portal

The projected total cost of the alternative alignment around the EJMT, as shown by the yellow line in Figure B-15, is $165 million while the cost of a new EJMT transit tunnel alone is $333.5 million. Hence, the recommended alignment for the maglev system for the FTA study would traverse the alternative alignment, providing the commensurate savings to the overall capital cost of the maglev system. In subsequent phases of this project further detailed evaluation of this and other prospective alternative alignments including the EJMT tunnel alignment will need to be performed to assure conformance to design criteria as well as mitigation for rock falls and avalanches and environmental clearances to traverse across Arapaho National Forest lands.

B.2. SYSTEM SIZE

The maglev system passenger demand in the I-70 Mountain Corridor has been projected by CDOT's Region 1 contractor, JFSA, who completed a thorough ridership forecast for the I-70 PEIS effort. The ridership modeling has projected a peak-season, bi-directional transit use ranging from 54,200 transit passengers per weekend day at the Twin Tunnels just east of Idaho Springs to 21,500 transit passengers per weekend day at Dowd Junction west of Vail in the I-70 corridor. For purposes of sizing the maglev transit system, the FTA effort utilizes a maximum ridership of 40,000 transit passengers per weekend day, further implying a unidirectional daily flow of 20,000 per day. Assuming that two, three-hour, alternate direction peaks would occur each day within this volume level, and also assuming that originating traffic would commence predominantly from Denver area stations including the Golden area station, the character of the flow can be described.

Each peak-hour volume is likely to constitute 60% of the unidirectional flow, or 12,000 trips. The duration of the peaks is likely to average around three hours per direction. Since two daily peaks are expected, the central hour of the three-hour peak is also likely to be the time of heaviest flow. During this central hour, it is assumed that 6,000 trips would occur as the heaviest hourly flow in each of the morning and afternoon peaks.

The following table summarizes the ridership estimate that determined the vehicle-sizing requirement.

Table B-1 Ridership Projection

System Peak Ridership
40,000 riders per day (weekends)[1]

Patronage / Vehicle Sizing
20,000 directional travel
3-hour peak am and pm produces 60% of total ridership – 12,000 trips[2]
1-hour peak hour patronage am and pm is 50% - 6,000 trips[3]

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 optimizations is not warranted until better system definition (particularly station locations) is available, and was beyond the scope of the present study.

B.3. THE COLORADO MAGLEV VEHICLE

One of the central tasks in the CMP was the definition of the system vehicle that could both operate in the I-70 mountain corridor and carry the projected patronage demand. In seeking a suitable vehicle, it was necessary to find a vehicle capable of meeting both speed and capacity requirements while operating in the rigorous conditions experienced along the corridor.

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[1] The ridership projection, as developed by PEIS consultants to CDOT, ranges from 54,200 to 21,500 riders per day based
on weekend ridership, the maximum ridership period.

[2] The peak three hour ridership will be 60 percent of the total daily directional travel

[3] The peak hour patronage will be 50 percent of the peak three hour ridership

B.3.1. *Colorado 200 Car*

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.

CHSST has extensive experience with the configuration of the vehicles that have been used in various CHSST deployments since the 1980s. The current Nagoya TKL deployment in Nagoya, Japan utilizes the 100L vehicle, Figure A-1, with a seating arrangement that meets the demands of the short 9-kilometer (5.6-mile) alignment interconnecting the Nagoya subway system to a regional train line.

For the Colorado I-70 application, the CHSST-200 vehicle has the approximate required 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 advantageous for the application in Colorado.

The approach of using an existing and extensively tested vehicle in the I-70 corridor will allow less expensive deployment with greater success than could be expected from a system deployment starting with a newly developed, untested vehicle.

A rendering of the Colorado 200 is shown in Figure B-20.

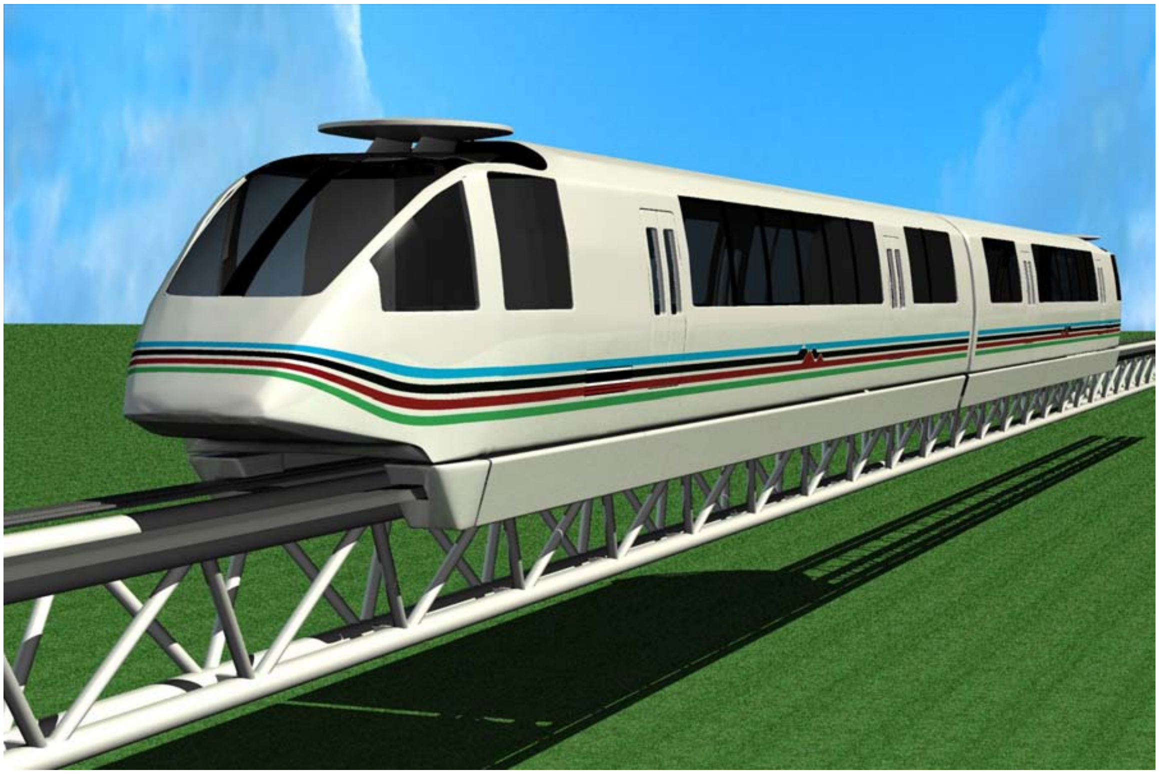


Figure B-20 Colorado 200 Vehicle

The Colorado maglev train consists of two Colorado 200 vehicles in a permanent married-pair configuration. Each vehicle carries two sets of bi-parting doors on each side, through which passengers embark and disembark. 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. Figure B-21 shows the Colorado 200 vehicle seating configuration.

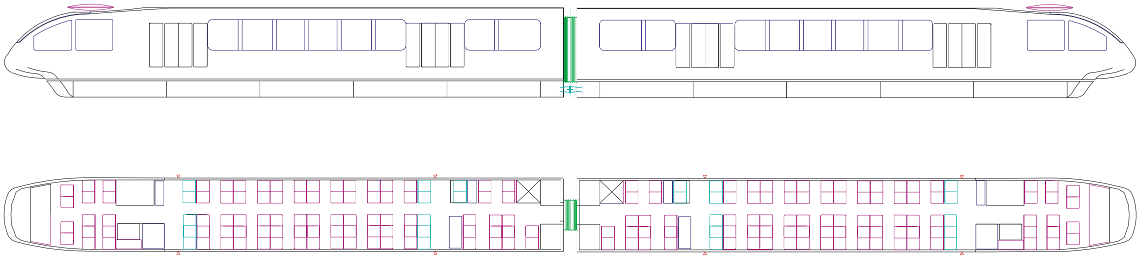


Figure B-21: Colorado 200 Vehicle Seating Configuration

B.3.1.1. Propulsion System

A critical decision in the selection of the baseline vehicle resulted from technical evaluations of existing systems including the Transrapid and the CHSST maglev systems. In addition, Sandia National Laboratory completed a trade study of LIM-based and LSM-based systems for the Colorado application. The findings are summarized below with a discussion of the LIM used in the CHSST system found in this Executive Summary and the LSM used in the Transrapid system found in the Comprehensive Technical Memorandum. The full trade study is found in the Comprehensive Technical Memorandum. This comprehensive evaluation process confirmed a decision to utilize the LIM as the vehicle prime mover.

B.3.1.1.1. *The CHSST LIM*

Japanese LIM technology is fully developed and is utilized for the Chubu CHSST (Maglev) in Nagoya, Japan and Linear Metro Subway (supported by the conventional steel-wheel/rail system) in Tokyo, Japan.

The basic construction of the CHSST short-stator linear induction motor (LIM) drive is shown in the following figures. Each vehicle propulsion/levitation module contains a LIM stator along with four levitation magnets. These magnets pull the module up toward the steel section of the guideway rail, lifting the vehicle and creating a well-defined gap between the LIM stator and the aluminum reaction rail secondary Figure B-22. Figure B-23 shows a side-view cross-section of the LIM with the 3-phase primary winding embedded in the vehicle's LIM stator core and the guideway's aluminum rail cap and steel backiron, that forms the secondary circuit for magnetic flux from the motor.

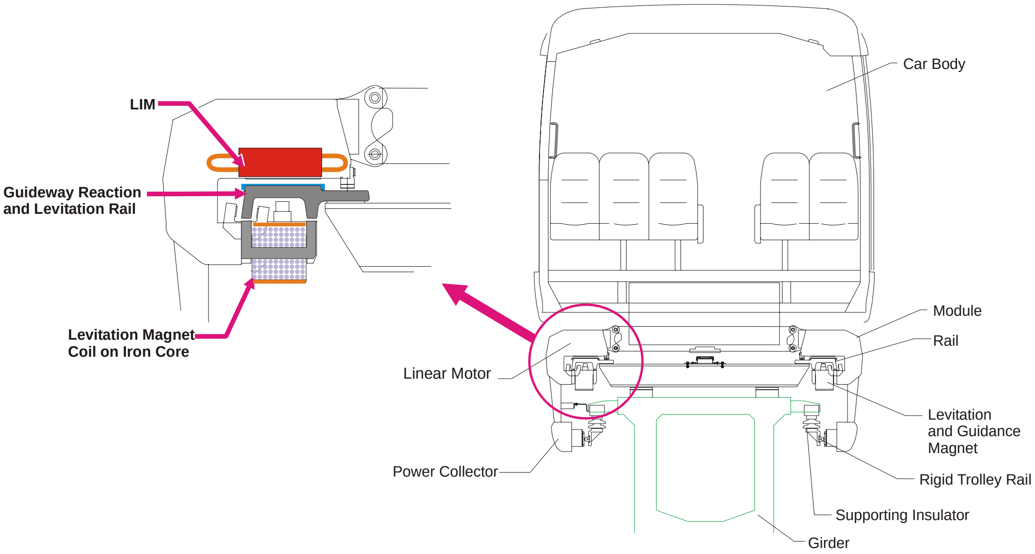


Figure B-22: Close-up of propulsion/levitation module for LIM.

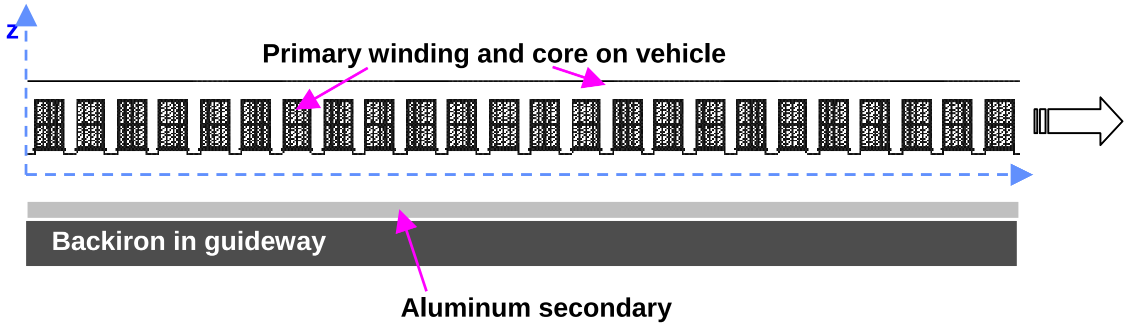


Figure B-23: Side-view, cross-section of single-sided LIM components.

The guideway power feed is a solid rail carrying DC power, the same method currently used by conventional railways. The power collectors are the vehicle's sliding or wheel contacts to the power feeder. Sliding collectors have been operated up to 130 kph at the CHSST Nagoya test track, although testing facilities for higher speed operation exist at the Railway Technical Research Institute (RTRI) Test Track in Kokubunji, Tokyo. Wheeled collectors have been tested up to 200 kph at the RTRI for the DC linear motor car project.

The linear induction motor as shown above is a single-sided structure that generates a non-uniform normal force, side force, and rotational moments on the LIM stator core. Its operation is somewhat less efficient than an equivalent conventional rotary induction motor because of the large air gap between the on-board stator and guideway rail, which results in higher leakage of magnetic flux.

The passive guideway reaction rail consists of an aluminum or copper cap plate backed by the guideway rail steel. It is structurally very simple, and is fully integrated with the levitation rail in the CHSST system. The reaction rail's performance and durability has been tested thoroughly in cooperation with the Japanese Ministry of Transportation during the development of the CHSST maglev system.

A significant advantage of the LIM drive is that the on-board power conditioning system concept and construction is similar to equipments used in conventional urban and high-speed electric railway vehicles. This is important from several perspectives. Many of the power conditioning equipment system sections and components are common, and there exists a significant database of practical experience and design with manufacturers and line operators.

In addition to this, a major incentive for use of LIM propulsion in the Colorado Project is the all-weather capability to negotiate tight curves and steep grades, and meet precise stopping requirements with high deceleration, not possible with power-driven steel-wheels.

The LIM utilizes a very simple reaction rail track, hot-rail power pickup on the vehicle, and passive guideway rails that simplify the track switches. The reaction rail can be installed in discrete sections along the track as needed, simplifying construction.

Use of LIM propulsion also permits vehicles with different design and performance parameters to be adapted easily without changes to the guideway within the guideway load (electrical and mechanical) limits. The simple guideway mechanical structure can provide small radius horizontal and vertical curves, and either bending or transfer switches.

Finally, this guideway system has been shown to be as safe and reliable as a conventional rail track.

A LIM-driven transit system has a great degree of flexibility to respond to variable or uncertain demand. This includes adjusting the number and size of vehicles on a short-term or long-term basis, since the maximum number of vehicles is determined by system factors other than guideway structure. In the short term, the ability to add and move vehicles provides rapid response capability for the operator confronted with volatile demand and quick recovery from any off-normal shutdown or schedule deviation. In the long-term, if additional power is needed to accommodate an upgrade in the system capacity, the impact to the guideway structure is almost negligible, requiring only the addition of wayside power electrification and conditioning equipment. To meet operational requirements, the moving block control can be easily adjusted with little, if any, modification to the civil structures.

However, the weight and size of the on-board power conditioning equipment must also be larger as must the size of the wayside power systems. This increase in vehicle weight limits the operational speed capability of the LIM-driven system to 200 – 250 kph (120 – 150 mph) since the weight penalty makes higher speed operation impractical. However, this is not to say that the efficiency of the LIM is impractical. For the Colorado I-70 route the anticipated average and maximum speeds are 114 and 160 kph, respectively. For this route, higher speed did not provide significant advantages, but the maximum speed of ~225 kph could be obtained with the Colorado 200 LIM-driven vehicle. The electrical-to-mechanical efficiency of the LIM at the power pickup hot-rail is 70% at the average speed and 77% at maximum speed.

B.3.1.2. Colorado 200 Propulsion System

The propulsion elements for the Colorado 200 vehicle consist of one inverter and ten LIMs for every car, as shown in Figure B-24. Each LIM is installed on the under surface of the module's main structure and is supported at multiple fixed points. When supplied with current, each LIM generates horizontal and vertical thrust in a controllable manner.

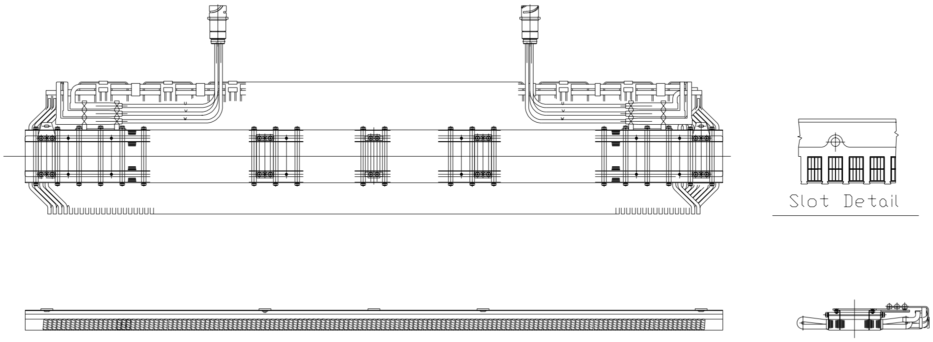


Figure B-24: CHSST Colorado 200 Propulsion Motor Diagram

B.3.1.3. Levitation System

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 at any given speed, and lower stresses on transportation infrastructure than any other transportation technology.

CHSST uses the electro-magnetic suspension (EMS) that concentrates the magnetic flux between the levitation rail and the bogie magnets, resulting in low magnetic field levels in the interior of the vehicle. Sensors are employed to maintain constant gap between the bogie magnets and the levitation rails. The magnet current is modulated electronically to compensate for external forces on the vehicle, thereby maintaining a constant gap.

The geometrical structure of the magnets and rails, embodying the familiar geometry of horseshoe magnets (U-shaped iron cores energized by electric coils wrapped into the bottom of the “U”), also provides lateral restoring forces to resist winds or centrifugal forces applied laterally to the vehicle; this is shown in Figure B-25. Although this magnet configuration exhibits natural stability in the lateral direction when floating freely below the levitation rail, the levitation servos controlling these magnets use information from the gap sensors to counter all external forces dynamically as they occur, ensuring a smooth ride for passengers.

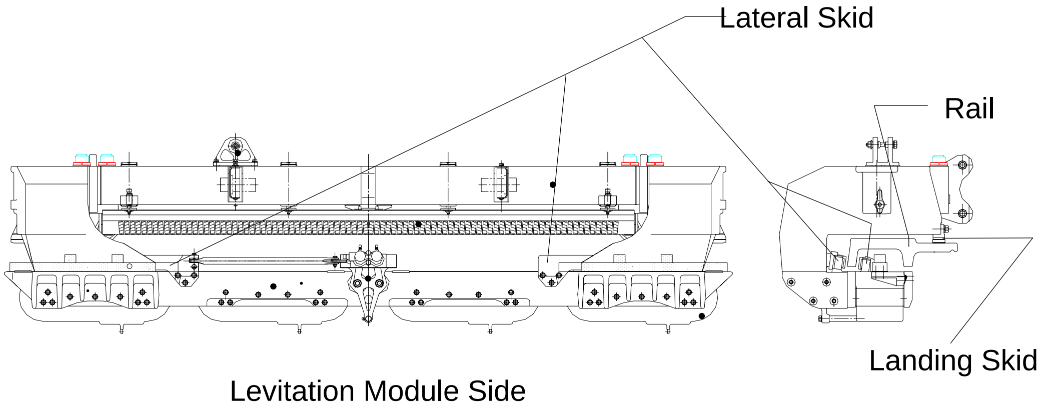


Figure B-25: Colorado 200 Vehicle Levitation Module

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").

The magnets are carried in the levitation modules. Four individual levitation magnets are housed in each module. The gap sensor is installed on the top of the magnet in close proximity to an accelerometer.

B.3.1.4. Vehicle Control System

The levitation control element of the Colorado 200 vehicle 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, or unless the vehicle is levitated and under manual control. 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, however 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.

B.4. COMMAND, CONTROL AND COMMUNICATIONS SUBSYSTEM (CCCS)

The Command, Control, and Communications Subsystem (CCCS) coordinates and controls all activity in the maglev system. As a new system design, the Colorado maglev system should employ the most advanced, safest, CCCS available consistent with its deployment schedule and other equipment. The most promising updated modern control technology available for the CMP, besides the standard Japanese fixed block control system, appears to be the system developed by the Bay Area Rapid Transit District (BART). 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 project's 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 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, the BART CCCS represents a good choice for a baseline control system for the CMP.

Evaluation has shown that the system is compatible with the Chubu CHSST maglev technology, and could be readily interfaced to existing vehicle designs with little modification. The BART 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.

The BART control system is schematically described in Figure B-26.

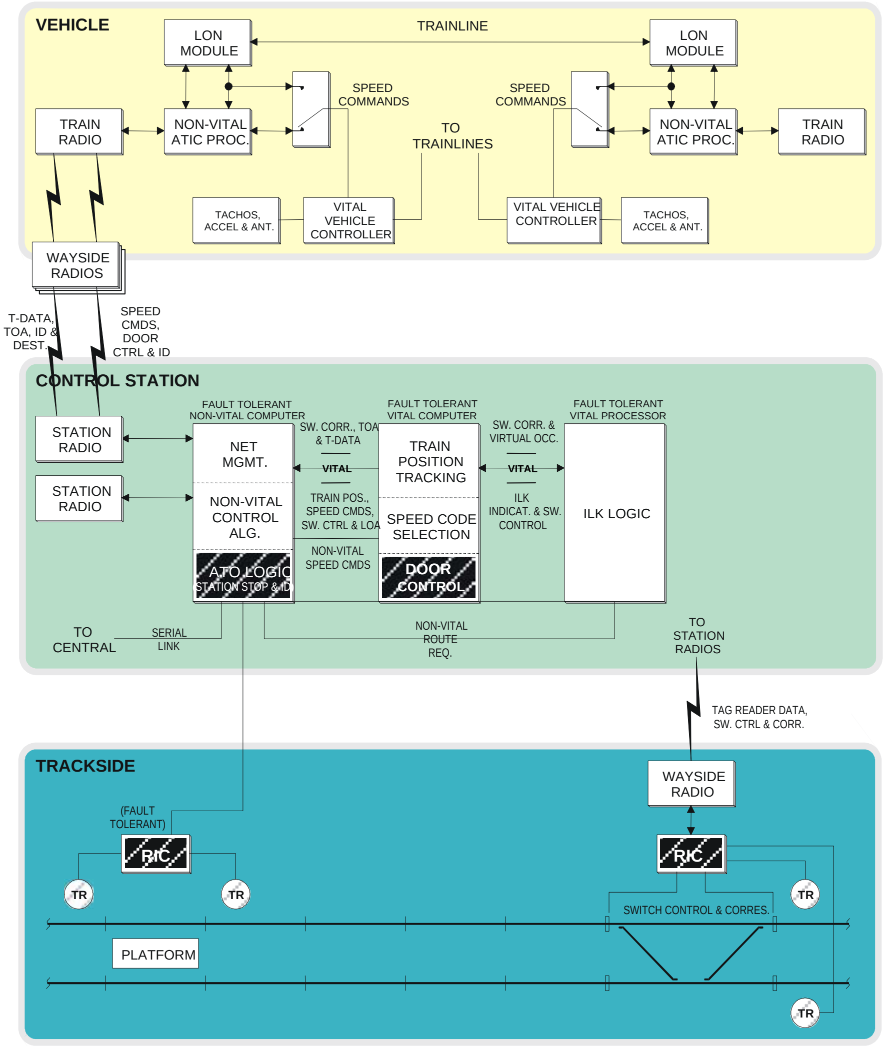


Figure B-26: BART Moving Block Train Control

B.5. COLORADO MAGLEV SYSTEM POWER SUPPLY AND DELIVERY

The power supply needs and delivery electrification analysis identified the options for meeting the electric power needs of the CMP by comparing its aggregated energy needs with the existing capability of the electric utilities serving the I-70 corridor. The electrification analysis evaluated existing and planned power supply resources, power requirements and supply adequacy, feasibility of distributed generation, and compared electric supply options and formulated recommendations for the maglev system corridor. The I-70 maglev system corridor was defined for the electrification analysis as an area 16 kilometers (10 miles) from the maglev system right of way.

There are eight utilities serving the corridor with some utilities serving only a small enclave surrounded by another utility's service area. The power plants within the defined corridor zone, and some within very close proximity to this region, were identified showing that the largest generation stations along the route are owned by XCEL (formerly PSCO) in the 300 to 700 MW size range, followed by several smaller generation facilities owned by municipals as well as merchant plants. Data for all transmission lines in the voltage class of 115 kV and above shows that generally, these are single line corridors; however, there are a few parallel circuits.

The analysis has shown that the peak power requirement for the maglev system is 2,320.12 kW per car, or 4,640.24 kW for each 2-car train. This demand occurs at a 7.48% grade at a distance of 171.85 km west of DIA on the eastbound track with a 90 kph headwind. Similarly, the peak in the westbound direction will be 2,098.05 kW per car, or 4,0196.10 kW per train and occurs at a 6.59% grade at a distance of 124.45 km west of DIA under 90 kph headwind conditions. For those sections with higher grades, the sections are very short compared to the entire route length, and offset by the stored, regenerated power from braking. The impact of the additional electrical energy demand is expected to be small.

With four trains between adjacent substations, it was determined that each substation could have a peak load of 20 MW. Based on this load, a 25 MVA transformer was selected for each substation, which is approximately 5 MVA larger than the estimated traction load of the trains. The higher rating allows for some margin in the power requirement estimates and accommodates ancillary loads such as station power, communication and control loads. This margin also offers operational flexibility and accommodates higher train traffic patterns, or off-normal operations due to unforeseen conditions.

Most of the train stations for the maglev system were assumed to be at the higher elevation of the guideway and will require elevators or escalators for passenger use. Additionally, all the stations have winter heating requirements. Thus, the station load, including lighting, was determined to be 50 kW. Additionally, each station was assumed to have a combination pneumatic and electric track switching capability to move the cars between tracks. This load was assumed to be approximately 150 kW. Thus, the total station load was calculated at 200 kW and is to be supplied by a dedicated 200 kVA/480 V transformer.

A key finding resulting from the electrification analysis concluded that due to the increasing difficulty of licensing and building of new transmission paths, shared access of the transmission corridor with the maglev system could be a very valuable resource. Implementing a new transmission corridor with conventional overhead lines is an impractical proposition, especially near environmentally sensitive communities, unless it is made virtually invisible by fully integrating it into the design of the guideway. Passenger safety and operational reliability considerations precluded this option with a bare conductor. However, an insulated transmission system that is structurally integrated into the guideway design, such that it meets safety requirements, does not have the visual impact of an overhead line. This approach would likely obtain public and regulatory approval. It should be further noted that CDOT generally has a policy excluding electric transmission facilities from highway right-of-way. A transmission facility design that could potentially be exempted from this policy is the gas insulated transmission line (GIL). The electrification analysis defined a potential solution that incorporated the use of a gas-insulated transmission system incorporated within the guideway design. In the maglev system application, the steel enclosed GIL tubes would be mounted in between the east/west guideways in a triangular configuration, as shown in Figure B-27 below. The metal grating above the three GIL tubes serves as a passenger emergency exit path.

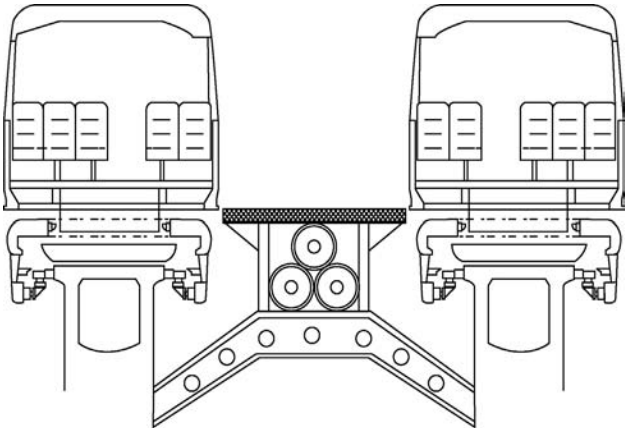


Figure B-27: GIL Transmission Shown Between Guideways

The electrical characteristics of the GIL are such that it lends itself very well to such a continuous run over long distances, without the need for any special vaults or terminations.

B.6. 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 60% of the overall cost of such a system, making them the single largest cost component. CHSST's standard guideway is shown in Figure B-28.

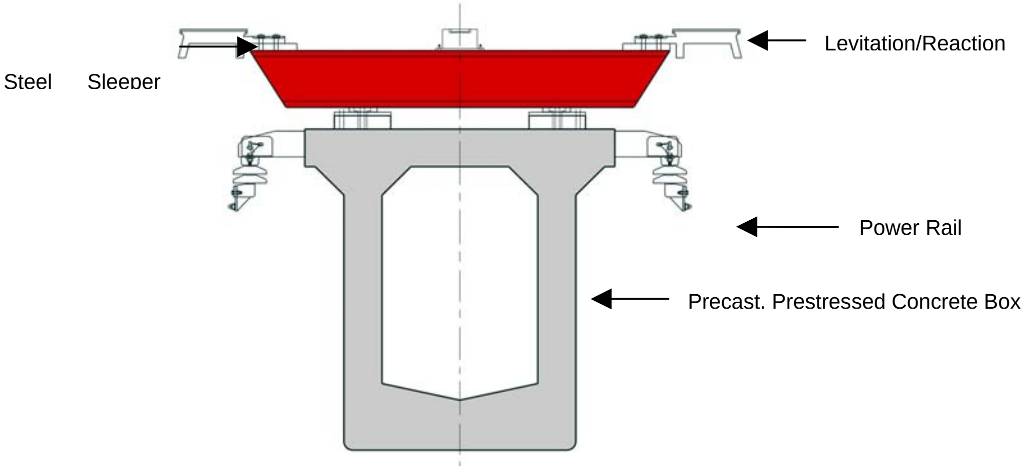


Figure B-28: CHSST Standard Guideway

A primary goal of the CMP is to develop economical and aesthetically pleasing guideway design concepts with estimates of probable cost considering the challenging environmental conditions of the I-70 corridor.

Numerous factors affect the cost of transit system guideways, which are essentially bridge structures equipped to carry the selected vehicle technology. These include general market conditions and labor, material and equipment costs, as well as specific site conditions affecting access and construction difficulty. Raw guideway construction costs have been estimated based on Colorado highway cost data and range between $10.7 million and $13.8 million for a standardized double-track guideway design applicable to the majority of the I-70 alignment. This cost range includes the beams, columns and foundations for the guideway. The cost of the required levitation and reaction rails and the power system and the emergency walkway must be added to these amounts, and are estimated separately.

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, three structural system concepts (see Figures A-9 through A-11) have been developed for spans in the range of 25 m (82 feet) to 30 m (98 feet). These concepts are:

- Concept A: Precast, prestressed concrete U-girder with precast concrete deck panels
- Concept B: Steel box girder with composite concrete deck slab
- Concept C: Tubular steel space truss

Although the tubular steel space truss offers potentially the most advantages in deployment, no single concept is likely to meet all requirements over the entire length of the unique Colorado system. 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 for these spans, where the use of falsework is feasible for construction. The cost premium for this type of structure, as compared with the standard guideway, is estimated to be approximately $10.6 million above the standard guideway cost estimate.

Like any transit system technology, switching is required to satisfy the operational needs of a maglev system. A high-speed pivoting guideway switch is shown in Figure B-29 and presented in detail in the final report in addition to discussions of both a low-speed and high-speed docking switch. The cost for each single-track pivoting switch utilized in the system is estimated to be $1.9 million over and above the cost of the standard guideway that would be replaced by the switch section.

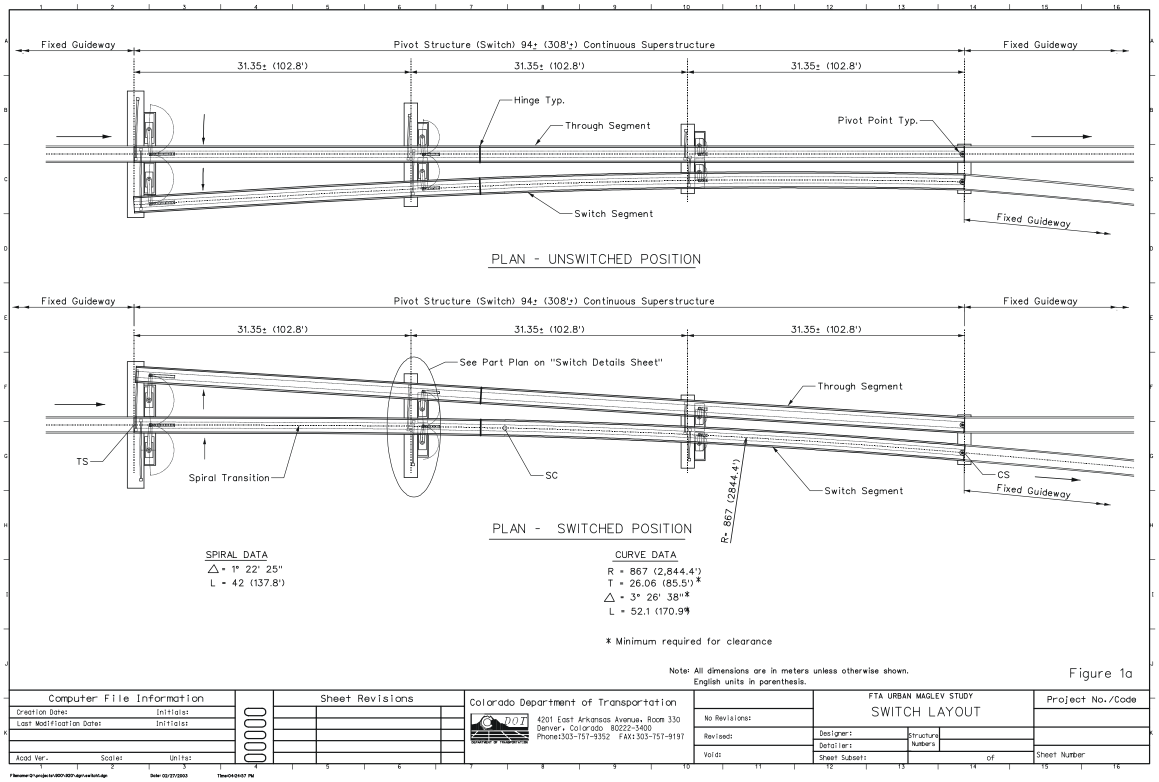


Figure B-29: High-Speed Pivoting Switch Layout

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 tenet. The ability to evacuate a disabled vehicle in an emergency, such as a fire, has been explored and several alternatives are feasible. The use of an auxiliary emergency walkway beam, as shown in Figure B-30, appears to be the most reliable approach, although this walkway would need to be installed along the full length of the alignment.

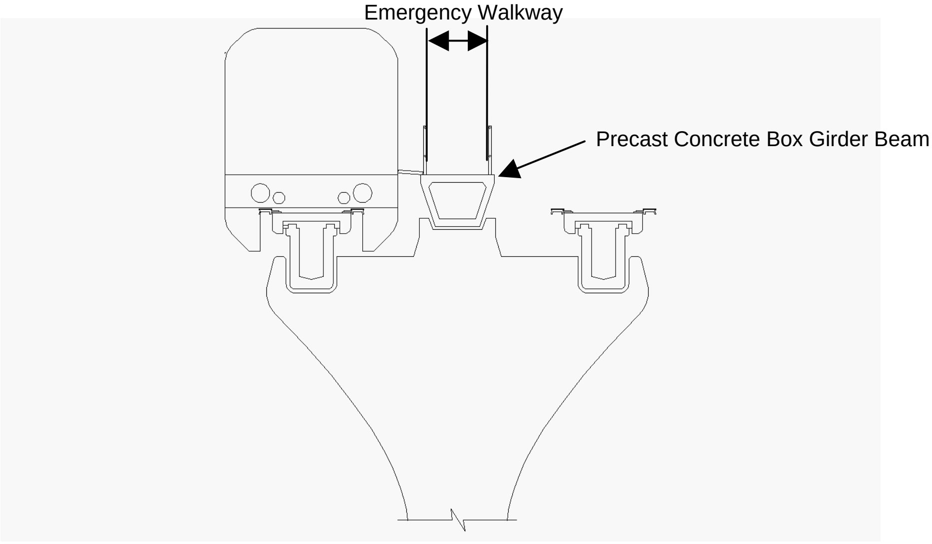


Figure B-30: Separated Walkway Beam

In the extreme environment of the mountain corridor along I-70, drainage on the guideway was evaluated. 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. 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.

Figure B-31: Avalanche Chute East of the Eisenhower Tunnel

Both avalanche sheds (Figure B-32) and fender systems (Figure B-33) have been considered as mitigation measures to protect the maglev guideway from destruction due to avalanche. The fender system can also be designed for use against rock falls as well as avalanches. The additional cost of providing the avalanche shed, which would provide the most reliable protection, is estimated to be $33.2 million per mile; if sheds are determined to be necessary. Only limited use of sheds, if any at all, is envisioned in Colorado.

Figure B-32: Avalanche shed located in the Swiss Alps

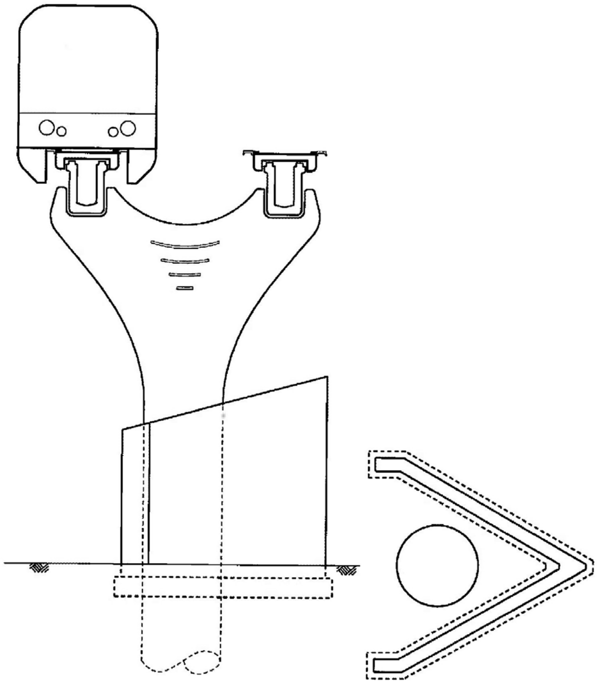


Figure B-33: Avalanche Fender

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 fully competitive with conventional transit technologies. In addition, the necessary safety and reliability characteristics can be achieved without serious cost implications: electrical transmission lines can be incorporated into the guideway design while using the path above the transmission line as an emergency walkway. The shared use of the guideway provides unique opportunities to share costs of the maglev system with utilities or other potential users of a shared right of way.

B.7. STATIONS

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 a maglev system 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" (i.e. stairs, elevators, escalators) to connect the platforms with tunnels under or bridges over the tracks.

For purposes of the research effort fourteen prospective stations were defined from DIA to Eagle County Airport including:

1. ***DIA*** (Denver International Airport, mile 0): This station represents one terminus of the entire system, serving the new Denver Airport.
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 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 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, 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, and Edwards.
14. ***Eagle County 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.

Three prototype stations have been identified as belonging to three main types:

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), as shown in Figure B-34, is integrated with the functional and aesthetic design of Denver International Airport 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.

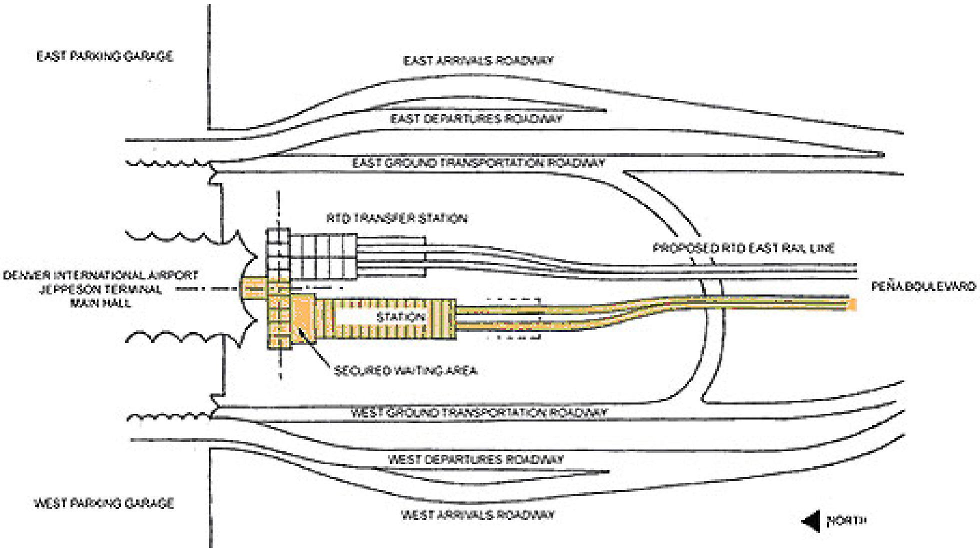


Figure B-34: Maglev Station Prototype 1 Terminal Station (DIA)

Urban/suburban collector station. This station type (Prototype 2), shown in Figure B-35, 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.

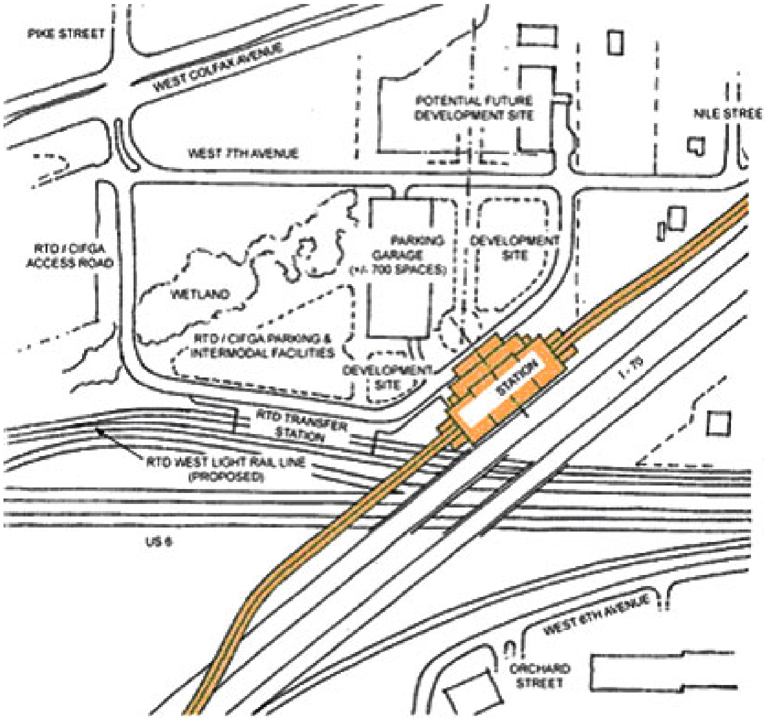


Figure B-35: Maglev Station Prototype 2 Urban/Suburban Prototype (West Denver Metro)

The rural destination station. This type of station (Prototype 3), shown in Figure B-36, 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.

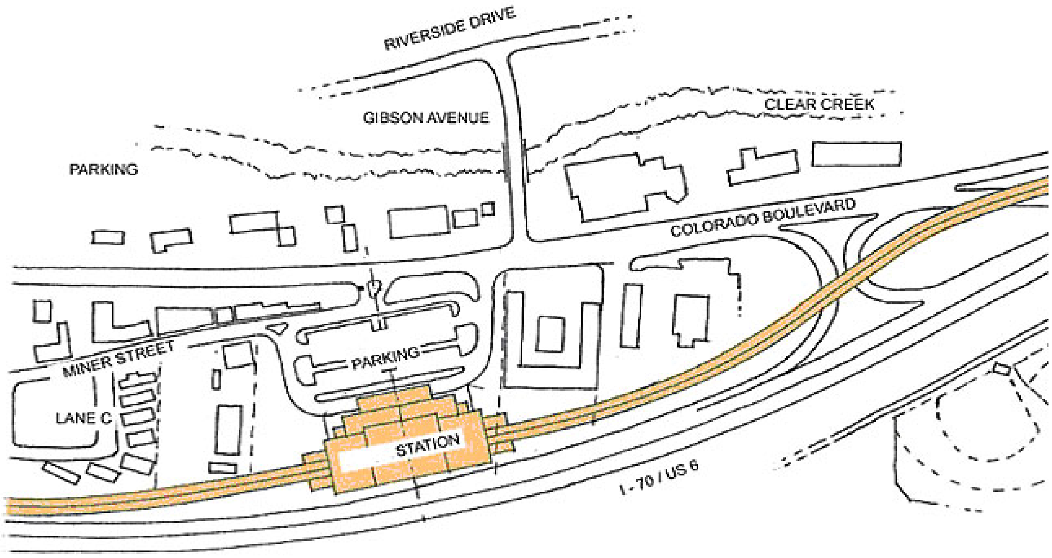


Figure B-36: Maglev Station Prototype 3 Rural Destination Prototype (Idaho Springs)

C.0 *COLORADO MAGLEV PROJECT DEPLOYMENT GUIDE*

The Deployment Guide describes the deployment process for the CMP. The objective of the Deployment Guide is to identify critical issues, phases and steps that are necessary for the successful implementation of the maglev system along the I-70 corridor.

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 all the cognizant entities must adhere to the long and complex process of certification and approval.

The following project deployment phases need to be completed:

Phase 1 Finalize Detailed Design and Cost

1. Public outreach
2. Identify first segment of maglev system
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

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 following technical issues and 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 3000 VDC 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.

In addition to the technical issues and modifications identified for the vehicle, another critical issue identified during the course of this analysis was the need to winterize the system. Winterizing the CMP is a critical issue 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^{o}C (54^{o}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.

Snow and ice have a tendency to build up on solid objects during the winter months. Much of the impact on a maglev system 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.

Switches are used along the guideway to move vehicles from one guideway to another or to reverse directions at the end of the line. To minimize the impact of snow and ice on switch guidance systems, heaters could be used to warm particular rail sections when there is substantial snowfall.

There are three independent braking systems on the Colorado 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.

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.

The second step in the creation of the Deployment Guide was the development of a rational plan for staged deployment.

The completed Staging Plan identifies 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 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. This Staging Plan is intended as an example of the approach to be followed in Deployment planning rather than an agreed to staging plan developed jointly by the various stakeholders involved in this process.

The CDOT PEIS consultant team has identified that the major congestion relief is needed between the C470/I-70 interchange and the EJMT and the CMP team concurs with this conclusion. 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 Colorado Maglev system would connect Golden and DIA.

For a complex project such as this, it is important to attempt to provide some reasonable expectation of implementation time and ancillary costs beyond the estimates of capital and operating costs. A considerable amount of effort must be expended over many years to fully implement such a potentially useful system.

Although the CHSST system technology is thoroughly proven, the technology must be applied in the Colorado Project through a system design and implementation process. The present research is the first step in such a process, but hardly the last. Further steps can be laid out, based on a three-stage implementation approach:

Stage 1

1. Route refinement
2. Station siting
3. Station design including station access design
4. Environmental studies
5. Public Hearings
6. System performance studies
7. System operational design
8. System safety planning

9. System performance targets
10. System infrastructure planning
11. System structural design (Guideway/Stations)
12. System electrical design (Guideway/Stations)
13. System manufacturing plan
14. Production vehicle design
15. Control system design
16. Right-of-way acquisition
17. First stage procurement
18. First stage construction
19. First stage integration and test
20. First stage certification
21. First stage acceptance

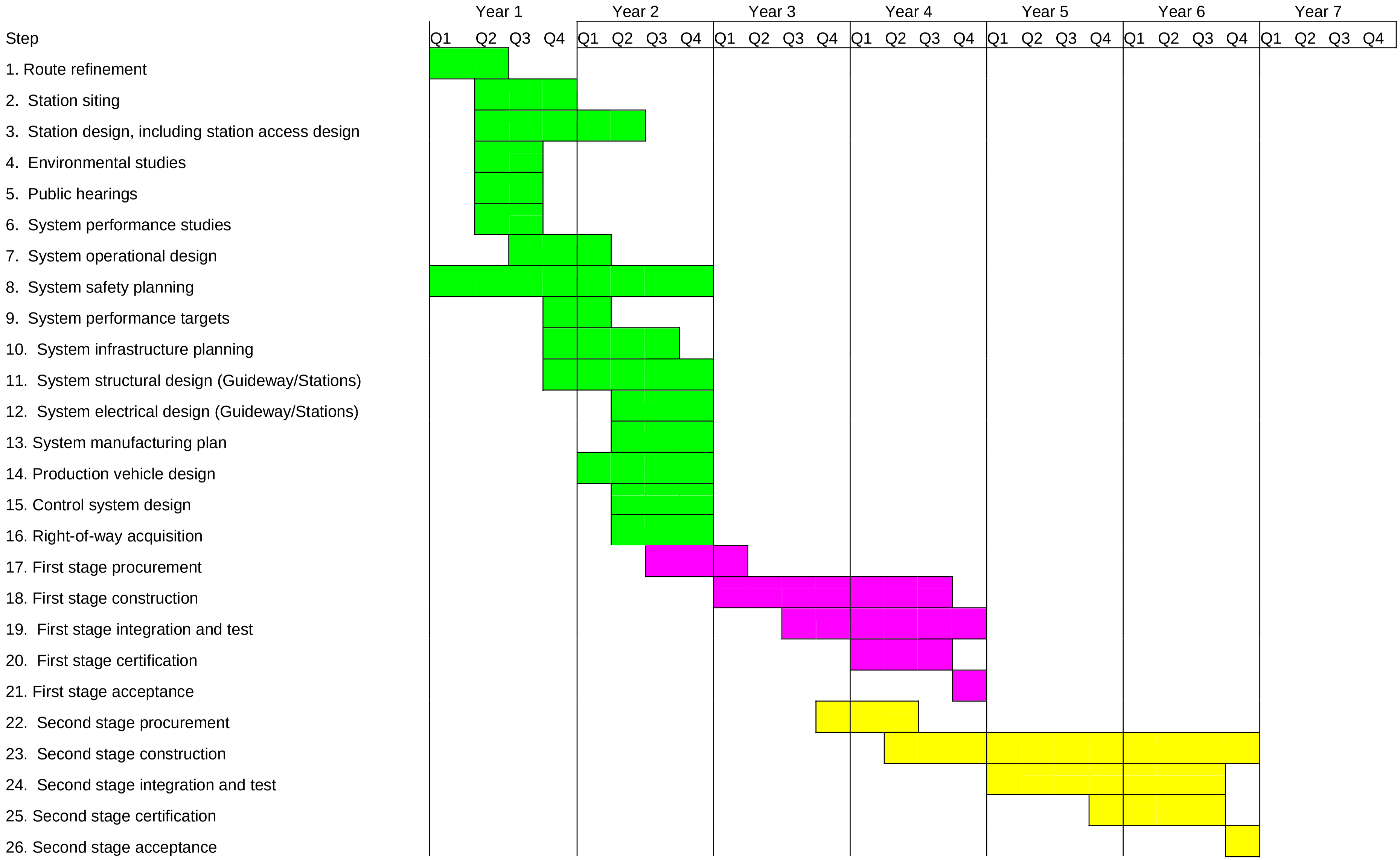
Stage 2

22. Second stage procurement
23. Second stage construction
24. Second stage integration and test
25. Second stage certification
26. Second stage acceptance

Stage 3

27. Final stage procurement
28. Final stage construction
29. Final stage integration and test
30. Final stage certification
31. Final stage acceptance

Steps 1 through 15 can be characterized as the design stage of the process. Depending on the scope, these steps can take up to two years to complete (when the entire system design is being produced). However, many of these steps can proceed in parallel. The approximate sequencing of these steps is shown in Figure B-37.



	Year 1				Year 2				Year 3				Year 4				Year 5				Year 6				Year 7			
Step	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Route refinement	🟩	🟩																										
2. Station siting		🟩	🟩	🟩																								
3. Station design, including station access design		🟩	🟩	🟩	🟩	🟩																						
4. Environmental studies		🟩	🟩																									
5. Public hearings		🟩	🟩																									
6. System performance studies		🟩	🟩																									
7. System operational design			🟩	🟩	🟩																							
8. System safety planning	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																				
9. System performance targets				🟩	🟩																							
10. System infrastructure planning				🟩	🟩	🟩	🟩																					
11. System structural design (Guideway/Stations)				🟩	🟩	🟩	🟩	🟩																				
12. System electrical design (Guideway/Stations)						🟩	🟩	🟩																				
13. System manufacturing plan						🟩	🟩	🟩																				
14. Production vehicle design					🟩	🟩	🟩	🟩																				
15. Control system design						🟩	🟩	🟩																				
16. Right-of-way acquisition						🟩	🟩	🟩																				
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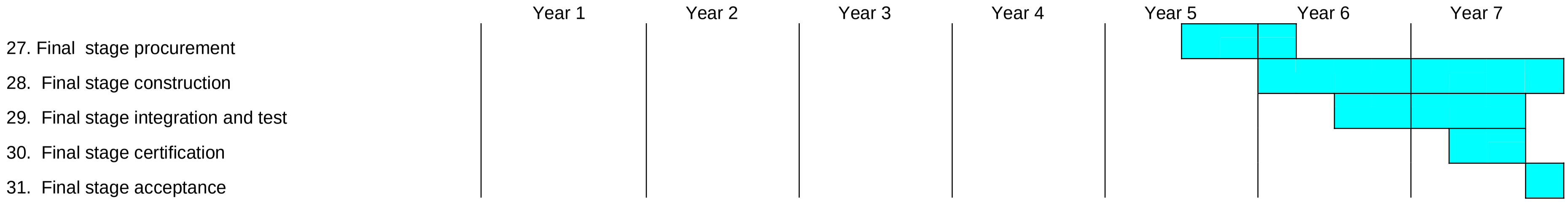


Figure B-37: Deployment Guide Sequence

Following these activities, procurement, construction, testing, certification, and acceptance would proceed by segment, with three basic stages envisioned for the process. The difficulties of each stage are different, and hence, overlap would occur among the stages. However, if so desired, each stage could be run sequentially, which would increase both the cost and time of execution of the project.

Basically, as laid out here, the first stage would correspond to the first segment, the second stage would carry the system to Frisco, including the transit of the Continental Divide, and the third would encompass the extension of the system on each end, to DIA and Eagle County Airport. Given that the second stage may require considerable tunneling, a three to four year period may be necessary for its completion, while the first stage could be complete in two years and the final stage in three. These time estimates assume the support of an adequate manufacturing plan. With this approach, the overall time span for the project would range from five to seven years.

Additional costs over and above the estimates previously given must fundamentally include the design costs associated with steps 1 through 15. Current estimates for these costs are between $400 and $600 million.

As part of the Staging Plan approaches to operation and maintenance have been developed and designated as the Systems Operation Plan which describes the plan for operating a maglev system for the entire length between DIA to Eagle County Airport; operations plans would be further developed for each individual segment as policy decisions are made on the construction staging. 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 system is designed for a maximum of 6,000 persons/hour per direction. The 2-car train, with a capacity of approximately 200 passengers will be operated at a minimum headway of 120 seconds. The train configuration of 2-car trains will not change throughout all service patterns. Train coupling during the service is not planned. There are no requirements for vehicle operating crews since the system is automated. The system functional organization is planned with two major divisions, administrative and operational, as shown in Figure B-38.

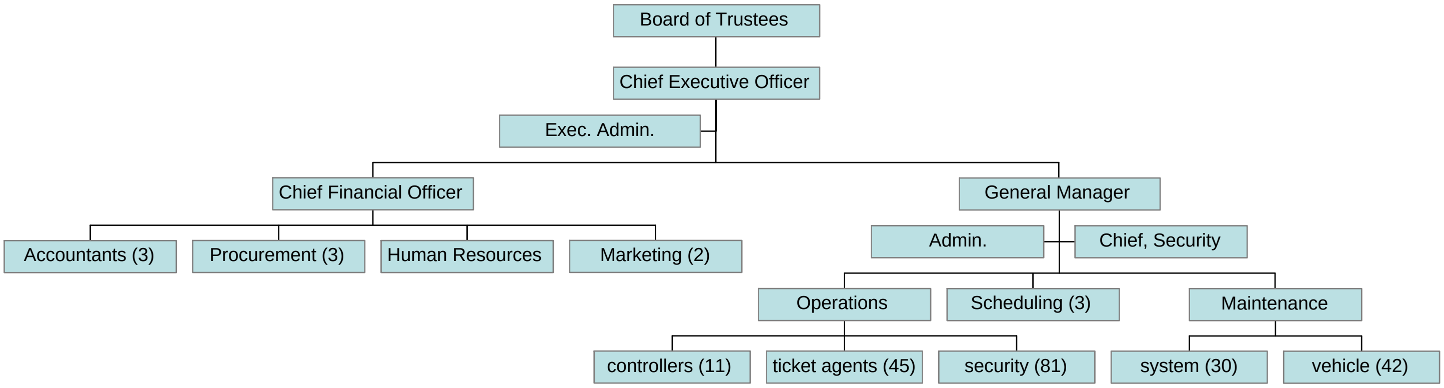
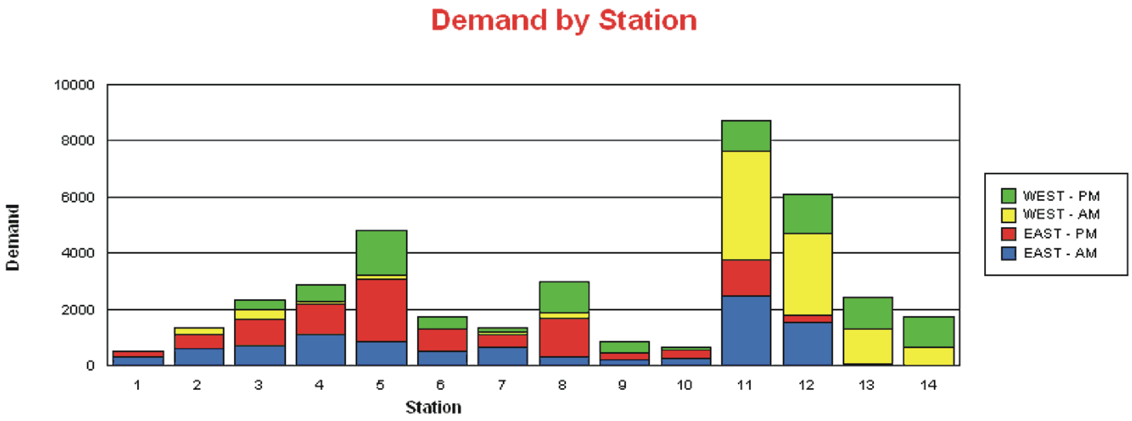


Figure B-38: System Organizational Chart

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.

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 is to be offered. For a winter Saturday, the projected system demand, morning and afternoon, is shown in Figure B-39.



STATION

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
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 B-39: Eastbound and Westbound Passenger Demand by Season and Time-of-Day

The number of trains needed to handle the passenger demand through purely local service is shown in Figures B-40 and B-41.

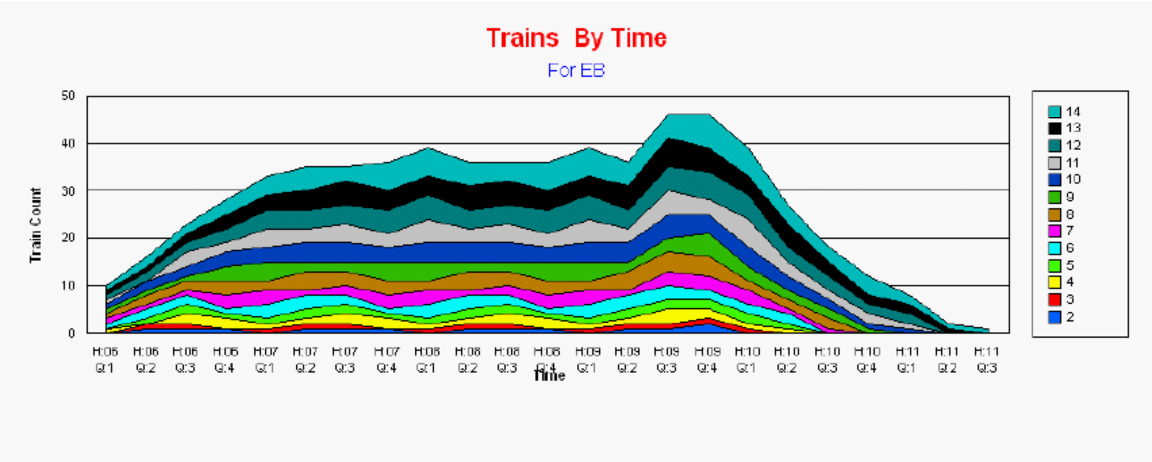


Figure B-40: Winter Saturday Eastbound Morning Trains

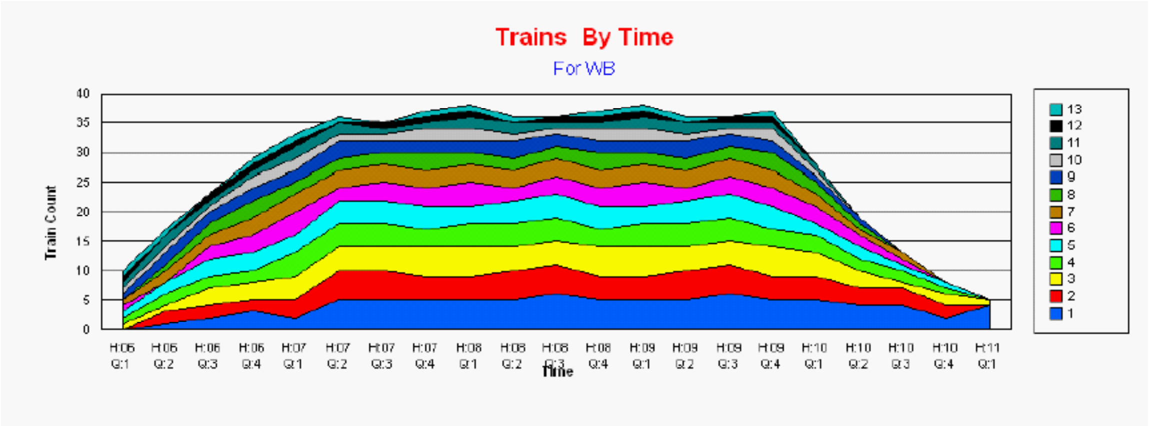


Figure B-41: Winter Saturday Westbound Morning Trains

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)

Operational safety measures such as emergency responses may be subject to regulatory acts, government policies and local ordinances. The Safety Program 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.

Finally, the CMP Deployment Guide provides the sequence of events and subsidiary supporting documentation, which are integral components of deployment. A necessary 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.

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.

The following elements will need to be completed and established for the CMP certification:

1. System Safety Program Plan (SSPP)
   The SSPP ensures 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.

2. 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.

3. Safety Review Committee
   The Safety Review Committee (SRC) is responsible for assessing hazards and overseeing compliance with the Safety Certification Program.

4. 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.

5. 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. A Hazard Identification, Analysis and Resolution Plan will be developed for the Project.

6. Safety Certification Plan
   The Safety Certification Plan 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.

C.1. COLORADO MAGLEV PROJECT COSTS

A cost analysis of capital costs has been completed. Maintenance planning has also been developed to support an operational plan, in order to estimate the operation and maintenance (O&M) costs. These costs are presented as Year 2003 dollars with no further economic escalation factors taken into account. Simple contingencies have been added to account for potential uncertainties in some estimates. The contingencies are ample, and consistent with the experience of the estimators. The methodology used to develop these estimates is described in the Final Report. An M following the Table number indicates that the cost is given in millions.

Capital costs include initial costs of establishing the vehicle fleet, guideway construction, station construction and maintenance facility construction. The total system capital cost has been estimated for building a maglev system from DIA to Eagle County Airport and is summarized in Table C-1.

Table C-1 Maglev System Capital Costs

Major System Elements	Unit Costs
Guideway	Standard Guideway $10.7-13.8 M, per mile Exceptional Guideway (Long Span Bridges, Curves) $24.4 M, per mile
Rails	$1.6 M, per mile
Switches	$2.6 M, each
Stations	$30 M, each
Vehicles	$7 M, per consist
Communication Controls	$2 M, per mile
Power Substations	$4 M, per substation
Electrification	$1 M, per mile

*Aggregated Capital Costs:
System Parameters:
Total Guideway Length – 252.6 kilometers/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)[4]
Rails	$251 M	

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[4] $32M per mile includes the use of the dedicated EJMT tunnel. Use of the higher tunneling alternative reduces the per mile cost to $31M.

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 per mile	$30 M	(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.

The estimated operating costs for selected key operating cost elements for the CMP are summarized in Table C-2

Table C-2 Projected Total Annual Operating Cost Elements

Salaries / Benefits	$13,437,000
Electricity	$13,861,000

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.

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.

Scheduled 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. Unscheduled 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. 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.

The staff requirements have been estimated based on the vehicle fleet requirements, the route with its difficult terrain and weather, and the initial Mean Time Between Failures (MTBFs) calculations.

The CMP operation is automated with no drivers on the vehicles. For safety and security situations that may occur on trains, the staffing requirement assumes one maintenance professional assigned to each station during operating hours. This will provide system personnel at each station with immediate access to situations where trains are located between stations and require emergency personnel. Also the trains will have communications availability between the trains and the system control center to allow for direct communications between passengers and system operating personnel.

Table C-3 summarizes the O&M cost estimates.

Table C-3 Operation and Maintenance Cost Summary

Items	Cost 2003$
1. Personnel Cost	
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
2. Energy Expenses	
A. System	$ 13,451,000
B. Stations and O&M Facilities	$ 410,000
3. Maintenance Materials (Parts) Expenses	
A. System	$ 3,000,000
5. Other Expenses	$ 12,700,000
A. Station usage fees	
B. Guideway usage fees	
C. Insurance	
D. Taxes	
E. Office rent	
F. Other	
TOTAL O&M COST	$ 42,998,000
6. Expense Contingency (Up to l0% on the total expenses)	
TOTAL O&M COST PLUS CONTINGENCY	$ 47,298,000

D.0 *CONCLUSIONS*

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* <u>or $47 million per year with contingency</u>.
- 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.