THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

GUIDEBOOK
Use of Highway ROW for High-Speed Intercity Passenger Rail and Dedicated Freight Transportation Systems

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GUIDEBOOK: Use of Highway ROW for High-Speed Intercity Passenger Rail and Dedicated Freight Transportation Systems

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TxDOT Project 0-6698: Examining the Use of Existing Public Rights-of-Way for High-Speed Rail or Other Infrastructure

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Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AREMA	American Railway Engineering and Maintenance of Way Association
CHSRA	California High-Speed Rail Authority
DFO	Distance from origin
DMU	Diesel multiple unit
DOT	Department of Transportation
EIS	Environmental Impact Statements
EIR	Environmental Impact Report
EMU	Electric multiple unit
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GIS	Geographic information systems
HSIPR	High-speed intercity passenger rail
HSR	High-speed rail
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
ROW	Right-of-way
SNCF	Société Nationale des Chemins de fer Français (French National Railway Company)
SWSR	Steel wheel on steel rail
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation

Section 1. Introduction

1.1 Purpose and Content of Guidebook

The purpose of this guidebook is to help TxDOT staff evaluate proposals for using new or existing highway right-of-way (ROW) for high-speed intercity passenger rail (HSIPR) or dedicated freight transportation systems. This guidebook is intended to provide the foundation for a new manual covering such evaluations.

The Federal Railroad Administration (FRA) lists four types of intercity passenger rail corridors for high-speed rail (HSR) planning purposes (FRA, 2009). HSIPR for this guidebook is defined as an "express" service.

- **HSR – Express:** Frequent, express service between major population centers 200–600 miles apart, with few intermediate stops. Top speeds of at least 150 miles per hour (mph) on completely grade-separated, dedicated ROW (with the possible exception of some shared track in terminal areas). It is intended to relieve air and highway capacity constraints.
- **HSR – Regional:** Relatively frequent service between major and moderate population centers 100–500 miles apart, with some intermediate stops. Top speeds of 110–150 mph, grade-separated, with some dedicated and some shared track (using positive train control technology). It is intended to relieve highway and, to some extent, air capacity constraints.
- **Emerging HSR:** Developing corridors of 100–500 miles, with strong potential for future HSR Regional and/or Express service. Top speeds of up to 90–110 mph on primarily shared track (eventually using positive train control technology), with advanced grade crossing protection or separation. It is intended to develop the passenger rail market, and provide some relief to other modes.
- **Conventional Rail:** Traditional intercity passenger rail services of more than 100 miles with as little as one to as many as 7–12 daily frequencies; may or may not have strong potential for future HSR service. Top speeds of up to 79 mph to as high as 90 mph generally on shared track. It is intended to provide travel options and to develop the passenger rail market for further development in the future.

A dedicated freight transportation system refers to a system of guideways and vehicles intended only for freight movement, such as the freight shuttle system (Roop et al., 2003).

This guidebook consists of the following sections after the section 1 introduction:

- Section 2 reviews the legal and administrative considerations of using existing highway ROW.
- Section 3 describes the design requirements for different HSIPR and freight technologies, a feasibility analysis methodology, and the conditions of approval needed for projects.
- Section 4 presents highway and road design criteria that accommodate potential co-location with HSIPR or dedicated freight transportation systems.

- Section 5 identifies procedures used by other state DOTs for use of ROW for innovative transportation systems.
- Section 6 synthesizes information from DOTs, past reports, and published literature regarding capturing revenue, matching grants or entering into private-public partnerships for use of state DOT ROW for HSIPR and dedicated freight transportation systems.

1.2 Examples of HSIPR in Highway ROW

Interest in the use of existing ROW, especially highway ROW, for adding transportation options such as HSIPR is increasing because of the technical, financial, and political difficulties of carving out space for new transportation corridors. The Transit Cooperative Research Program released TCRP Report 145 titled *Reinventing the Urban Interstate: A New Paradigm for Multimodal Corridors* (Ferrell, et al., 2011) that evaluated the potential and strategies to create multimodal highways, one of many signs that co-location of different transportation modes within one corridor should be considered by DOTs. Additionally, the Federal Highway Administration (FHWA) prepared a report that examined potential futures uses of highway ROW, and specifically listed rapid transit and the freight shuttle as possible uses (Federal Highway Administration 2012).

A review of the existing and proposed HSIPR lines being built inside and outside the US shows an increasing use of land adjacent to or within existing ROW, specifically highway ROW, for HSIPR lines primarily to prevent impacts on the environment, communities, and freight rail operations. In Europe and in international news sources, the co-location of HSIPR with roadways has been referred to as *road-rail parallel layout*.

For example, Table 1 presents the US HSIPR projects proposing use of highway ROW. As of this time, the only US project considering co-locating a dedicated freight transportation system within highway ROW only is the freight shuttle proposed for Texas highways by the Texas A&M Transportation Institute (TTI).

Table 2 presents the HSIPR lines in other countries already in operation or proposed for operation adjacent to and within highway ROW for notable distances.

There is a history in Texas of considering use of highway ROW for HSIPR and dedicated freight transportation systems. Those projects are discussed in Section 1.3.

Table 1. HSIPR Projects Considered for Existing Highway ROW

Location	HSIPR Technology	Highway ROW	2011 Status
Philadelphia, PA-Atlantic City, NJ	Maglev	Median of I-295 and RT 42 in the Atlantic City Expressway	The proposed highway that the maglev would have operated alongside was not built because of opposition concerned with environmental impacts of the new transportation corridor. No studies have been completed.
Northern New Jersey (New Jersey Turnpike Authority)	Rail	Median of proposed Alfred E Driscoll Expressway	The 1970s plan for proposed Alfred E. Driscoll Expressway was dropped and the acquired ROW was sold in the late 1980s (Eastern Roads, 2010).
New York City, NY – Montreal, Quebec, Canada (State of New York)	Rail	I-87	Pre-feasibility study completed in February 2004 excluded use of I-87 ROW from consideration because of concerns about the steep grades and sharp curves (Parsons-Clough Harbour, 2004).
Baltimore, MD-Washington, D.C. (Maryland Transit Administration (MTA))	Maglev	I-95, Baltimore Washington Parkway	I-95 and Baltimore Washington Parkway were both dropped as alternatives during the scoping process (Maryland Transit Administration, n.d.).
Tampa, FL- Orlando, FL- Miami, FL (Florida HSIPR Authority (FHRSA))	Rail and maglev	I-4, Florida turnpike, I-95	Draft EIS completed for I-4 in 2005 (Florida High-Speed Rail Authority, 2005). Planning study for Ronald Reagan Turnpike and I-95 completed in March 2003. EIS updated in 2009 (Florida Department of Transportation, 2009) and federal funding received; however, funding offer was declined by the Governor.
Denver, CO area (Rocky Mountain Rail Authority (RMRA))	Rail and maglev	I-70, I-76 and I-25	Feasibility study completed in 2010 (Transportation Economics & Management Systems, Inc., 2010).
Los Angeles, CA- Las Vegas, NV (DesertXpress Enterprises, LLC	Rail	I-15	Draft EIS for steel-wheel on steel-rail technology (DesertXpress) completed in March 2009 (Federal Railroad Administration, California DOT and Nevada DOT, 2009).
California-Nevada SuperSpeed Commission (CNSSC)	Maglev	I-15	Environmental review not completed.
San Francisco, CA-San Diego, CA (California HSIPR Authority (CHSIPRA))	Rail	I-5, US 101,SR 99 and other multiple state highway routes	EIS in process for segments of route (California High Speed Rail Authority, 2008) and received federal funding (Wall, Rachel, California High-Speed Rail Authority, 2011).

Location	HSIPR Technology	Highway ROW	2011 Status
West Los Angeles, CA – Ontario Airport, CA (Southern California Association of Governments (SCAG))	Rail	I-10	Feasibility study completed in 2009 at the request of SCAG (Cambridge Systematics, Inc., 2009).
Detroit- Lansing, MI (Interstate Traveler Company, LLC)	Maglev	I-96	Feasibility study not yet completed. Michigan House and Senate reviewed conceptual proposal in 2003 and issued resolutions to US Congress requesting support for research and development of the Interstate Traveler system in the TEA-21 legislation. No action, funding, or studies have been completed (Interstate Traveler Company, LLC, 2011).
Southeast HSIPR Corridor (Georgia to North Carolina Link) (Georgia DOT)	Rail	I-75, I-85	A 2008 initial planning and feasibility study for the segment connecting Charlotte, NC to the cities of Atlanta and Macon in Georgia examined the feasibility of routing alternatives (Volpe National Transportation Systems Center, 2008).
Texas Triangle Dallas/Fort Worth – San Antonio-Houston, TX (TxDOT)	Rail	I-35, I-45, I-10, I-20	Feasibility study completed at the request of the State Highway and Public Transportation Department in 1985 (Peterson, et al., 1985); another completed in 2010 for I-35 only as a thesis (Larsen, 2010).

(Source: Larsen [2010], updated)

Table 2. HSIPR Lines Adjacent to or Within Existing Highway ROW

Country	Description
China	The Shanghai Maglev operates within the median (Figure 1) and along the north side (Figure 2) of Yingbin Freeway, and within new and other roadway ROW for a portion of the 19-mile route between the Pudong Airport and Shanghai. The maglev started revenue service in 2004, travels to a maximum speed of 267 mph, has 10–20-minute headways, and a total trip time of 8 minutes.
France	The first TGV route (the Paris Sud East) started operation in the early 1980s and runs between Paris and Lyon parallel to existing motorways for only 14% (60 km) of the total route. Increasing concerns regarding the land use and environmental impacts of new HSIPR lines led to an increased percentage of French TGV routes operating within or parallel to existing motorway, railway, or abandoned railway corridors. Operational since 1989, the TGV-Atlantique follows existing ROW, such as abandoned and existing rail ROW or motorway ROW, for nearly 60% of its length from Paris to Courtalain (Streeter, 1992). The Paris to Lille TGV Nord line that began operation in 1993 operates parallel to motorways for 41% (135 km) of the total route length (International Union of Railways, 2010). Another rail line operates parallel to A432 (Figure 3).
Germany	The Cologne-Frankfurt ICE route consists predominately of new, dedicated track, and 140 km of the route (71% of the total route) parallels the A3 autobahn (see Figure 4) (International Union of Railways, 2010). A new high-speed line proposed between Wendlingen and Ulm, Germany, would also have many segments adjacent to the A8 autobahn (Deutsche Bahn AG, 2011)
United Kingdom	To provide a faster connection from London to the Channel Tunnel, a channel tunnel rail link, currently managed by High Speed 1, was constructed and began HSIPR operation in 2003 (Figure 5). For much of the distance, the rail link is adjacent to the M20 motorway and the A20 trunk road. A total of 60% of the route (55km) is within existing road or rail transportation corridors (Omega Centre, n.d.).
Italy	To minimize land acquisition and environmental impacts, the Italian HSIPR system predominately operates adjacent to existing motorways. For instance, 71% of the Milan (Milano) to Bologna HSIPR route parallels the A1 autostrada for 130 km (about 80 miles) (International Union of Railways, 2010). Figure 6 shows the Milan-Bologna HSIPR tracks within close proximity of the highway. The Turin (Turino) to Milan line segment runs adjacent to the A4 autostrada.
Sweden	The European Corridor is a proposed high-speed transportation system to link Sweden's metropolitan areas with each other and with continental Europe (Europakorridoren AB, 2011). The corridor would consist of the expansion of two rail lines tentatively proposed to both operate adjacent to highways. The European Line would link Stockholm, Sweden, with Jonkoping (Sweden), Copenhagen (Denmark), and Hamburg (Germany) with a HSIPR line that follows the E4 motorway. The Gotaland Line is an east-west route between Stockholm and Goteborg Sweden adjacent to the "riksvag" 40 motorway (Europakorridoren AB, 2011).

Figure 1. Transrapid Maglev in the Median of the Yingbin Freeway in Shanghai, China
(Source: Google Earth)

Figure 2. Transrapid Maglev Parallel to the Yingbin Freeway in Shanghai, China
(Source: Google Earth)

Figure 3. French TGV Route Parallel to Highway A432 near Lyon, France
(Source: Google Earth)

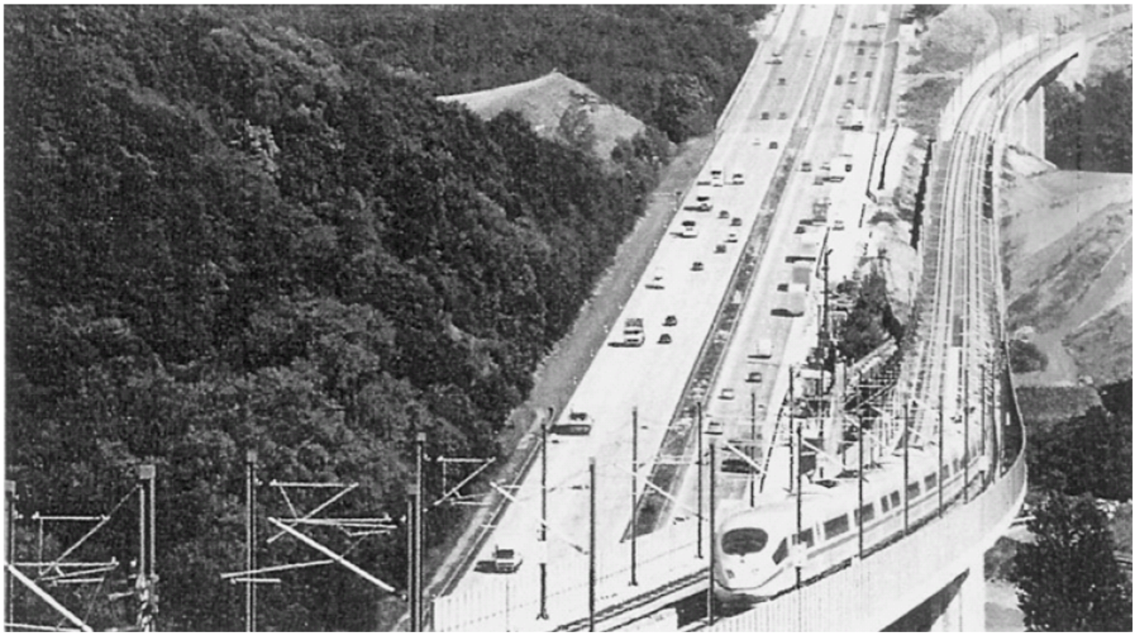


Figure 4. A German ICE Train Parallel to the A3 Autobahn between Cologne and Frankfurt

(Source: Ebeling, 2005)

Figure 5. HSIPR (High Speed 1) in the UK

(Source: http://highspeed1.co.uk/business-updates/hs1-ltd-publishes-freight-access-terms)

Figure 6. Milan-Bologna Italian HSIPR Tracks Adjacent to A1 Autostrada
(Source: http://en.wikipedia.org/wiki/File:Pieve_Fissiraga_ferrovia_autostrada_1.JPG)

1.3 Accommodation of Rail in New Highway Construction Projects

The idea of multimodal highway corridors is not new to Texas, conceptually or in actuality. Several initiatives in Texas promoted multimodal corridors and the constructed State Highway (SH) 130 project in Central Texas east of Austin incorporated in the design potential co-location of rail with the highway.

1.3.1 Multimodal Corridors

Several initiatives and reports advocated for the creation of new multimodal corridors that co-locate highway, rail, and utilities. The most recent concept of a *new* multimodal corridor system crossing Texas, eventually referred to as the Trans-Texas Corridor (TTC), motivated the passage of House Bill (HB) 3588 by the 78th Texas Legislature to establish, construct, and operate the 4,000-mile-long TTC. The TTC would have created a multimodal corridor, up to 1200 feet wide, of highways, railways, and pipelines in newly acquired ROW.

The idea of a multimodal "supercorridor" for Texas pre-dates passage of HB 3588 and the TTC. McCullough, et al. (1996) proposed and evaluated the following three alternatives to help alleviate congestion for the rural parts of I-35:

1. Add lanes to I-35

2. Retrofit I-35 with an intelligent transportation system (ITS) and add separate wider traffic lanes for heavy trucks

3. Build a separate managed transportation system (MTS)

Of those three alternatives, only the third envisioned possible future inclusion of rail within the corridor (Figure 7 and Figure 8).

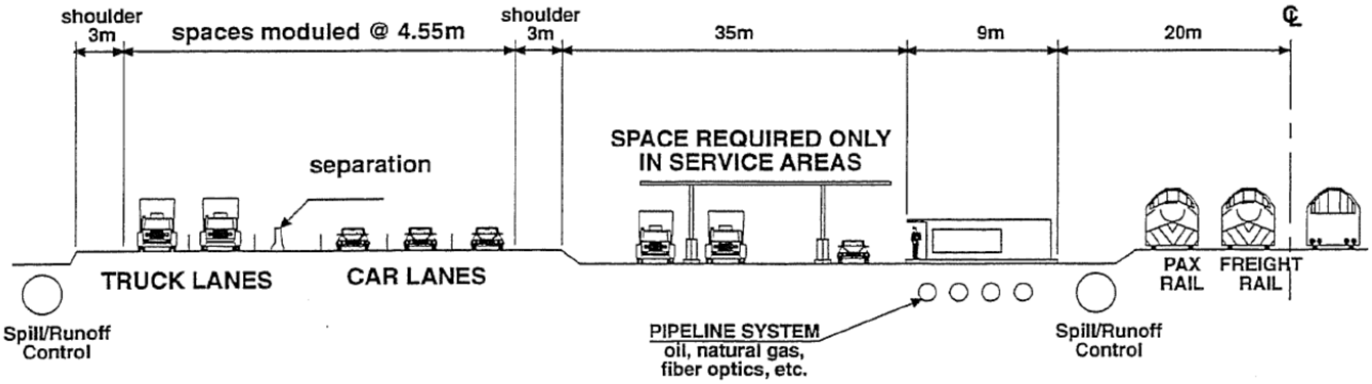


Figure 7. Conceptual Cross Section of the MTS Approach to Capacity
(Source: McCullough, et al., 1996)

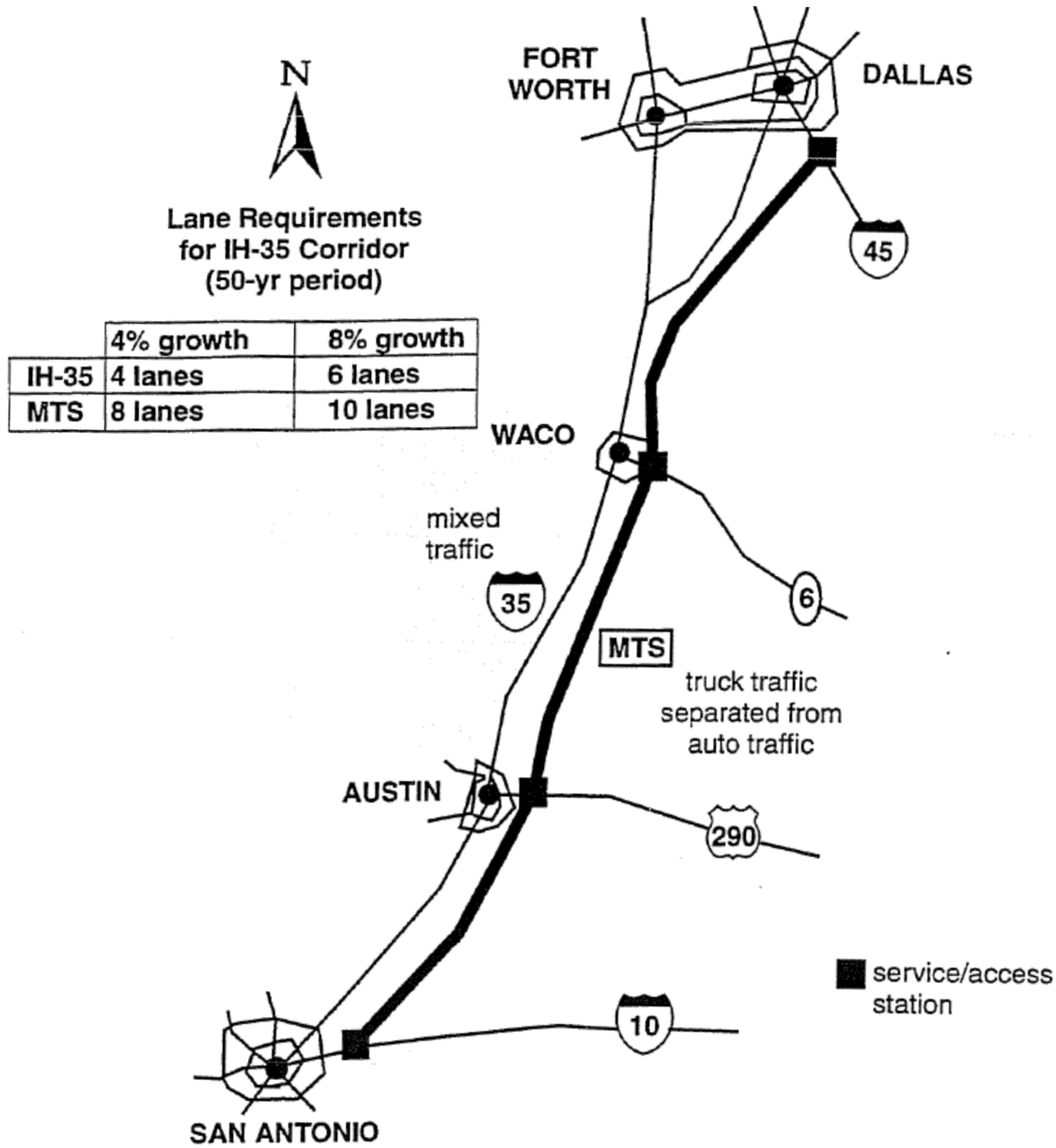


Figure 8. MTS Configuration between San Antonio and Dallas/Ft. Worth
(Source: McCullough, et al., 1996)

In response to concerns about the TTC, the Texas Transportation Commission appointed 18 citizens to an I-35 Corridor Advisory Committee in March of 2008. The Committee released a report titled *A Citizen's Report on the Current and Future Needs of the I-35 Corridor* in November 2008 stating that "this advisory committee does not support the TTC concept. Instead we recommend a more inclusive solution that respects local communities and private property rights while addressing statewide and local transportation needs" (I-35 Corridor Advisory Committee, 2008). TxDOT ended the TTC program in January 2009.

The Corridor Advisory Committee established principles in their report, with two in particular advising a solution that is the focus of this TxDOT research project (I-35 Corridor Advisory Committee, 2008):

- *Alternative modes should be a part of any future development plans for the I-35 Corridor*. Given current freight and passenger traffic, a road-only option will not sustain projected growth. Rail alternatives, technology improvements, and other transportation advances should be explored to their fullest potential for the corridor.
- *The use of existing ROW wherever possible should be considered first.* Where the route must follow the existing alignment and additional ROW is necessary, acquisitions should be limited in nature. For new alignments, local elected officials should fully vet alternatives and decisions so that the best choices are made for the benefit all of the users of I-35. In all cases, efforts should be made to minimize the impact to private property owners.

1.3.2 State Highway 130

TxDOT required that the new SH 130 Segments 1 through 4 in Central Texas be designed and constructed according to rail compatibility requirements to allow for potential use by passenger or freight rail (see Figures 9 and 10). The engineers were required to produce rail compatibility reports for each segment demonstrating the feasibility of the inclusion of rail, although feasibility did not necessarily consider rail construction costs or optimum operations. Unfortunately, the rail compatibility requirements were not contractually extended for the design and construction of segments 5 and 6, and a 2008 report prepared for the Austin/San Antonio Intermunicipal Commuter Rail District (now called the Lone Star Rail District) determined segments 5 and 6, as designed at the time of the report, were unable to support the inclusion of rail because of inadequate vertical clearances and bridge obstructions at SH 45 and SH 182 interchanges (Jacobs Carter Burgess, 2008).

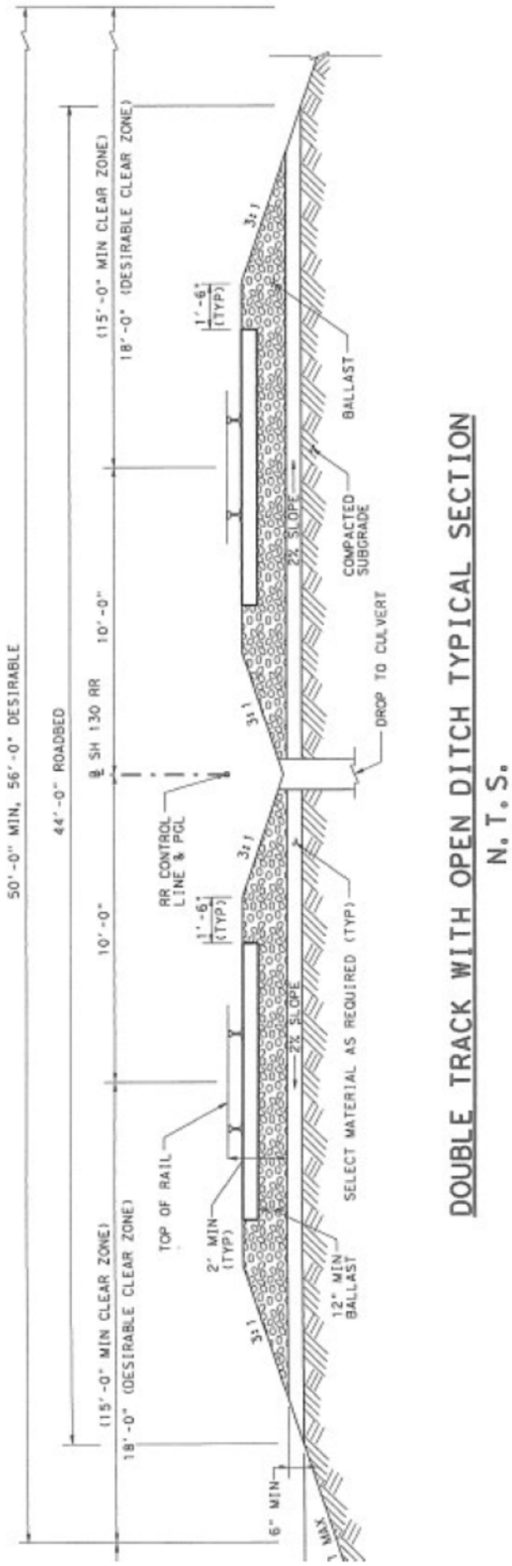


Figure 9. Preferred Double-Track Design for Rail in SH 130 ROW

(Source: Jacobs Carter Burgess, 2008)

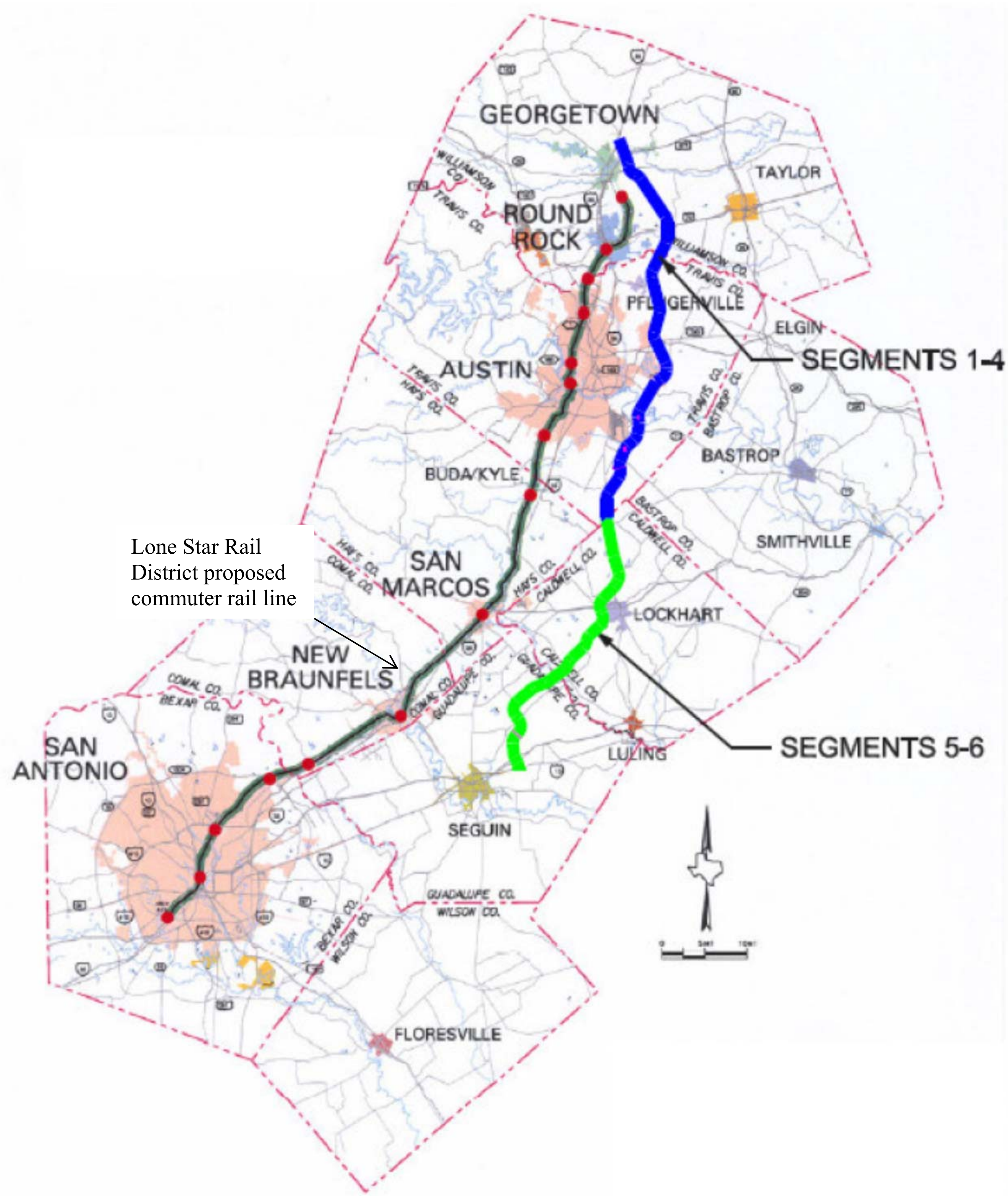


Figure 10. SH 130 Segments
(Source: Jacobs Carter Burgess, 2008)

Section 2. Legal and Administrative Considerations

Section 2 presents the following legal and administrative considerations for HSIPR or dedicated freight transportation systems:

- existing row manuals at other state dots that address use of state dot row,
- existing federal, state, and local regulations regarding the use of txdot's row for hsipr and dedicated freight transportation,
- federal legislation regarding the use of dot real-estate assets purchased with federal funds, and
- environmental reviews unique to utilizing existing ROW.

2.1 State ROW Manuals

This section is intended to put use of existing ROW within the context of how other states handle such requests. Many state DOTs organize their requirements for ROW-related matters in manuals with procedures and policies intended to comply with Uniform Relocation Assistance and Real Property Acquisition Act of 1970, and other federal rules and regulations. The FHWA can officially approve the manuals for compliance. The ROW manuals typically cover the following topics:

- appraisal,
- acquisition,
- relocation,
- legal issues, and
- property management.

Table 3 lists all the states and whether they have ROW manuals or similar sources of ROW information. Of all the state DOTs with manuals, none explicitly discuss the use of existing ROW for HSIPR or dedicated freight transportation, except in Section 10.9 of Florida's ROW manual (revised May 30, 2013), where it states in section 10.9.1.3 that "consideration of any proposed lease involving rail, aviation, or mass transit shall be coordinated with FDOT's State Freight & Logistics Administrator prior to advertisement soliciting additional joint use proposals" (10-9-3). Less directly, several states (e.g., California, Hawaii, Idaho, Maine, Massachusetts, and Montana) discuss airspace leasing in their ROW manuals that has relevance at least to the use of highway ROW for HSIPR or dedicated freight transportation system facilities. TxDOT offers a manual titled *Use of Right of Way by Others* that other states appear to not offer; however, the manual does not explicitly mention rail. Section 5.2 of this guidebook describes the TxDOT manual in more detail.

Table 3. ROW Manuals by State

State (linked)	ROW manual	ROW website	
Alabama	Yes	Yes	http://www.dot.state.al.us/rwweb/proceduralmanuals.html
Alaska	Yes	Yes	http://www.dot.state.ak.us/stwddes/dcsrow/pop_rowmanual.shtml
Arkansas	Yes	Yes	http://www.arkansashighways.com/right_of_way_division/ROWManual%20Final.pdf
Arizona	Yes	Yes	http://www.azdot.gov/business/RightofWay_Properties
California	Yes	Yes	http://www.dot.ca.gov/hq/row/
Colorado	Yes	Yes	http://www.coloradodot.info/business/manuals/right-of-way
Connecticut	No	No	
Washington DC	Yes	Yes	http://dc.gov/DC/DDOT/Projects+and+Planning/Standards+and+Guidelines/Right+of+Way+Manual
Delaware	No	Yes	http://www.deldot.gov/information/business/drc/rightofway.shtml
Florida	Yes	Yes	http://www.dot.state.fl.us/rightofway/ProceduresManual.shtm
Georgia	Yes	Yes	http://www.dot.ga.gov/localgovernment/row/Pages/default.aspx
Hawaii	Yes	No	http://hidot.hawaii.gov/highways/files/2012/10/ROW-MANUAL-2011.pdf
Iowa	Yes	Yes	http://www.iowadot.gov/rightofway/sections.html
Idaho	Yes	Yes	http://itd.idaho.gov/row/new/ http://www.itd.idaho.gov/manuals/ManualsOnline.htm
Illinois	Yes	No	Land Acquisition Manual only: http://www.dot.state.il.us/landacq/lamanual/land%20acquisition%20manual.pdf Right of Way Engineering Policies and Procedures: http://www.dot.state.il.us/landacq/lamanual/Chapter1/Chapter%201%20Text.pdf
Indiana	Yes	No	ROW Design: http://www.in.gov/dot/div/contracts/standards/dm/2011/Part9/Ch85/ch85.htm
Kansas	No	Yes	http://www.ksdot.org/burRow/default.asp ROW Acquisition Guide for Local Public Agencies http://www.ksdot.org/burlocalproj/LPA/Requirements/LPA_ROW_Manual.pdf
Kentucky	Yes	Yes	http://transportation.ky.gov/right-of-way-and-utilities/Pages/default.aspx
Louisiana	No	Yes	Right-of-way Permits website: http://www.dotd.la.gov/highways/maintenance/maintmgt/home.aspx
Massachusetts	Yes	Yes	http://www.mhd.state.ma.us/default.asp?pgid=rowIndex&sid=level2
Maryland	No	No	
Maine	Yes	Yes	http://www.maine.gov/mdot/technicalpubs/row.htm
Michigan	No	Yes	ROW permits: http://www.michigan.gov/mdot/0,1607,7-151-9623_26662_26679_27267_48606-182161--,00.html
Minnesota	Yes	Yes	http://www.dot.state.mn.us/row/rowmanuals.html
Missouri	No	No	http://www.fhwa.dot.gov/modiv/programs/oversite/chap14.cfm
Mississippi	No	Yes	http://sp.mdot.ms.gov/Right%20of%20Way/Pages/Home.aspx
Montana	Yes	No	http://www.mdt.mt.gov/publications/manuals.shtml
Nebraska	Yes	Yes	http://www.transportation.nebraska.gov/roway/doc-pub.htm#rowmanual
New Hampshire	No	Yes	http://www.nh.gov/dot/org/projectdevelopment/rightofway/links.htm http://www.nh.gov/dot/org/projectdevelopment/rightofway/index.htm

State (linked)	ROW manual	ROW website	
New Jersey	Yes	Yes	http://www.state.nj.us/transportation/eng/documents/ROWAM/
New Mexico	Yes	Yes	ROW Division: http://dot.state.nm.us/en/Infrastructure.html Manual: http://dot.state.nm.us/content/dam/nmdot/Infrastructure/ROW_Handbook.pdf
Nevada	Yes	Yes	ROW Division: http://www.nevadadot.com/About_NDOT/NDOT_Divisions/Engineering/ROW/Right_of_Way.aspx
New York	No	No	
North Carolina	Yes	No	https://connect.ncdot.gov/resources/row/Resources/Right%20of%20Way%20Manual.pdf
North Dakota	Yes	No	http://www.dot.nd.gov/manuals/manuals-publications.htm
Ohio	Yes	Yes	http://www.dot.state.oh.us/divisions/engineering/realestate/row/Pages/row.aspx
Oklahoma	No	No	
Oregon	Yes	Yes	http://www.oregon.gov/ODOT/HWY/ROW/pages/row_manual_info.aspx
Pennsylvania	No	No	
Rhode Island	No	No	
South Carolina	Yes	Yes	http://www.scdot.org/doing/publications_RightOfWay.aspx
South Dakota	No	No	
Tennessee	Yes	Yes	http://www.tdot.state.tn.us/chief_engineer/assistant_engineer_design/row/index.htm
Texas	Yes	Yes	http://onlinemanuals.txdot.gov/manuals/CollectionList.html
Utah	Yes	Yes	http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:199,
Virginia	Yes	Yes	http://www.virginiadot.org/business/row-default.asp
Vermont	Yes	Yes	http://vtransengineering.vermont.gov/publications#m
Washington	Yes	Yes	http://www.wsdot.wa.gov/publications/manuals/m26-01.htm
Wisconsin	No	No	ROW permits: http://www.dot.wisconsin.gov/business/rules/property-permits.htm
West Virginia	No	Yes	http://www.transportation.wv.gov/highways/right-of-way/Pages/default.aspx
Wyoming	No	No	

2.2 Existing Federal, State, and Local Regulations

This section documents the federal, state, and affected local community regulations that impact the use of the existing ROW for HSIPR and dedicated freight transportation systems.

Previous TxDOT research reviewed the types of facilities TxDOT can accommodate within its ROW. Project report 0-6634-1 from Prozzi et al. (2012), *Guidance on Extracting Value from TxDOT's Land Holdings*, examined potential ways to extract value from existing ROW (see that report's Appendix I) via the following uses:

- airspace leasing (for buildings, parking lots, utilities, and telecommunications),
- advertising,

- solar panels,
- wind turbines,
- solar roads/piezoelectric asphalt,
- geothermal and carbon energy,
- carbon sequestration and biomass, and
- wildlife crossings.

HSIPR or dedicated freight transportation technologies are not explicitly listed in the Prozzi et al. (2012) report, although inclusion of those technologies or supporting facilities in the ROW could fall under airspace leasing. Appendix I of the Prozzi et al. (2012) report provides a thorough overview of the applicable regulations. In addition, Nash et al. (2010) in project 0-6495 evaluated the potential to place high voltage transmission lines in the ROW and the applicable regulations.

Since both those research projects conducted a thorough legal analysis, the most relevant findings are highlighted in the following sections. The Texas Transportation Code (TC) contains several sections applicable to the use of highway ROW for HSIPR and dedicated freight system use. Since the Prozzi et al. (2012) report is comprehensive and complete, the reader is directed to their report for more information. The following sections of 2.2.1 and 2.2.2 include verbatim excerpts from the Prozzi et al. (2012) report. Missing from the Prozzi et al. (2012) report, however, is the federal legislation explicitly allowing publically owned mass transit to use existing federal-aid highway ROW; this is the first regulation presented in Section 2.2.1.

2.2.1 Federal Regulations

Title 23: Highways and Title 49: Transportation in the United States Code (USC) contains the approved federal acts related to transportation. An approved act may authorize federal agencies to promulgate standards or regulations to implement the act. The standards are published in the Code of Federal Regulations (CFR) after a public review process announced via postings in the Federal Register. The federal government also prepares guidance manuals outside the rules posting process. This section presents several applicable regulations in the CFR.

> **Use of ROW for publically-owned mass transit – 23 CFR 810.200**
> Use of interstate highway ROW requires approval from the Federal Highway Administration (FHWA) pursuant to regulations and evaluation criteria set forth in Chapter 23, Subpart C, Section 810 of the Code of Federal Regulations (CFR). Specifically, prior to authorizing the use of federal-aid highway ROW for publically-owned mass transit, the FHWA requires evidence that:
>
> 1) *Utilization of ROW from a federal-aid highway would not impair future improvements to the highway or the safety of highway users;*
> 2) *The public interest will be served thereby; and,*
> 3) *Within urbanized areas, the proposed project (i.e., the proposed commuter rail station) stems from a continuing and comprehensive*

transportation planning process developed in accordance with federal transportation planning regulations (23 CFR 450).

As an example of the use of 23 CFR part 810.200, the "Rail Runner" intercity passenger train service in New Mexico between Santa Fe and Albuquerque secured permission from the FHWA to use the I-25 median for a portion of the route and the ROW at the NM 599 interchange for a station, a park-and-ride lot, and pedestrian walkway (Valerio, 2008). In 2007, the New Mexico DOT requested permission to place rail track in the highway median of I-25. The request was approved by the FHWA with the understanding that any future widening of I-25 would have to occur next to the outside lanes and not the inside lanes. Figure 11 shows the Rail Runner operating within the highway median.

Figure 11. Rail Runner Operating within I-25 Median in New Mexico
(Source: http://www.hdeshazo.com/house/aoh-page-001.htm)

If any construction within the existing ROW requires changes to the existing geometric design of the automobile lanes, pursuant to federal law the sponsoring/participating DOT must submit an Interstate Justification Report (IJR) to FHWA for the highway modifications. The IJR must include a detailed assessment of the safety and traffic operations impact of the proposed highway modification.

Acquisition of ROW: 23 CFR Part 1 – General: Section 1.23

23 Code of Federal Regulations (CFR) 10 Part I Section 1.23 Rights-of-Way stipulates the purposes whereby ROW can be acquired for federal aid highway projects. The interest that shall be acquired under Section 1.23 (a) shall be of such nature and extent as are adequate for the construction, operation and maintenance of a project. The use for which ROW is acquired is for highway purposes. Paragraph (b) states that except as provided under paragraph (c) of this section, all real property, including air space, within the ROW boundaries of a project shall be devoted exclusively to public highway purposes. Paragraph (b) also notes that state highway departments are responsible for preserving such ROW free of all public and private installations, facilities or

encroachments, except for those approved under paragraph (c) and those that the Administrator approves as constituting a part of a highway or as necessary for its operation, use or maintenance for public highway purposes such as information sites established and maintained under §1.35 of the regulations.

The exception in §1.23(c) allows for temporary or permanent occupancy or use of the ROW approved by the Administrator as either being in the public interest and will not impair the highway or interfere with free and safe flow of traffic thereon.

Funding and Reimbursement: 23 CFR Sub-chapter H – ROW and Environment: Part 710 ROW and Real Estate

Section 710.203 23 CFR Section710.203 details the conditions under which a DOT will be funded and reimbursed for ROW acquisition. In general the section requires the project to have been included in the Statewide Transportation Improvement Program (STIP), the DOT has executed a project agreement, NEPA provisions have been complied with, and costs have been incurred in conformance with state and federal law requirements. Direct eligible costs that are covered include the cost of property incorporated into the final project and the associated direct costs of acquisition, unless provided otherwise. Participation is provided for real property acquisition and services associated with this, including incidental expenses, administrative settlements, and contracting costs for private acquisition services or the use of local public agencies (§710.203 (4)(b)). Damages, for cost of severance of consequential damage are covered, along with net costs of managing real property prior to and during construction, and payroll related expenses for technical guidance (§710.203 (4) (b) (3-4)). The section also allows for the cost of property not incorporated into a project to be eligible for reimbursement under the following circumstances (§710.203 (4) (b) (6)):

(i) costs for construction material sites, property acquisitions to a logical boundary, or for eligible transportation enhancement, sites for disposal of hazardous materials, environmental mitigation, environmental banking activities, or last resort housing; and

(ii) the cost of acquiring easements outside the ROW for permanent or temporary use.

Real Property Control: 23 CFR Sub-chapter H – ROW and Environment: Part 710 ROW and Real Estate: Section 710.401

This subpart describes the acquiring agency's responsibilities to control the use of real property required for a project in which federal funds participated in any phase of the project. Prior to allowing any change in access control or other use or occupancy of acquired property along the Interstate, the DOT shall secure an approval from the FHWA for such change or use. The DOT shall specify in the ROW operations manual, procedures for the rental, leasing, maintenance, and disposal of real property acquired with money under 23 CFR. The DOT shall assure that local agencies follow the State's approved procedures, or the local agencies own procedures if approved for use by the DOT.

Real Property Management: 23 CFR Sub-chapter H – ROW and Environment: Part 710 ROW and Real Estate: Section 710.402

Under Section 710.403 (a) the DOT has to assure that all properties within the boundaries of the federally aided facility are devoted exclusively to the purposes of that facility and is preserved free of all other public or private alternative uses, unless these have been permitted by regulation or the FHWA. The alternative use must be consistent with the continued operation, maintenance, and safety of the facility and the use shall not result in the exposure of the facility's users or others to hazards. Under 710.403 (b) The DOT is required to comply with specific procedures in their ROW manual for determining when the real property interests is no longer needed. This includes provision for coordination among DOT divisions (including, maintenance, safety, design, ROW, environment and traffic operations).

The DOT under sub-section (c) shall evaluate the environmental effects of disposing or leasing property and must obtain FHWA approval under 23 CFR Part 771. DOTs are required to charge current fair market value or rent for the use or disposal of these property interests, including access control, if the properties were obtained with Title 23 United States Code (USC) funding. An exception to this is provided under 710.403 (d) (1) through (5) of this section. Herein if property no longer needed for a project was acquired with public funding, the principle guiding disposal would normally be to sell the property at fair market value and use the funds for transportation purposes. The term fair market value as used for acquisition and disposal purposes is defined by State statute and/or State court decisions. Exceptions to the general requirement for charging fair market value may be approved in the following situations:

(1) With FHWA approval, when the DOT clearly shows that an exception is in the overall public interest for social, environmental, or economic purposes; nonproprietary governmental use; or uses under 23 USC. 142(f), Public Transportation. The DOT manual may include criteria for evaluating disposals at less than fair market value. Disposal for public purposes may also be at fair market value. The DOT shall submit requests for such exceptions to the FHWA in writing.

(2) Use by public utilities in accordance with 23 CFR Part 645.

(3) Use by Railroads in accordance with 23 CFR Part 646.

(4) Use for Bikeways and pedestrian walkways in accordance with 23 CFR Part 652.

(5) Use for transportation projects eligible for assistance under 23 USC, provided that a concession agreement, as defined in section 710.703, shall not constitute a transportation project.

Air Rights on the Interstate: 23 CFR Sub-chapter H – ROW and Environment: Part 710 ROW and Real Estate: Section 710.405

Section 710.405 promulgates FHWA policies regarding the management of airspace on the interstate for non-highway purposes. The section's preamble notes that while it deals with approval for actions on the highway, DOT contemplated airspace use, must assure that such occupancy, use, or reservation is in the public interest and does not impair the highway or interfere with the free and safe flow of traffic as provided in 23 CFR 1.23 (710.405 (a)). This section applies to interstate facilities that received any assistance, through 23 CFR. The sub-part does not apply to non-interstate highways, railroads, and public utilities that cross or otherwise occupy federally aided ROW, relocations of railroads/utilities for which reimbursement is claimed under 23 CFR Part 140 Subparts E and H, and bikeways and pedestrian walkways under 23 CFR Part 652 (710.405 (2) (i through iv). The DOT may grant rights for temporary or permanent occupancy or use of Interstate airspace if the DOT has acquired sufficient legal right, title, and interest in the ROW of a federally assisted highway to permit the use of certain airspace for non-highway purposes; and where such airspace is not required presently or in the foreseeable future for the safe and proper operation and maintenance of the highway. The DOT must obtain prior FHWA approval, except where paragraph (c) of the section applies (710.405 (b)).

Under Paragraph (c) the DOT may make ROW available—without charge—to a publicly owned mass transit authority for public transit purposes where it serves the public interest, and can be accommodated without impairing safety, or future highway improvements. The section allows an individual, organization, company or public agency to submit a written request to the DOT for an airspace lease. If the DOT recommends approval, it must submit an application to the FHWA along with supplemental documentation describing the project and any proposed lease agreement. The submission is required to comply with provisions in the FHWA's Airspace Guidelines (710.405 (d)).

Leasing of Property: 23 CFR Sub-chapter H – ROW and Environment: Part 710 ROW and Real Estate: Section 710.407

Under 710.407 (a) the leasing of real property acquired with 23 CFR funds, shall be covered by an agreement between the DOT and lessee which must contain provisions to insure the safety and integrity of the federally funded facility. It shall also include provisions governing lease revocation, removal of improvements at no cost to the FHWA, adequate insurance to hold the State and the FHWA harmless, nondiscrimination, and access by the State Transportation Department (STD) and the FHWA for inspection, maintenance, and reconstruction of the facility. Section 710.407 (b) provides that where the proposed use requires changes in the existing transportation facility, such changes shall be provided without Federal funds unless otherwise specifically agreed to by the DOT and the FHWA. Section 710.407 (c) requires that any proposed uses of the ROW shall conform to the current design standards and safety criteria of the FHWA for the functional classification of the highway facility in which the property is located.

2.2.2 State Regulations

General Provisions and Administration

TC Chapter 201, Sub-chapter C sets out the Commission's powers and duties in Sub-section 201.1055. The department and a private entity that offers the best value can enter into agreements for:

- Acquisition, design, and construction or renovation, which includes site development of facilities and buildings required to support department operations located on real property owned or acquired by the department.
- Acquisition from a private entity of real property, including a building or other facility to support department operations, that is constructed on the real property in exchange for department-owned real property. This includes any improvements.

Control of Transportation Assets

TC Chapter 202 lays out the control of transportation assets. Under TC Section 202.021 real property that is no longer needed –including ROW – can be transferred or sold if it was acquired for a highway purpose, and is determined it is no longer needed for a state highway.

TC Sub-chapter C of Chapter 202 governs leases, easements, and agreements that concern highway property. Section 202.052 allows the department to lease a highway asset, part of the ROW, or airspace above or underground a highway, if the department determines that the interest to be leased will not be needed for a highway purpose during the term of the lease. The lease may be for any purpose that is not inconsistent with applicable highway use under subsection 202.052 (b), and must charge not less than fair market value for the highway asset in cash, services, tangible or intangible property, or any combination thereof under Sub-section 202.052 (c). Exceptions for the charges under sub-section d can be made for lease to a public utility provider, leases for a social, environmental, or economic mitigation purpose, or for leases to an institution of higher education.

Control of Access

TC Chapter 203 Sub-chapter C – Control of Access sets out in Section 203.031(a) the duties of the commission who may:

(1) designate a state highway of the designated state highway system as a controlled access highway;

(2) deny access to or from a controlled access highway from or to adjoining public or private real property and from or to a public or private way intersecting the highway, except at specific locations designated by the commission;

(3) close a public or private way at or near its intersection with a controlled access highway;

(4) designate locations on a controlled access highway at which access to or from the highway is permitted and determine the type and extent of access permitted at each location; and

(5) erect protective devices to preserve the integrity, utility, and use of the controlled access highway.

ROW Acquisition

TC Chapter 224 provides the mechanism through which the department can acquire ROW. The department can acquire by purchase, gift or eminent domain any ROW necessary for the national system of interstate and defense highways (§224.001). Section 224.001 also allows counties or municipalities to acquire, highway ROW requested by the department.

Under Section 224.152 of the TC the department is authorized, subject to availability of federal and state funds, to improve air quality and develop innovative techniques to finance transportation projects and enhance the use of existing highways and facilities to further the purposes of the US Congress as expressed in 23 USC. Sections 134 (metropolitan transportation planning), 135 (statewide planning), 146 (carpool and vanpool projects), and 149 (congestion mitigation and air quality improvement program).

This directive could be interpreted to encourage State DOT participation in programs or initiatives such as providing ROW and/or property for renewable energy projects that would result in measurable improvements to air quality. The case would be more compelling if it was determined that a project could not move forward without DOT participation.

Property Management

Section 31.156 requires that the Division shall review the real property inventory of each state agency not less than every 4 years. The Division shall identify real property owned or controlled by the state that is not being used or is being substantially underused and make recommendations regarding the use of the real property or a real estate transaction involving the real property. As Section 31.155 only exempts highway ROW owned by TxDOT, under Section 31.156 other types of real property owned by TxDOT are subject to the review and recommendations of the Division.

Under Section 31.156 (c) the Division's recommendations must include an analysis of the highest and best use to which the real property may legally be placed and shall also include alternative uses of the real property addressing potential for commercial or agricultural lease of the real property or any other real estate transaction or use that the Division may deem to be in the best interest of the state. The section also requires submission of information pertinent to the evaluation of a real estate transaction involving the real property, including an evaluation of any proposals received from private parties that would be of significant benefit to the state and:

(1) if the Division recommends a real estate transaction, the market value of the real property and the current market conditions; or

(2) if the Division does not recommend a real estate transaction evidence of the real property's value in a form determined to be appropriate by the commissioner.

Title 43 Transportation Chapter 21 ROW

Sub-chapter J: Leasing of Highway Assets for Transportation Facility Rule 21.301 establishes the procedure for leasing state-owned ROW for freight movement to reduce congestion on the state highway system and to improve air quality when the commission authorizes such a lease for a specified project. Under Rule 21.301 (b) this subchapter may not be used for the lease of ROW for of a pipeline, electric transmission line, or other utility facility. Additionally, this sub-chapter may not be used for the lease of ROW for rail lines that are part of the general system of rail transportation and require a certificate from the United States Surface Transportation Board under 49 USC. §10901. The procedure provided by this sub-chapter is separate from and in addition to the procedure established under Sub-chapter L of this chapter that relates to the Leasing of Highway Assets.

Under Rule 21.303 the department can issue a request for proposal (RFP) from public and private entities for submitting a detailed document describing a proposed project and the associated lease of ROW. The RFP will provide the information necessary for a responsive proposal.

Sub-chapter L: Leasing of Highway Assets

Rule 21.602 notes that the commission can authorize the lease of a highway asset if it finds:

1. the interest to be leased will not be needed for highway purposes during the period of the lease;

2. the lessee's use of the property will be consistent (and not impede) with safety, maintenance, operation, and the beautification of the state highway system; and

3. the lease will be economically beneficial to the department.

Rule 21.605 sets out the general requirements relating to the leasing of federal-aid ROW.

Title 43 Transportation Chapter 22 Use of State Property

Sub-chapter B: Use of State Highway ROW

Rule 22.10 sets out the department’s policy to use ROW for certain public purposes, which benefit the general public and are consistent with the efficient and safe operation of the state highway system. This chapter prescribes policies and procedures governing the use of state highway ROW other than department business. Rule 22.14 sets out the policy vis-à-vis vendors using the state highway ROW.

2.2.3 Local Regulations

Regulations for use of highway ROW primarily fall within the jurisdiction of the state and federal level of government. However, some regulations or legal agreements at the local level could affect use of highway ROW, such as zoning of land parcels. Additionally, local governments could enter into agreements at the state level for use of highway ROW. Examples of such agreements between local transit agencies and the state department of transportation (DOT) are presented below.

Figure 12. Tri-Met MAX Light Rail in Portland under Construction in 1980
(Source: www.trimet.org)

An older TTI report titled *Planning and Policy Issues Associated with Developing Mass Transportation Improvements in Urban Freeway Corridors* examined the planning and policy issues associated with using urban freeways for high-occupancy vehicle (HOV) lanes and rail projects in the US (Bullard, 1988). The report describes the funding sources for projects planned, in progress or completed and the policies and legal agreements that specify the ownership and operations of the HOV and rail facilities in the freeway ROW. Of interest for this report are the agreements contained within the Bullard (1988) report that show how entities shared responsibilities within shared transportation ROW in Oregon, Georgia, and Florida.

The actual ROW services agreement and the cooperative work agreement between the Tri-County Metropolitan Transportation District of Oregon (Tri-Met) and the Oregon DOT for the light rail project located adjacent to the Banfield Freeway (Interstate 84) (pictured under construction in Figure 12 and completed in Figure 13) is included in the Bullard (1998) report. Tri-Met had employed the state to acquire the property and ROW needed for the light rail line; relocate and reconstruct the highway; and build or rebuild overpass structures, bridges, and ramps.

Figure 13. Portland MAX Light Rail next to Banfield Highway (Interstate 84)
(Source: http://www.wikipedia.org)

Bullard (1988) also described and included in the report the Metropolitan Atlanta Rapid Transit Authority (MARTA) temporary right-of-use agreement with the Georgia DOT to use a portion of the ROW for Main Street (Highway 29) for heavy rail transit adjacent to the street (Figure 14). Numerous provisions in the agreement included a requirement that all construction within the right-of-use area be approved by the Georgia DOT.

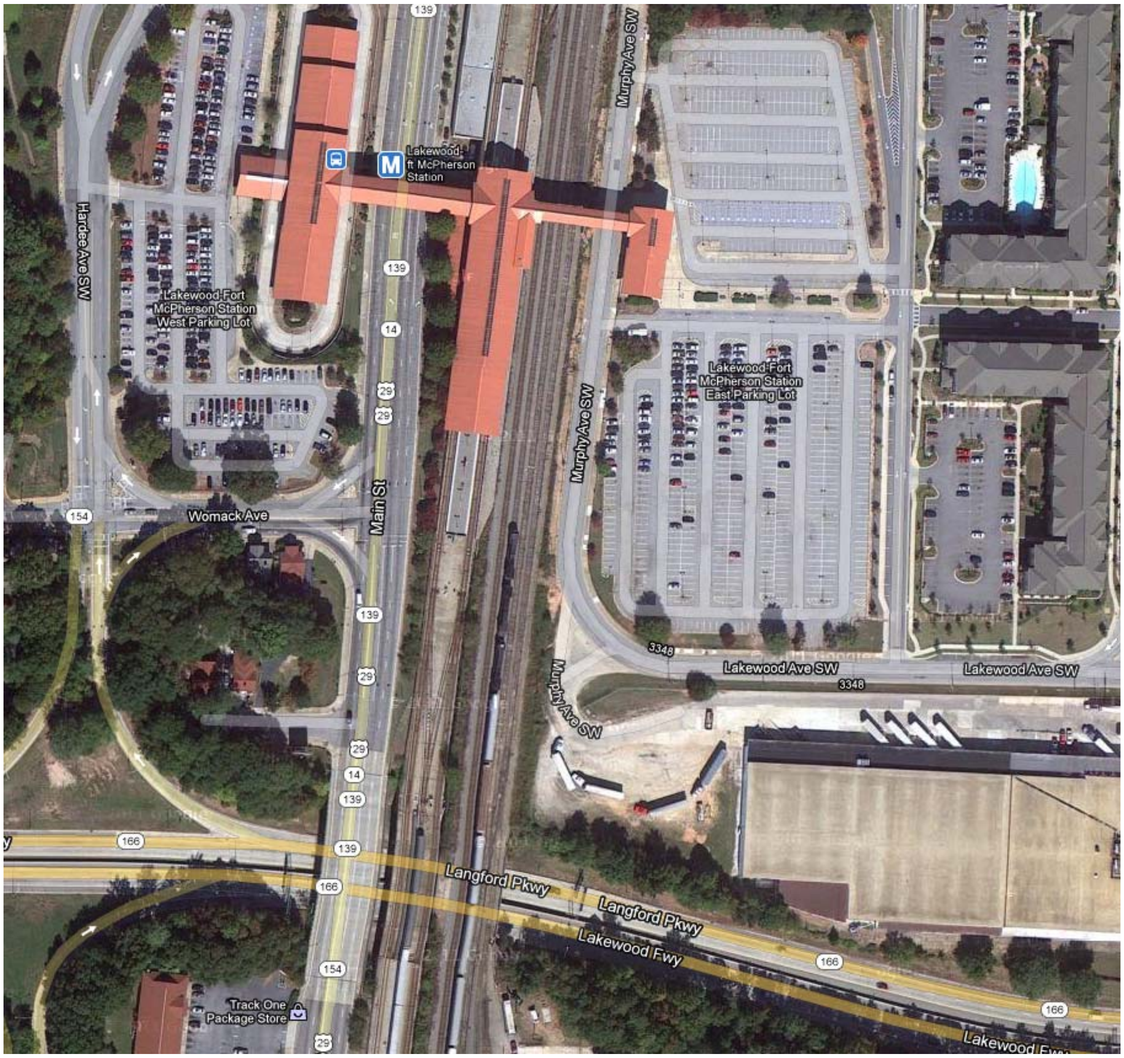


Figure 14. MARTA East Point, Georgia Station
(Source: Google Maps)

MARTA also developed an agreement, included in Bullard (1988), with the Georgia DOT around the time of the report that required the Georgia DOT to design and develop State Route 400 to allow for future placement of MARTA rail line within the State Route 400 ROW median. The construction of MARTA in the median of State Route 400, from just south of Interstate 285 to just south of Lenox Road, was completed in 1996 (Wikipedia for MARTA, 2011). The Buckhead MARTA station provides a platform in the median of the highway (Figure 15).

Figure 15. MARTA Rail Lines and Buckhead Station in Median of State Route 400

(Source: Google Maps)

The 1979 airspace agreement between the Florida DOT and Metropolitan Dade County for the Dade County public heavy rail passenger system (Metrorail) requires concurrence with the FHWA and that piers, columns or other supporting airspace structures not interfere with the safety and free flow of traffic on the highway along with other provisions. The agreement is included in the Bullard (1988) report. The Miami-Dade County Metrorail parallels US highway 1 for almost half the length of the 22-mile system (Figure 16).

Figure 16. Miami-Dade County Metrorail Rail Map
(Source: Miami-Dade County Metrorail website)

Though the previous examples are of older agreements, they provide examples of long-term agreements and their outcomes from local agencies partnering with the state DOT to support transit facilities within existing highway ROW.

2.3 Environmental Review

A major administrative consideration concerning placement of HSIPR or freight technology is how to review use of existing highway ROW for the federal environmental review process required by NEPA. In addition to the Environmental Protection Agency's requirements, the FHWA, through 23 CFR §771, requires a state to submit to the FHWA Division office environmental documentation that complies with NEPA and describes the purpose of using the ROW.

To identify what may be different for the environmental review for an HSIPR or freight project that uses existing ROW, the Environmental Impact Statements (EIS) and Environmental Impact Reports (EIR) of proposed US HSIPR projects planning use of existing ROW were reviewed.

Interestingly, for the HSIPR projects proposed in Florida and California/Nevada (formerly DesertXpress, now XpressWest), the minimization of noise, visual, and ecological impacts actually motivated the preference for an alignment within existing highway ROW.

Methodologies for assessing community and environmental impacts are well-documented and fairly uniform, allowing standardization of EIR/EIS preparation regardless of route type (i.e., existing or new ROW). The extent of the impacts, whether utilizing existing or new ROW, depends upon a variety of factors unique to a proposed route (e.g., land use, and historic and ecological significance of properties) and on the chosen HSIPR technology.

In the case of noise, the FRA has determined that noise impacts differ depending on the type of corridor (i.e., highway, rail, or new) used for the HSIPR. The remainder of this section provides an overview of the FRA methodology for assessing the noise impact of HSIPR in existing highway ROW.

The *High-Speed Ground Transportation Noise and Vibration Impact Assessment* manual (Federal Railroad Administration, 2005, updated 2012) specifies a noise screening procedure that establishes distances from a proposed HSIPR corridor for which noise impacts are possible. These distances vary depending on whether the proposed corridor is an existing or new railroad or highway corridor (Table 4). Properties within the screening distances could potentially be impacted and thus should become part of the study area for a noise impact assessment. The manual walks through an example of following the noise impact methodology for an HSIPR proposed within an existing highway median (Figure 17).

Table 4. Screening Distances by HSIPR Corridor Type

Corridor Type	Existing Noise Environment	Screening Distance in Feet for Project Type and Speed Regime*			
		Steel-Wheeled		Maglev	
		Reg. II	Reg. III	Reg. II	Reg. III
Railroad	Urban/Noisy Suburban - unobstructed	300 ft	700 ft	50 ft	400 ft
	Urban/Noisy Suburban - intervening buildings**	200	300	50	250
	Quiet Suburban/Rural	500	1,200	50	700
Highway	Urban/Noisy Suburban - unobstructed	250	600	50	400
	Urban/Noisy Suburban - intervening buildings**	200	350	50	250
	Quiet Suburban/Rural	400	1,100	50	600
New	Urban/Noisy Suburban - unobstructed	350	700	75	450
	Urban/Noisy Suburban - intervening buildings**	250	350	75	300
	Quiet Suburban/Rural	600	1,300	150	800

* Measured from centerline of guideway or rail corridor. Minimum distance is assumed to be 50 ft.
** Rows of buildings assumed to be at 200, 400, 600, 800, and 1,000 ft parallel to guideway.

(Source: Federal Railroad Administration, 2005, updated 2012)

In addition to differentiating between the type of corridor and existing noise environment, the screening distances also vary by HSIPR technology (e.g., steel-wheeled and maglev in Table 4). Figure 18 compares the sound exposure levels (*SEL*s, a measure used for assessing the noise impact) of different HSIPR technologies and their components. Maglev appears to produce less noise than other rail technologies for all speeds, although the difference becomes small at very high speeds of around 400 km/hr (249 mph); the generation of noise from air friction affects all the technologies at that speed (Federal Railroad Administration, 2005, updated 2012).

In addition to the type of technology, the design of the guideway affects the noise impacts. The reference SEL for an elevated HSIPR developed using the FRA noise impact manual (Federal Railroad Administration, 2005, updated 2012) is increased by +2 or +4 dBA, depending on the speed of the train, an adjustment to consider when proposing elevated systems near land uses sensitive to noise sources.

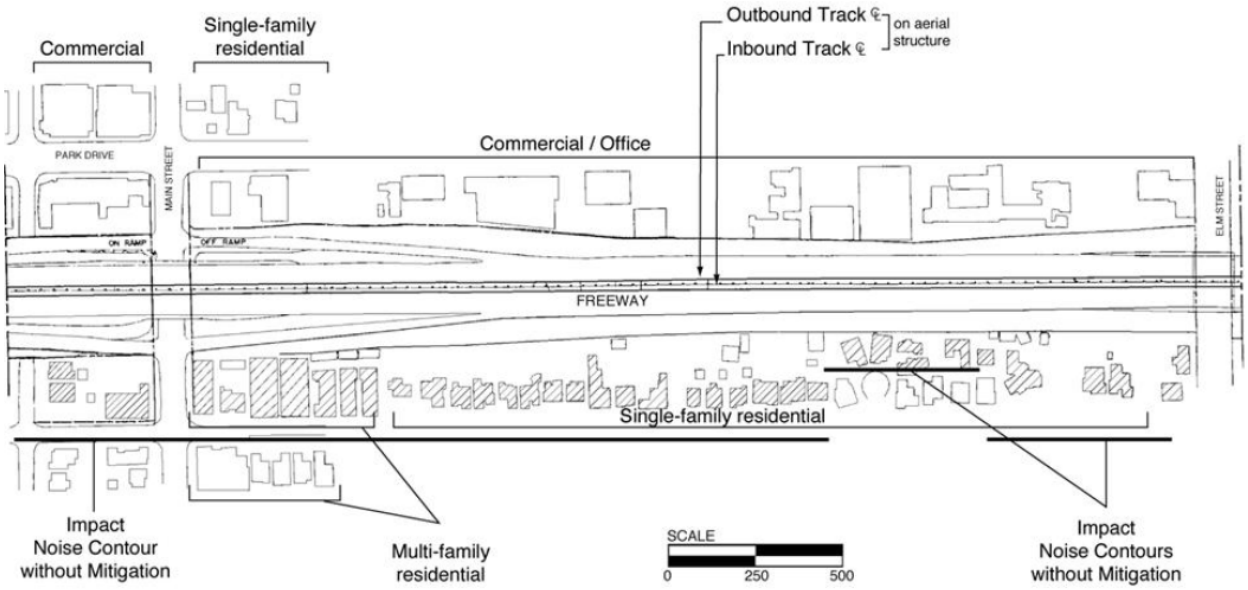


Figure 17. HSIPR in Freeway Median Noise Impact Contours
(Source: Federal Railroad Administration, 2005, updated 2012)

System Category and Features [(a)]	Example Systems		Subsource Component	Subsource Parameters: Length Definition, *len*	Subsource Parameters: Height above rails (ft)	Reference Quantities: SEL_{ref} (dBA)	Reference Quantities: len_{ref} (ft)	Reference Quantities: S_{ref} (mph)	Reference Quantities: *K*
HS and VHS ELECTRIC LOCOMOTIVE-HAULED TRAINS	Amtrak Acela TGV Eurostar X2000 KTX-I /KTX-II ETR 500		Propulsion	len_{power}	12	86	73	[(b)]	[(b)]
			Wheel-rail	len_{train}	1	91	634	90	20
		AERO	Train Nose	len_{power}	10	89	73	180	60
		AERO	Wheel Region	len_{train}	5	89	634	180	60
		AERO	Pantograph	[(c)]	15	86	[(c)]	180	60
		(Only include aerodynamic subsources for very high-speed trains above 150 mph.)							
HS and VHS EMU TRAINS	IC T ICE 3 AVE S103 ETR450 KTX-III		Propulsion	len_{power}	2	86	634	[(b)]	[(b)]
			Wheel-rail	len_{train}	1	91	634	90	20
		AERO	Train Nose	len_{power}	10	89	73	180	60
		AERO	Wheel Region	len_{train}	5	89	634	180	60
		AERO	Pantograph	[(c)]	15	86	[(c)]	180	60
		(Only include aerodynamic subsources for very high-speed trains above 150 mph.)							
HS GAS-TURBINE LOCOMOTIVE-HAULED TRAINS	Rohr RTL-2 Bombardier Jet-Train		Propulsion	len_{power}	10	83	73	20	10
			Wheel-rail	len_{train}	1	91	634	90	20
MAGLEV	TR08		Propulsion	len_{train}	1.5	68	165	90	8
			Guideway/Structural	len_{train}	-5	80	295	90	30
		AERO	Train Nose	[(c)]	0	61	[(c)]	90	50
		AERO	TBL [(d)]	len_{train}	10	78	295	120	50

[(a)] *HS (High-Speed)* = maximum speed 150 mph
VHS (Very High-Speed) = maximum speed 250 mph
MAGLEV = maximum speed 300 mph
[(b)] Source level is not adjusted for train speed
[(c)] Source level is not adjusted for train length
[(d)] Turbulent Boundary Layer

Figure 18. Comparison of Sound Exposure Levels from Different HSIPR Technologies
(Source: Federal Railroad Administration, 2005, updated 2012)

Section 3. Design Considerations, Feasibility Analysis Methodology, and Approval Conditions

Following are the purposes of Section 3:

- Describe the typical design requirements to consider for HSIPR and dedicated freight transportation systems to operate within existing highway ROW,
- Explain the methodology for determining feasibility to operate within existing highway ROW, and
- Outline possible conditions of approval needed for projects, such as passenger or freight prioritization, crash protection, and spacing requirements.

3.1 HSIPR Design Considerations

The components of an HSIPR system, from the vehicle components to the guideway and support infrastructure, are integrally related. For planning an HSIPR system, consideration must be given not only to the major type of vehicle technology (e.g., SWSR or maglev), but to the technology components of the chosen vehicle, for those affect and are affected by the constraints of the existing ROW. A choice of a vehicle component, such as the braking system, for instance, may affect the type of track that can be used for the vehicle. Sections 3.1.1 and 3.1.2 describe those types of components unique to SWSR and maglev, respectively. Section 3.1.3 describes the differences between SWSR and maglev to consider when designing either one for inclusion in existing highway ROW. Sections 3.1.4 and 3.1.5 explain the design considerations for supporting HSIPR facilities of electric power supply facilities, and station and maintenance areas.

3.1.1 Steel Wheel on Steel Rail (SWSR)

The SWSR HSIPR vehicle, power, and track technology components most likely to influence the design of a system within existing ROW include the following:

- power distribution, sources and supply facilities,
- wheel and axles (bogies),
- track technology (ballasted and ballast-less), and
- braking.

Power Sources

HSIPR vehicles can be either electric- or diesel-powered (or hybrid of the two). Diesel high-speed trains tend to be slower and heavier than electric trains. As the desired operating speeds increase (typically to 125 mph or more), electric becomes the power source of choice.

If electric-powered SWSR is used, connections to the power grid (or sources of power within the system) must be provided along with support infrastructure, such as electric substations and autotransformers to manage the voltage in the HSIPR electric system. The requirements for those facilities are described more in the later section on electric power supply.

Power Distribution

Power-distributed traction means instead of having a power car (locomotive) at the beginning of the train pulling (or at the end pushing), the power to move the wheels of the train is distributed to the axles under the passenger cars. The axles with an applied tractive force are distributed throughout the train, instead of on a few axles on the power cars. Japan was the first to adopt power-distributed technology for HSIPR, followed by Europe. Trains with *power-concentrated traction* are pushed or pulled by power cars (locomotives).

Trains with power-distributed traction are also called *multiple unit trains*. If powered by electricity, diesel, or a hybrid combination of the two (that uses diesel fuel to produce electricity), the trains are specifically called *electric multiple unit* (EMU), *diesel multiple unit* (DMU), and *diesel electric multiple unit* (DEMU), respectively.

Wheels and Axles (Bogies)

The choice of how the bogies and wheels move in relation to each other can impact the design requirements for the HSIPR alignment and support facilities. Articulated trains have bogies (the set of wheels and axles) located between the train's passenger cars, instead of directly underneath the passenger cars as in the non-articulated trains (see Figure 19). Alstom, the manufacturer of the articulated trains TGV (Train à Grande Vitesse) and AGV (Automotrice à Grande Vitesse), claims that articulated trains are less likely to jack-knife during derailment and create lower maintenance costs, among other benefits (Reseau Ferre De France, 2010). However, because articulated trains cannot be easily decoupled into single cars, maintenance facilities must be longer than for trains that can be decoupled. Countries like Germany and Switzerland are reluctant to introduce articulated trains for this reason. The choice of train technology (articulated versus non-articulated) thus directly impacts the amount of space needed for maintenance facilities.

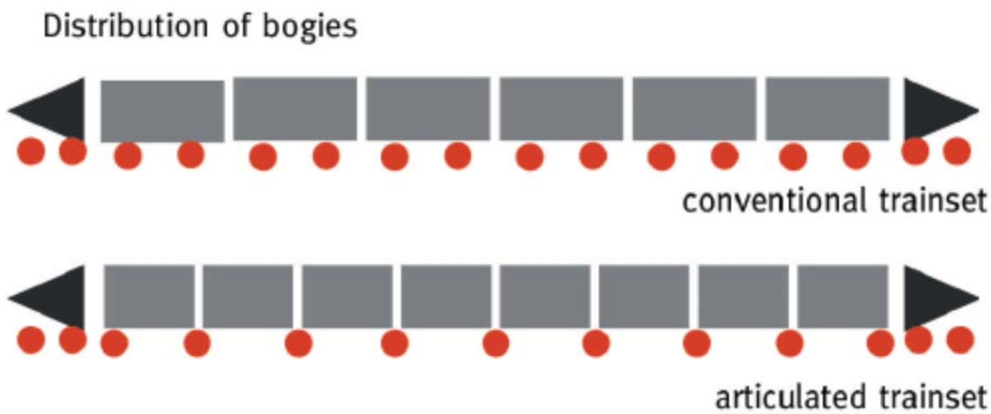


Figure 19. Articulated versus Non-Articulated Bogie Configurations
(Source: Reseau Ferre De France, 2010)

Braking

The type of braking used by a SWSR technology impacts the train's performance, safety, costs, maintenance, and compatibility with the existing or planned track infrastructure. Table 5 is a summary of the types of SWSR braking systems presented in an earlier report to TxDOT regarding technological options for HSIPR (Center for Transportation Research, 2011). Most new electric or diesel-electric SWSR train technologies use regenerative braking (including the Acela in the northeast US). Regenerative braking is a type of braking system that switches the electric motor to an electric generator, which converts the kinetic energy of the moving wheel to electrical energy that is then fed into a battery or the electrical system. The current fleet of conventional Amtrak trains uses mechanical and dynamic brakes. Most, if not all, SWSR HSIPR train systems have mechanical brakes for low-speed or emergency brakes.

Table 5. Types of SWSR Braking Systems

	Mechanical (Tread, Disk)	**Magnetic**	**Eddy Current**	**Regenerative**	**Dynamic (Rheostatic)**
Operational Speeds	Any speed	Any speed	Not at low speeds	Not at low speeds	Not at low speeds
Brake Contact with Rail	No contact	Direct contact	No contact	No contact	No contact
Components Involved	Wheel or axle and brake	Rail and brake	Rail and brake	Electric motor, axle and wheel	Electric motor, axle and wheel
Wheel-Rail Adhesion	Dependent	Independent (Depends on rail-brake)	Independent (Depends on temperature of rail)	Independent	Independent
Energy Converted To	Heat	Heat	Heat	Electrical and heat	Heat
Noise	High	Low	Low	Low	Low

(Source: Center for Transportation Research, 2011)

Electro-dynamic brakes are similar to regenerative brakes in that the electric motor is used as an electrical generator during braking to provide resistance to slow the train, but the electrical energy is dissipated as heat through resistors instead of being returned to a battery or the catenary lines.

Eddy current brakes never touch the rail; instead, they are lowered just above the steel rail. The eddy current braking system requires consideration of the entire HSIPR system (i.e., track and communications). The European Rail Infrastructure Managers limited the use of eddy current brakes to specific sites after their evaluation, because of the following potential impacts of the eddy current brakes on the track and communication infrastructure (European Rail Infrastructure Managers, 2009):

- electromagnetic and physical interference with train detection systems, such as axle counters and line side equipment used to monitor train conditions, and

- track buckling because of the dissipation of heat during braking that is absorbed by rail head (the top of the rail).

Ballast-less slab track offers resistance to the rail buckling that can occur from the heat generated by the eddy current brakes. Acceptance of eddy current brakes is slow because of the problems listed above, in addition to concerns that the braking power would be inadequate if the power needed to operate the brakes fails (European Rail Infrastructure Managers, 2009).

Braking mechanisms independent of wheel-rail adhesion (i.e., the friction between the wheel and rail) allow for shorter stopping distances, and stopping distances unaffected or minimally affected by conditions affecting wheel/rail adhesion (such as leaves or ice on the rails) (European Rail Infrastructure Managers, 2009).

The choice of braking mechanism affects the safety of an HSIPR system, a significant factor in designing an HSIPR system within the constraints of existing ROW. In addition, the choice of braking mechanism affects the design of the track system and vice versa, so the braking mechanism is an important component to consider along with the track system.

Tilting Mechanisms

Curved tracks limit how fast a train can travel on the curve because of the need to maintain an acceptable lateral acceleration comfortable for passengers and to reduce the risk of derailment. Tilting trains are those that detect, either through local or precedence control, the curving of the track and adjust the train such that it tilts into the curve at a degree to minimize passenger discomfort. This allows the train to travel through the curve at a higher speed than a non-tilting train. The number and radii of the curves along a route and the impact of the curves on speed and thus the total travel time are used to determine whether to use a SWSR technology with tilting abilities.

The total lateral acceleration increases on a tilting train because the train travels through the curve at a higher speed than a conventional train. The amount of lateral acceleration perceived by the passengers in the tilting and non-tilting train is the same, however, as Figure 20 demonstrates.

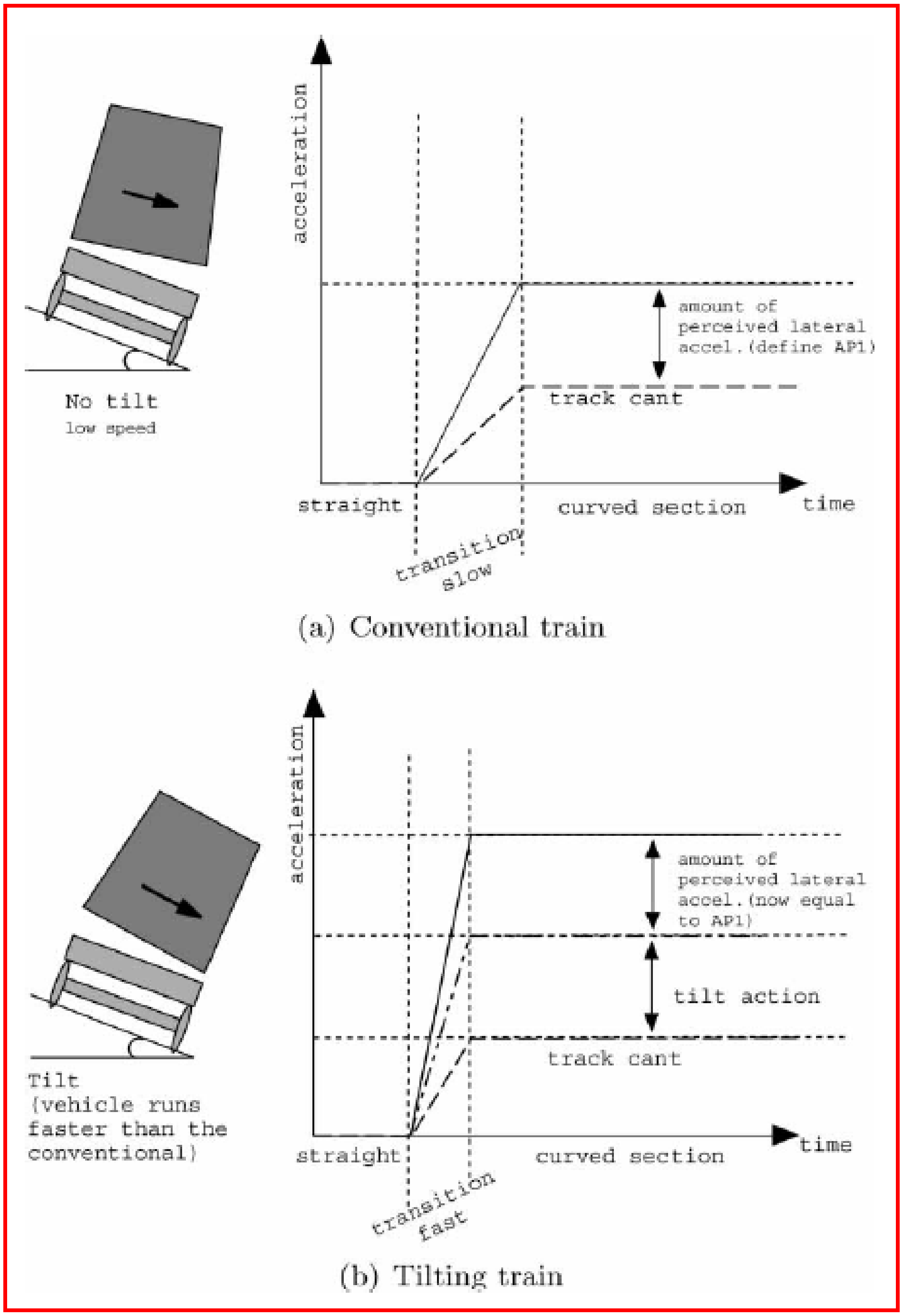


Figure 20. Passenger Perceived Curving Acceleration
(Source: Zolotas et al., 2007)

If new, dedicated HSIPR tracks are built with very few curves, tilting trains may not be needed. However, tilting trains, like the Acela Express in the northeast US, improve travel speeds along existing rail routes with speed-limiting curves. A non-tilting train must travel along the curve at a slower speed than a tilting train to maintain the same level of passenger comfort.

As mentioned earlier, tilting trains have either local or precedence controls. Local tilting controls detect and adjust the same passenger car where the controller is located. Precedence controls detect the necessary tilt adjustments ahead of time. One precedence option is to have an accelerometer mounted to a bogie on the vehicle in front that measures the cant deficiency (i.e., the amount of the angle of tilt needed to maintain passenger comfort standards) and sends a command to tilt the vehicle behind. Another option is to use existing track databases to predict curves by location or sensor data. The mechanical methods for tilting the train vary, such as pneumatic, hydraulic, and electro-mechanical (Zolotas et al., 2007). Figure 21 shows the differences in how the non-tilting trains look going through a curve compared to a tilting train. Figure 22 depicts a pneumatic tilt mechanism.

Non-tilting Amtrak train *Tilting Sweden X2000 Train*

Figure 21. Photos of Non-tilting and Tilting Trains

(Amtrak Image Source: http://www.translationdirectory.com/glossaries/glossary256.php
X2000 Image Source: http://publictransit.tripod.com/id4.html)

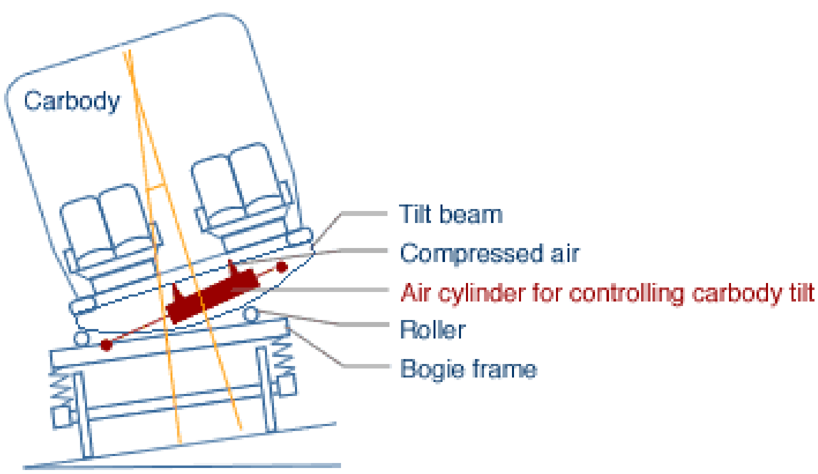


Figure 22. Pneumatic Tilt Mechanism

(Source: Hitachi Rail, 2011)

Track Technology

A pair of steel rails guides all SWSR technology, but several options are available for constructing the rails. The key distinction between the two major track construction options is whether the track contains ballast, typically consisting of a granular rock that provides an elastic reaction to the forces of the train load on the rails. Non-ballasted (i.e., ballast-less) track has been developed and used for HSIPR lines to overcome the disadvantages of ballasted track (such as maintenance and "kick up" of ballast by fast-moving trains). Table 6 highlights the characteristics of ballasted and non-ballasted track that can affect route HSIPR route alignment.

Table 6. Characteristics of Ballasted and Non-Ballasted Track Systems Affecting Route Alignment

Type	Ballasted	Non-Ballasted (Slab)
Examples	Ballasted KORAIL track with concrete ties (Esveld, 2010) 	German ICE track without ties (Esveld & Markine, 2007 (est.)) 
Construction Costs	Lower	Higher
Settlement of Track	Yes, but can be adjusted	Yes, but cannot be adjusted; Best locations for ballast-less track is on structures not subject to settlement (e.g., tunnels, viaducts, and earth formations with subgrade structures)
Noise and Vibration	Higher for passengers (lower for air-borne emissions, the external noise impact)	Lower for passengers (higher for air-borne emissions, the external noise impact) (Ogilvie & Quante, 2001)
Track Forces	Less resistance to lateral and vertical forces; requires tamping maintenance	More resistance to lateral and longitidunal forces; permits steeper grade and higher speeds
Other Factors to Consider	High-speed trains "kick up" ballast, causing damage to train	Long life track structure (40–50 years)

(Source: Mundrey, 2010)

An inventory of the type of track technology used for some European and Japanese HSIPR lines shows use of non-ballasted track technology for lines with a high percentage of tunnels and bridges/viaducts (Teixeira et al., 2006).

For designing track within the constraints of existing ROW, consideration may need to be given to the advantages and disadvantages and characteristics of the ballasted and ballast-less tracks.

3.1.2 Maglev Technology

Maglev's greater agility, higher speeds, and safer features (compared to SWSR) should make it the technology of choice, but there is a reluctance to consider a technology incorrectly assumed to be inaccessible for implementation. Maglev high-speed trains have been in operation since the 1970s in Japan and since the early 1980s, until 2012, in Germany, and over 10 years in commercial, revenue-generating operation in Shanghai, China. Japan plans to start a revenue-generating maglev route between Tokyo and Nagoya by 2027.

The vehicles and guideways for maglev technologies are intimately related to each other because the maglev vehicle's propulsion originates from the interaction of the vehicle with the guideway. The two types of maglev systems differ in terms of how the vehicle interacts with the guideway, using either an electromagnetic system (EMS) or an electrodynamic system (EDS) (see Figure 23). Both types of maglev systems have been built and are in operation. In both systems, the vehicle interacts electromagnetically with the guideway to levitate, accelerate, and decelerate. Unlike the SWSR, switching a maglev vehicle to another guideway requires the entire guideway to move. For SWSR, only a switch on the track is used to direct the train to another track.

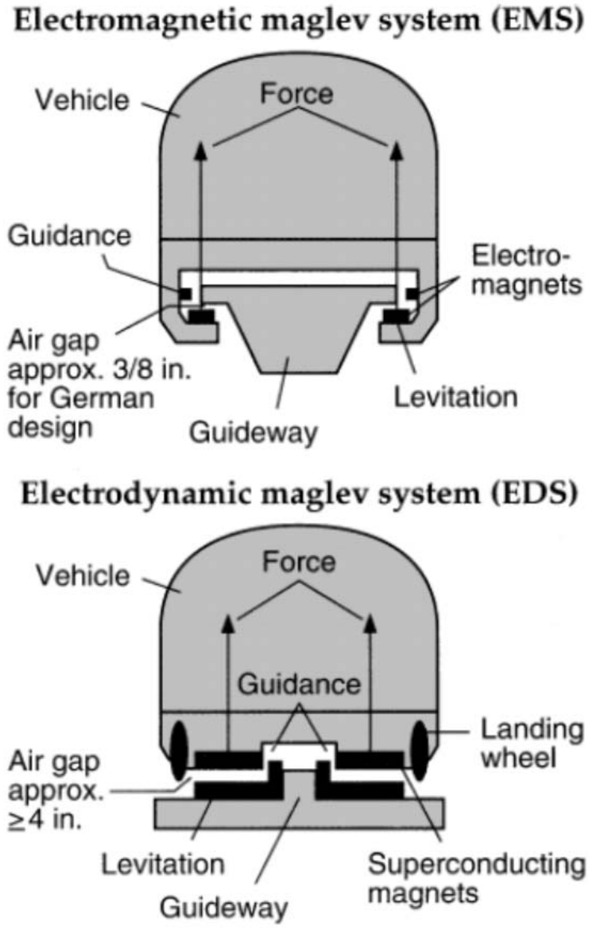


Figure 23. Comparison EMS and EDS Maglev Systems
(Source: Schetz, 2001)

Electromagnetic Maglev System

The EMS maglev technology design "wraps" the maglev vehicle around a guideway and creates levitation by attracting the vehicle to the guideway. An EMS system is thus sometimes called an *attraction-based system* because the vehicle's electromagnets are attracted to the underside of the guideway. An EMS maglev operates for revenue in Shanghai, China, and was developed by Transrapid International, a German company focused on maglev research and development. Transrapid had another maglev train in operation in Germany used for demonstration rides and research, but demolition of the system began in 2012, several years after the maglev vehicle collided with a maintenance vehicle on the guideway.

Electrodynamic Maglev System

The EDS maglev technology uses repulsion forces to levitate the maglev vehicle within or on the guideway, and is the type of technology used for Japan's maglev trains. An EDS is sometimes called a *repulsion-based system* because the vehicle levitates due to repulsion forces along the sidewalls and underneath the vehicle.

A disadvantage to the EDS repulsion-based technology is that wheels are needed until the vehicle is moving enough to induce a current to levitate. The EMS attraction-based maglev vehicle begins levitation without the need for movement and uses wheels only in the case of power failure when the vehicle must come to rest on the guideway.

3.1.3 Comparison of SWSR and Maglev

Table 7 comprises multiple tables from a Parsons Brinckerhoff Team (2001) report that provides a thorough overview of the differences in engineering design parameters, design speed, horizontal and vertical alignment, clearances and ROW requirements for SWSR and maglev. The following sections describe in more detail the differences in those types of characteristics.

Table 7. SWSR versus Maglev Engineering Parameters

Parameter	Very High-Speed	Maglev
Double Track	Full	Full
Power Source	Electric	Electric
Grade Separations	Full	Full
Potential for Shared Use	Yes	No
Corridor Width ❑ **Desirable** ❑ **Minimum**	 100 ft (30.4 m) 50 ft (15.2 m)	 100 ft (30.4 m) 50 ft (15.2 m)
Top Speed	220 mph (350 km/h)	240 mph(1) (385 km/h)
Average Speed	125-155 mph (200-250 km/h)	145-175 mph (230-280 km/h)
Acceleration	0.4-1.3 mph/s(3) (0.6-2.1 km/h/s(4))	1.1-1.9 mph/s (1.8-3.2 km/h/s)
Deceleration	1.2 mph/s (1.9 km/h/s)	1.8 mph/s (2.9 km/h/s)
Minimum Horizontal Radius	500-650 ft (150-200 m)	1,150 ft (350 m) (2)
Minimum Horizontal Radius (at top speed)	15,600 ft @ 220 mph (4,750 m @ 350 km/h)	11,500 ft @ 240 mph (3,500 m @ 385 km/h)
Superelevation ❑ **Actual (Ea)** ❑ **Unbalanced (Eu)**	 7 in (180 mm) 5 in (125 mm)	 16° 5°
Grades ❑ **Desirable Maximum** ❑ **Absolute Maximum**	 3.5% 5.0%	 NA 10.0%
Minimum Vertical Radius Crest Curve (at top speed)	157,500 ft @ 220 mph (48,000 m @ 350 km/h)	205,700 ft @ 240 mph (62,700 m @ 385 km/h)
Minimum Vertical Radius Sag Curve (at top speed)	105,000 ft @ 220 mph (32,000 m @ 350 km/h)	137,100 ft @ 240 mph (41,800 m @ 385 km/h)
Horizontal Clearance (centerline of track to face of fixed object)	10 ft 4 in @ 220 mph (3.1 m @ 350 km/h)	9 ft 5 in @ 240 mph (2.8 m @ 385 km/h)
Vertical Clearance (top of rail to face of fixed object)	21 ft (6.4 m)	12 ft 2 in (3.7 m)
Track Centerline Spacing	15 ft 8 in @ 220 mph (4.7 m @ 350 km/h)	15 ft 9 in @ 240 mph (4.8 m @ 385 km/h)
Notes: 1- Top Speed Defined in Federal Maglev Deployment Plan 2- Transrapid USA, 1998. 3- mph/s – miles per hour-second 4- km/h/s – kilometers per hour-second		

Design Speeds

	VHS (Steel Wheel)	Maglev
Top Speed	220 mph (350 km/h)	240 mph (385 km/h)
Average Speed	125 – 155 mph (200 – 250 km/h)	145 – 175 mph (230 – 280 km/h)
Acceleration	mph/s[1] (km/h/s[2])	mph/s (km/h/s)
0 – 62 mph	1.3 2.1	1.9 3.2
62 – 124 mph	1.0 1.6	1.9 3.2
124 – 186 mph	0.6 1.0	1.5 2.5
186 + mph	0.4 0.6	1.1 1.8
Deceleration	mph/s (km/h/s) 1.2 1.9	mph/s (km/h/s) 1.8 2.9

Note: 1- mph/s – miles/hour-second
2- km/h/s – kilometers/hour-second

Horizontal Alignment Criteria

	VHS	Maglev
Minimum tangent length (Lt)	2.22 V (>500')	not required
Equilibrium superelevation (Ee)	$\frac{4.01 V^2}{R}$	$\sin^{-1}\left(\frac{V^2}{14.95R}\right)$
Unbalance superelevation (Eu)	Ee-Ea	Ee-Ea
Max Ea	7 "	16°
Max Eu	5 "	5°
Minimum length of circular curve (Lc)	2.22 V	2.22 V
Minimum radius (absolute @ minimum speed)	650 ft (200 m)	1,148 ft (350 m)
Spiral length (Le) (greater of) none required if Ls<0.01 R	l.38 Ea V 0.98 Eu V 62 Ee	1.47 Ea V 56.05 V sin Eu 66 Ee

Notes: **Ea** = actual superelevation (inches or degrees), **Ee** = equilibrium superelevation (inches or degrees), **Eu** = unbalanced superelevation (inches or degrees), **Lc** = minimum length of circular curve (feet), **Le** = spiral length (feet), **Ls** = minimum length of transition spiral (feet), **Lt** = minimum tangent length (feet), **R** = radius (feet), **V** = velocity (mph)

Vertical Alignment

	VHS	Maglev
Length of constant grade (Lt)		
Desirable	4.38 V	not required
Minimum	2.22 V (<500')	not required
Gradient (in %)		
Mainline Tracks:		
(desirable maximum)	3.5	not required
(absolute maximum)	5.0	10.0 (1)
Station Tracks: (desirable minimum)	0.0	0.0
(absolute maximum)	0.25	0.25
Yards and secondary tracks:	0.0	0.0
Storage and transfer tracks:	0.0	0.0
Vertical curve radius (R)		(2)
Crest	$3.33 V^2$	
Sag	$2.22 V^2$	
Length of vertical curve (LVC)		(2)
Desirable	4.38 V	
Minimum	2.22 V	
(increase 50% if in horizontal curve)		

Notes:
Lt = length of constant grade (feet), **LVC** = length of vertical curve (feet), **R** = vertical curve radius (feet), **V** = velocity (mph)
(1) Combined effects of steep grades and horizontal curves on passenger comfort will need to be considered in design phase of project.
(2) More information has been requested from Transrapid International regarding geometric formulae. Use VHS criteria for Maglev alignment development in this screening evaluation.

Clearances

	VHS	Maglev[1]
Horizontal		
Centerline of Track/Guideway to Face of Fixed Object	10 ft 4 in (3.1 m) @ 220 mph (350 km/h)	9 ft 5 in (2.85 m) @ 240 mph (385 km/h)
Vertical		
Top of Rail/Guideway to Face of Fixed Object (minimum)	21 ft (6.4 m)	12 ft 2 in (3.7 m)
Minimum for shared operation	26 ft (7.9m)	N.A.
Track/Guideway Centerline Spacing		
Double Track Center to Center Distance	15 ft 8 in (4.7 m) @ 220 mph (350 km/h)[2]	14 ft 5 in (4.4 m) @ 240 mph (385 km/h)
Emergency Walkway Width		
Minimum Clear	30 in (76.2 cm)	30 in (76.2 cm)

Notes: 1-Transrapid Maglev.
2-TGV system requires 4.5 m, ICE requires 4.7m @ 350 km/h.

Minimum Right-of-Way Requirements

Type of Section	VHS	Maglev
At-Grade/Cut-and-Fill/Retained Fill	50 ft (15.2 m)	47 ft (14.3 m)
Aerial Structure	50 ft (15.2 m)	49 ft (15 m)
Tunnel (Double Track)	67 ft (20.4 m)	67 ft (20.4 m)
Tunnel (Twin Single Track)	120 ft (36.6 m)	120 ft (36.6 m)
Trench/Box Section	70 ft (21.3 m)	73 ft (22.2 m)

(Source: Parsons Brinckerhoff Team, 2001)

Dimensions and Spacing

Maglev and SWSR share similar vehicle dimensions and spacing requirements. The Florida HSIPR project indicated either technology could fit within their 44-foot-wide clearance envelope (see Figure 24). The maglev manufacturer, Transrapid, reported in their product literature that the minimum clearance envelope ranges from 33.1 feet to 37.4 feet, depending on speed (Transrapid International, 2003). The minimum 15-foot track centerline-to-centerline separation between two SWSR tracks is also comparable to the maglev technology (14.4 to 16.7 feet, depending on speed). The use of a double-deck HSIPR train, such as the one used by the French rail line SNCF, would of course require a taller envelope, depending on the manufacturer's design.

Figure 24 through Figure 34 present a gallery of HSIPR cross sections, for both SWSR and maglev, showing the range of dimensions and clearances for a variety of situations (e.g., elevated above at-grade highway and elevated above elevated highway).

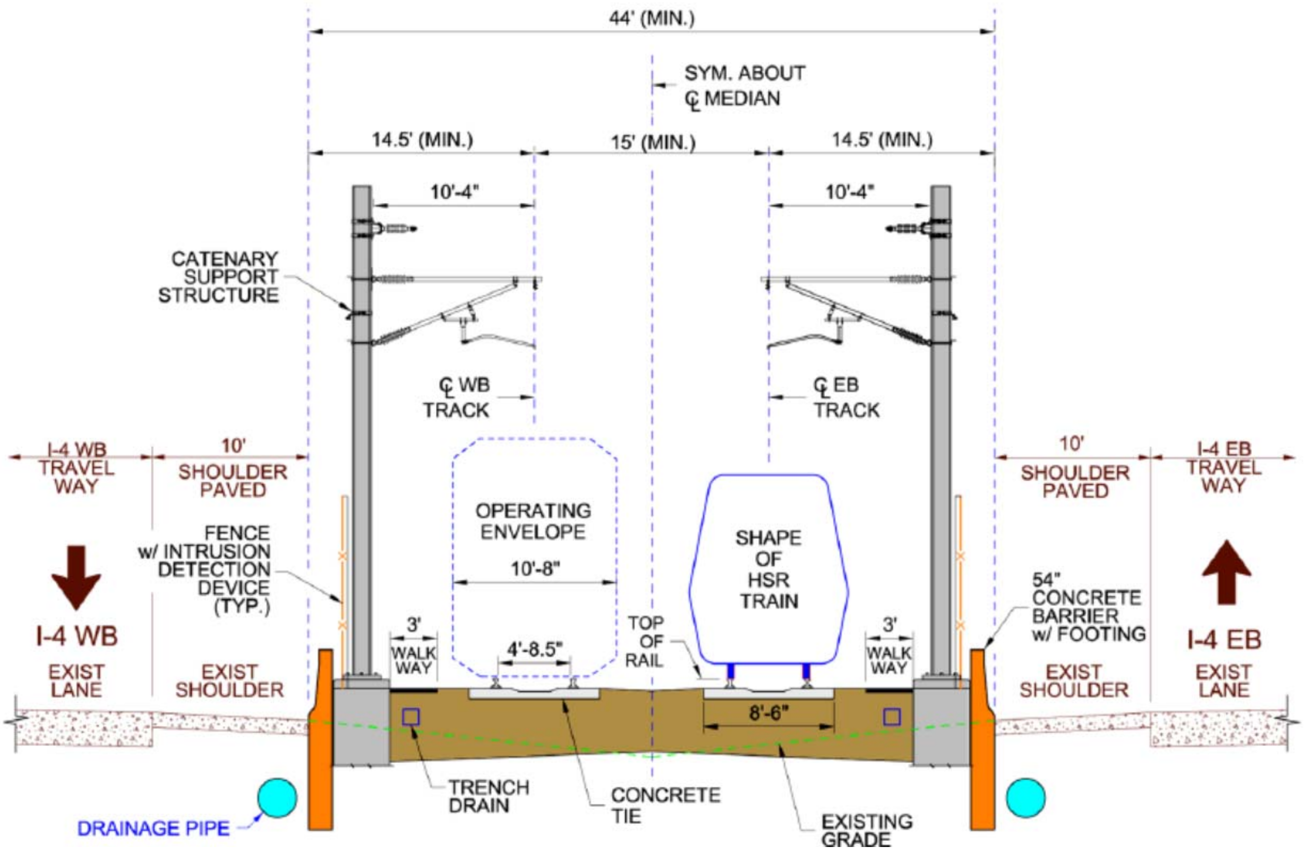


Figure 24. Florida High-Speed SWSR Cross Section

(Source: Share, 2010)

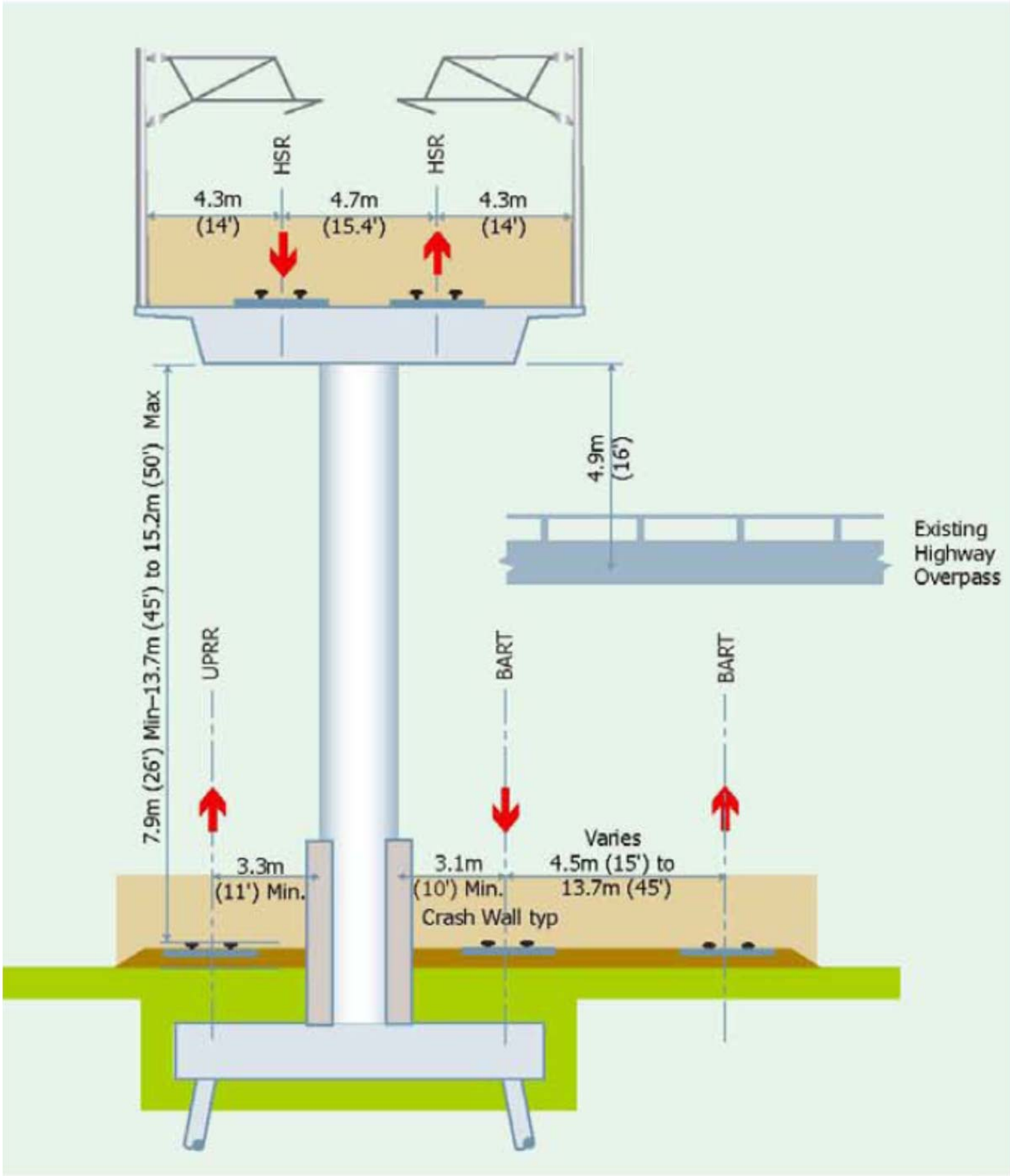


Figure 25. California to Nevada Elevated HSIPR above Highway Overpass and Rail Cross Section

(Source: California and Nevada Departments of Transportation, Federal Railroad Administration, 2009)

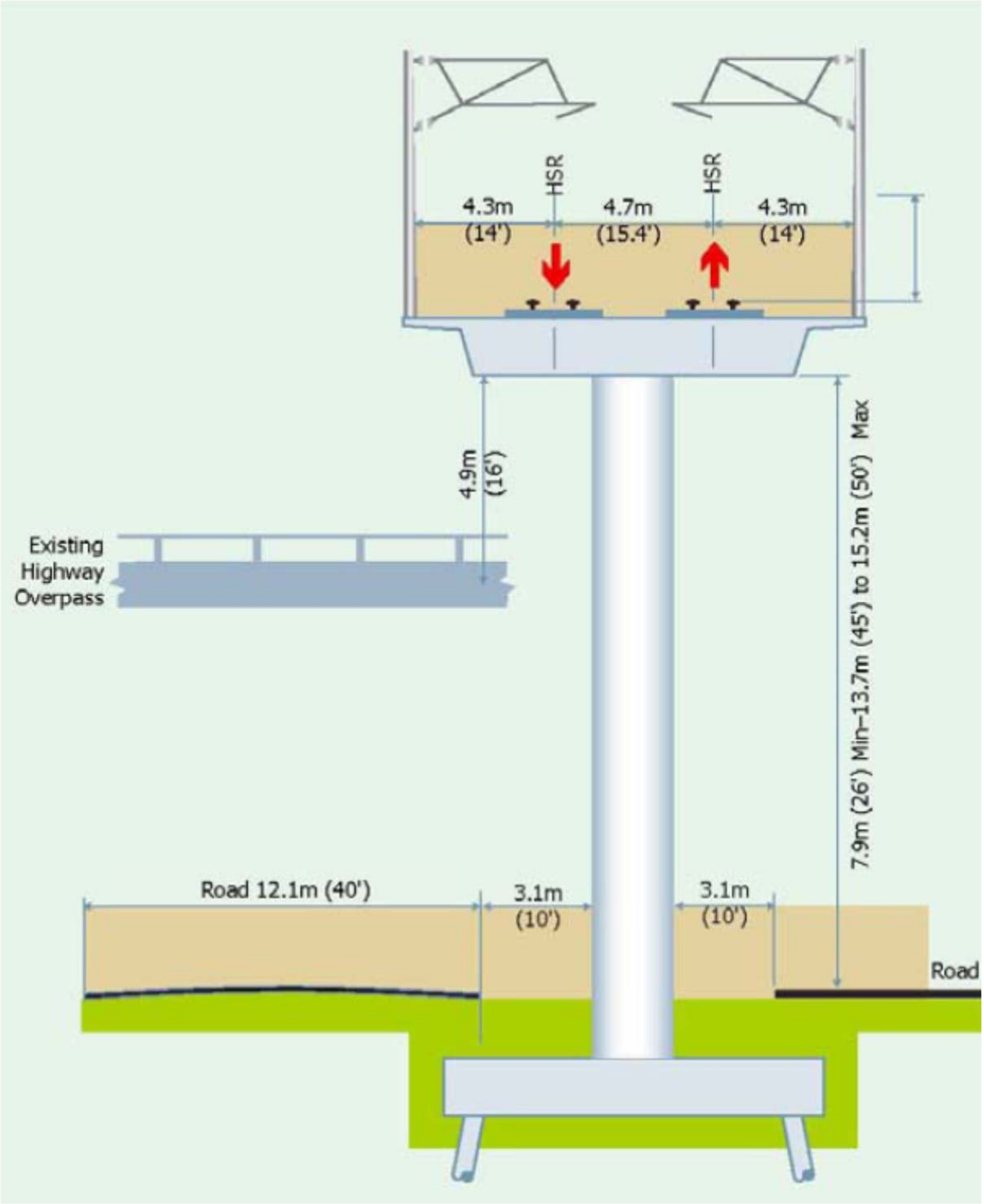


Figure 26. California to Nevada Elevated HSIPR above Highway Overpass and Road Cross Section

(Source: California and Nevada Departments of Transportation, Federal Railroad Administration, 2009)

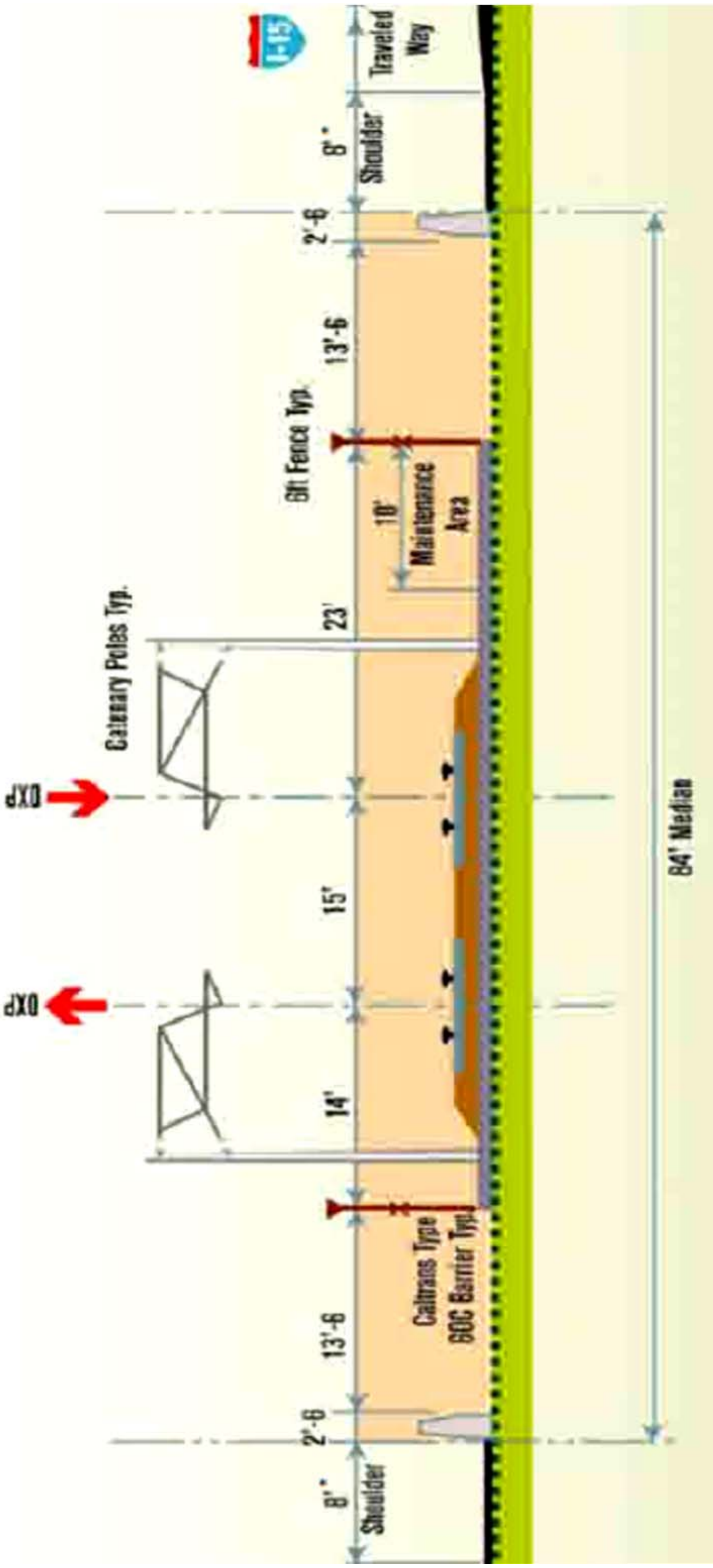


Figure 27. Typical Median Cross Section for DesertXpress
(Source: California and Nevada Departments of Transportation, Federal Railroad Administration, 2009)

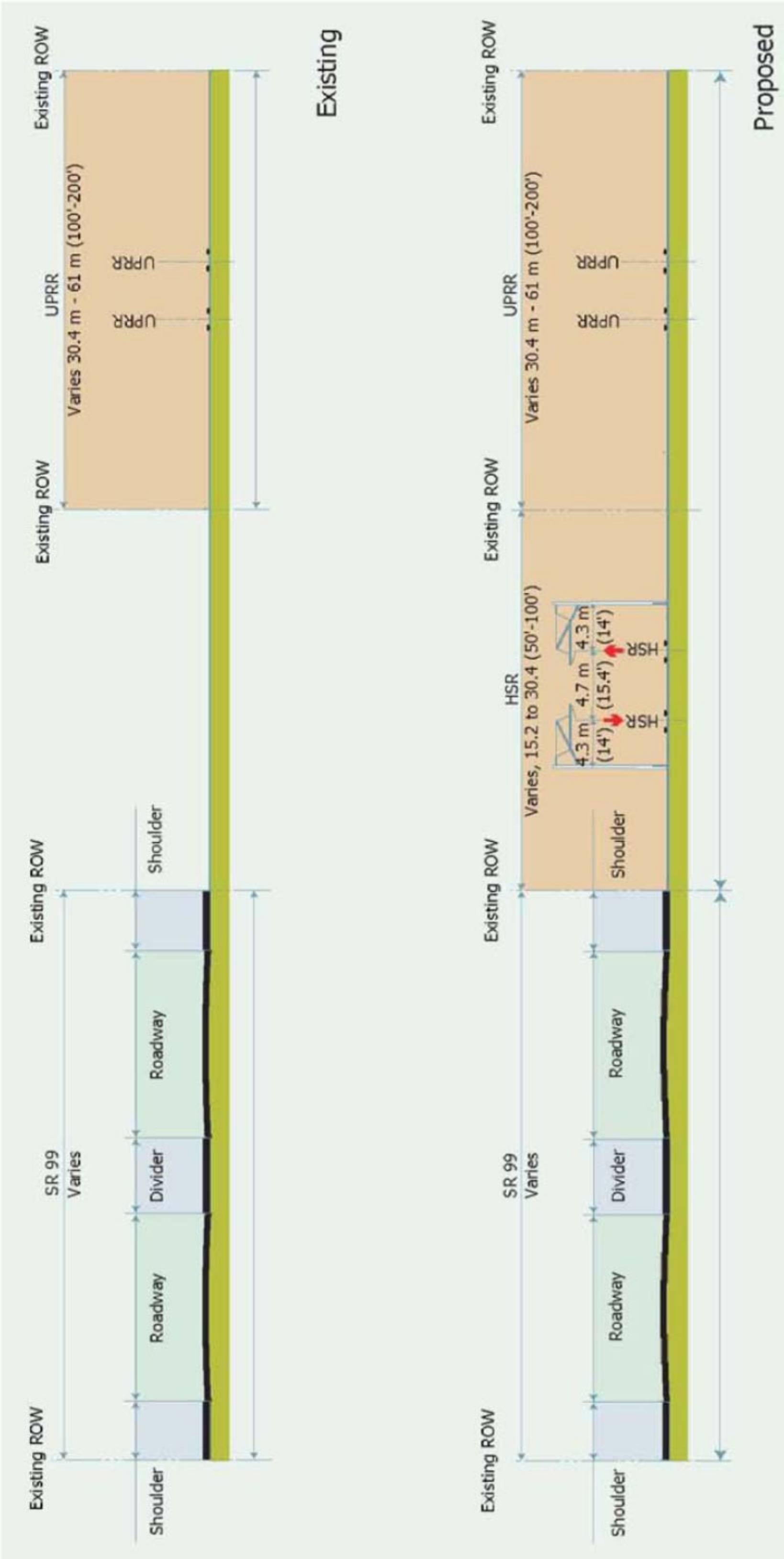


Figure 28. California Cross Section of HSIPR between Highway and Freight Rail

(Source: California and Nevada Departments of Transportation, Federal Railroad Administration, 2009)

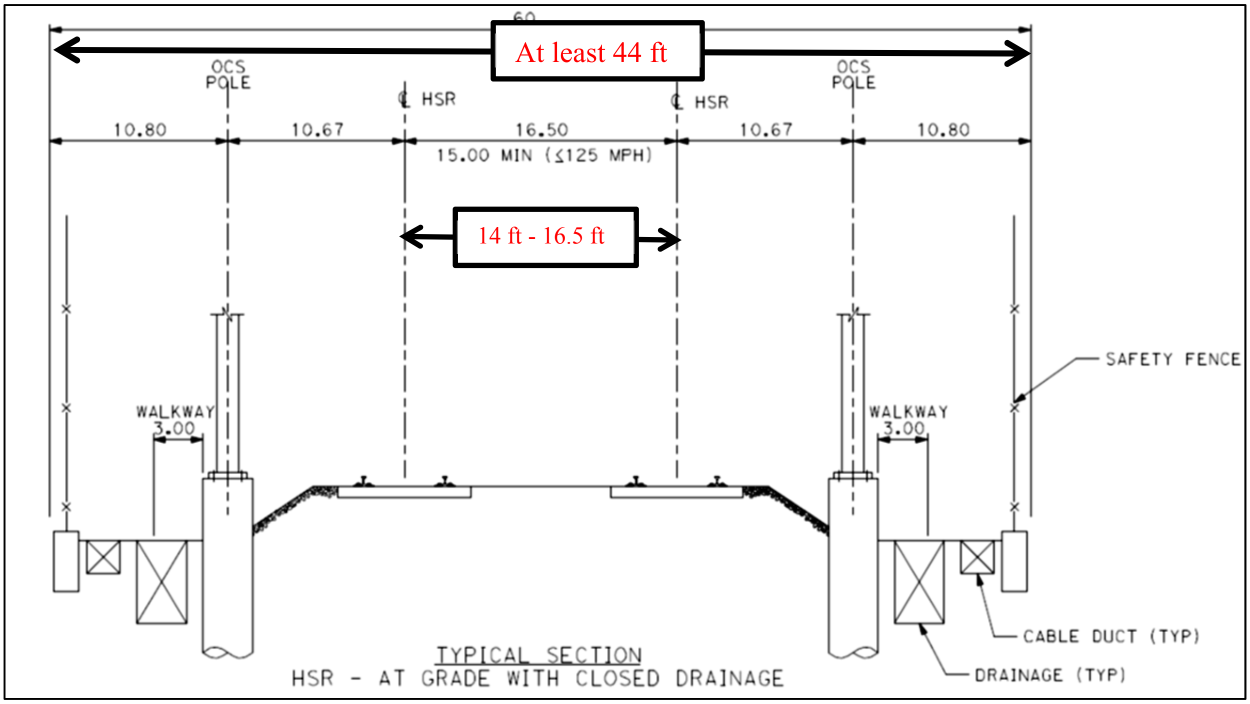


Figure 29. At-Grade Tracks
(Source: California High-Speed Rail Authority, 2009b)

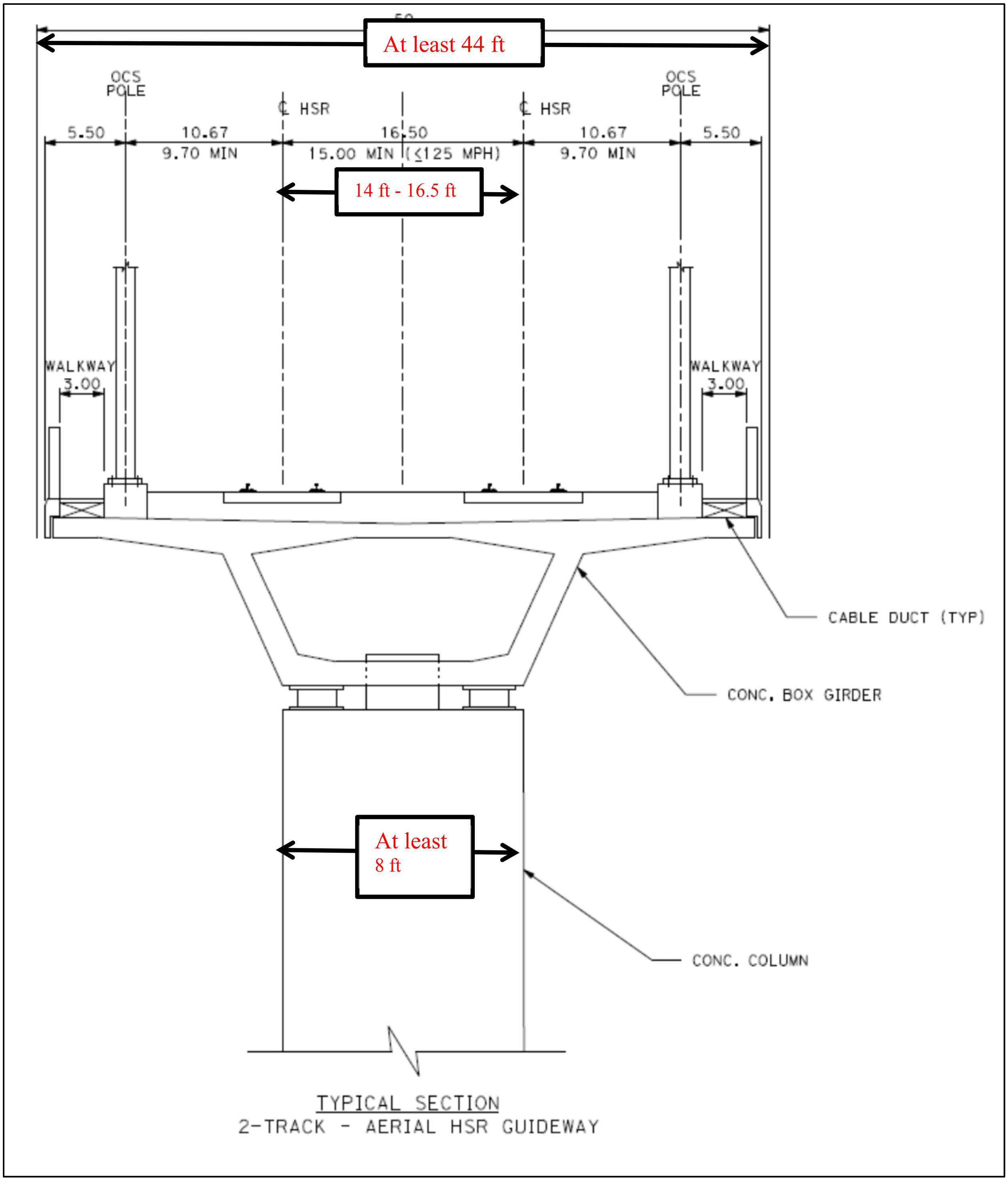


Figure 30. Elevated Dual Tracks
(Source: California High-Speed Rail Authority, 2009b)

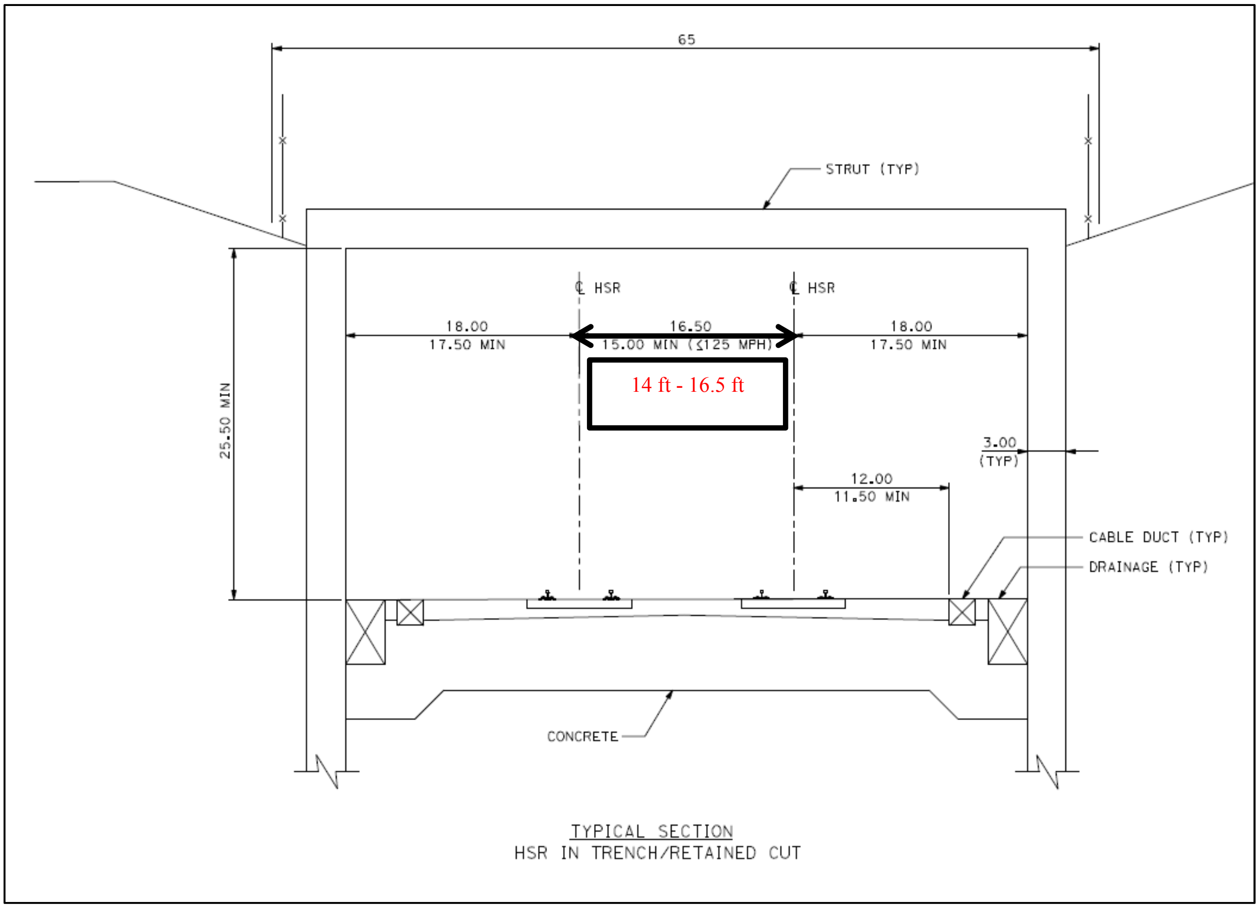


Figure 31. Trench/Retained Cut

(Source: California High-Speed Rail Authority, 2009b)

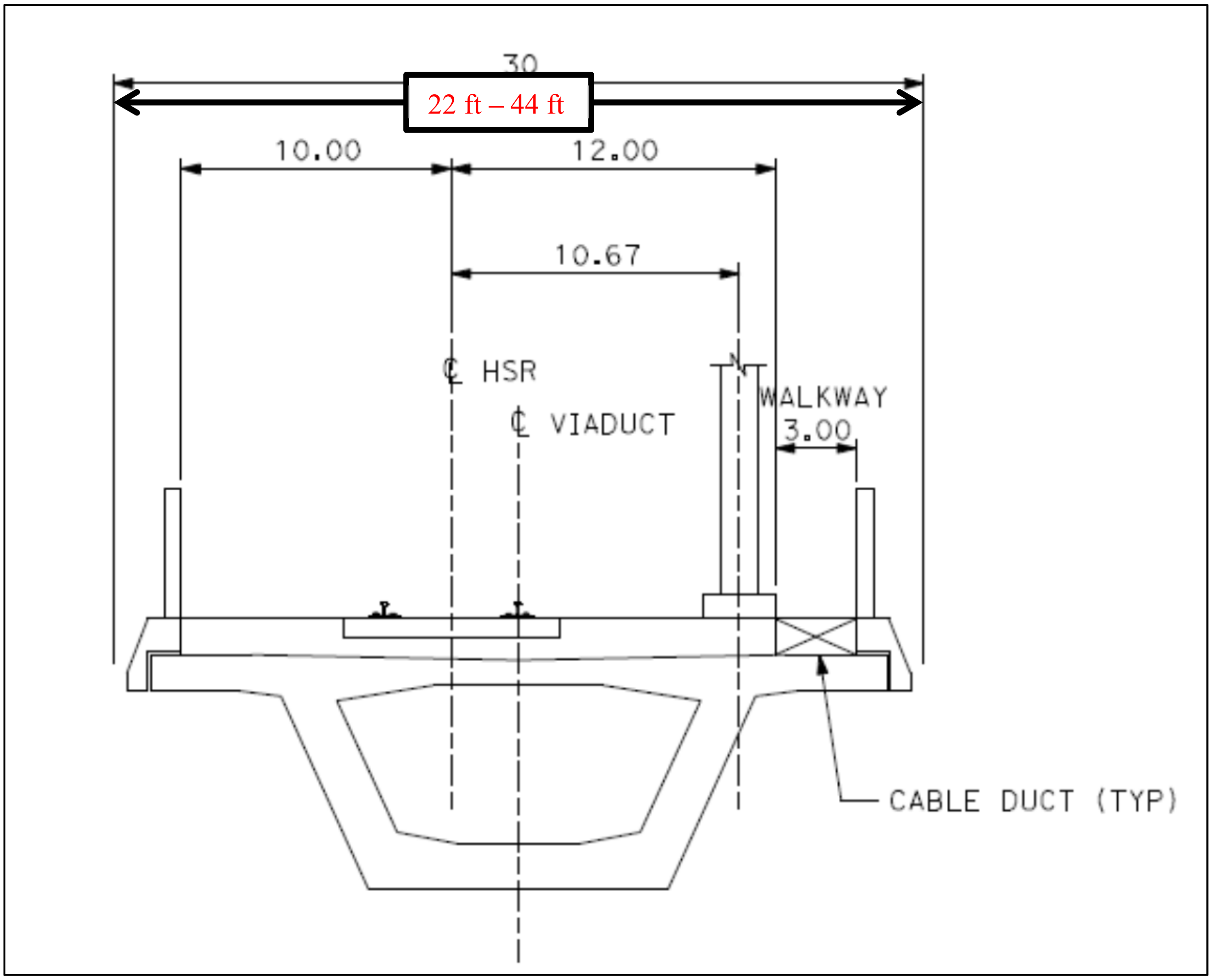


Figure 32. Viaduct

(Source: California High-Speed Rail Authority, 2009b)

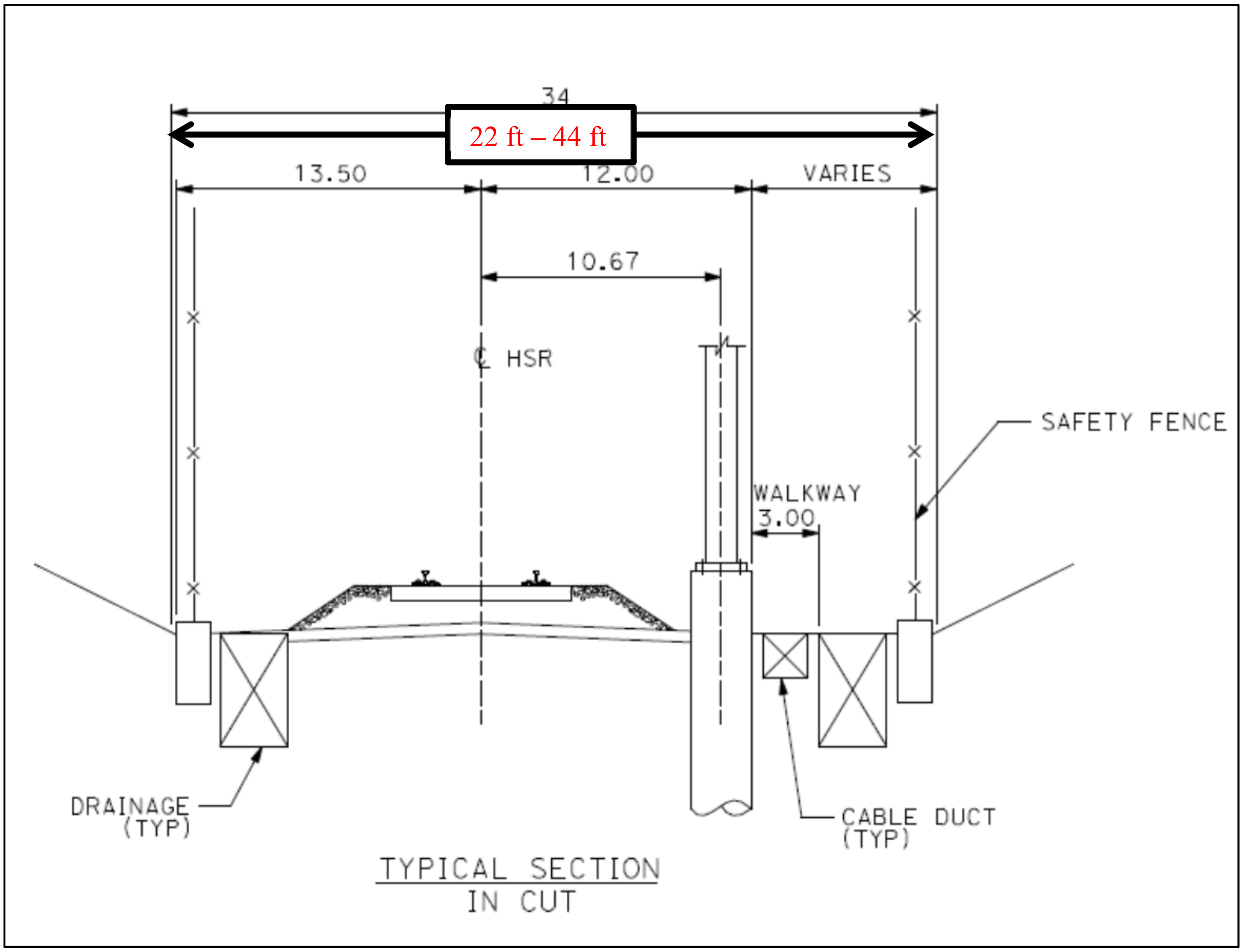


Figure 33. Section in Cut
(Source: California High-Speed Rail Authority, 2009b)

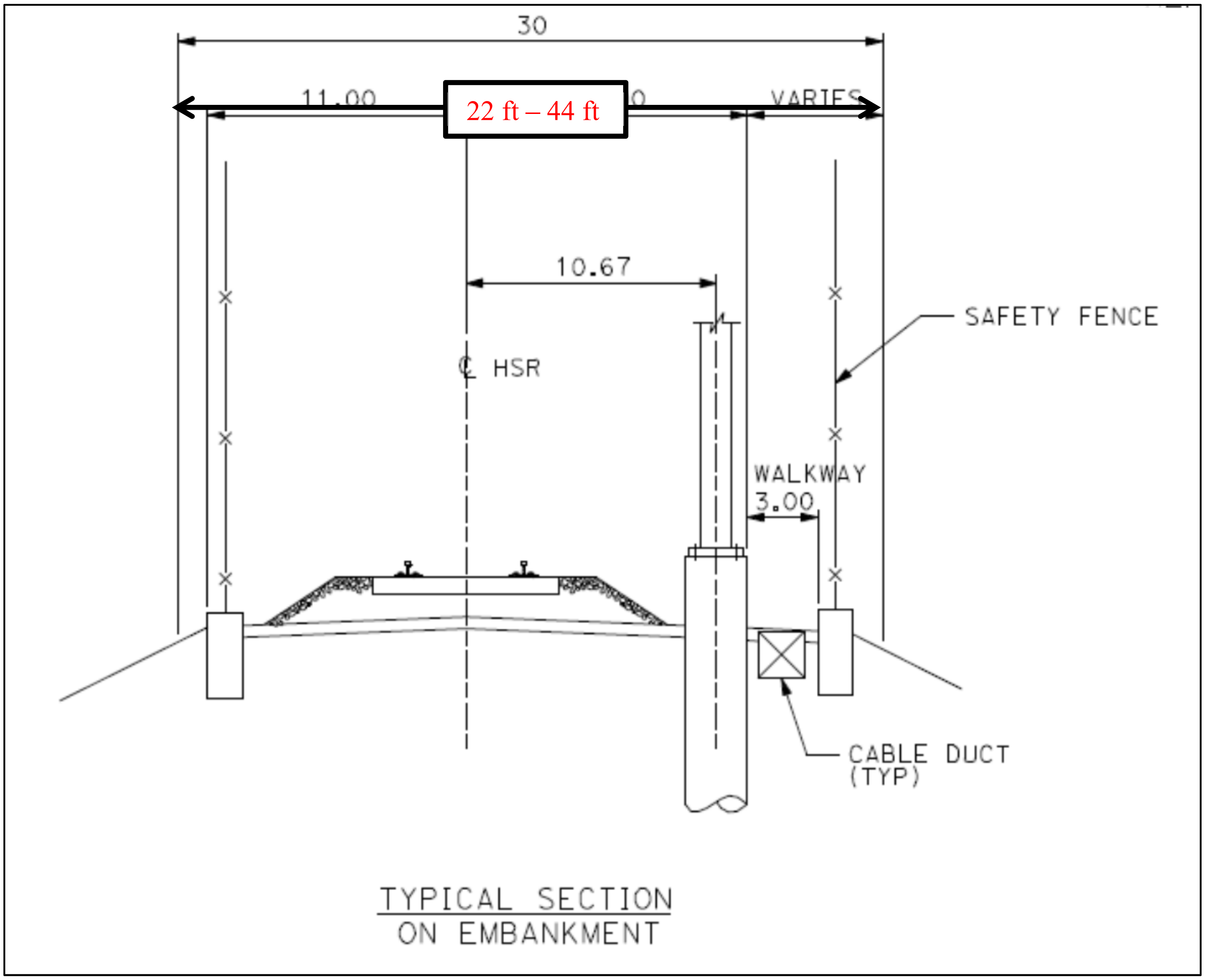


Figure 34. Section on Embankment
(Source: California High-Speed Rail Authority, 2009b)

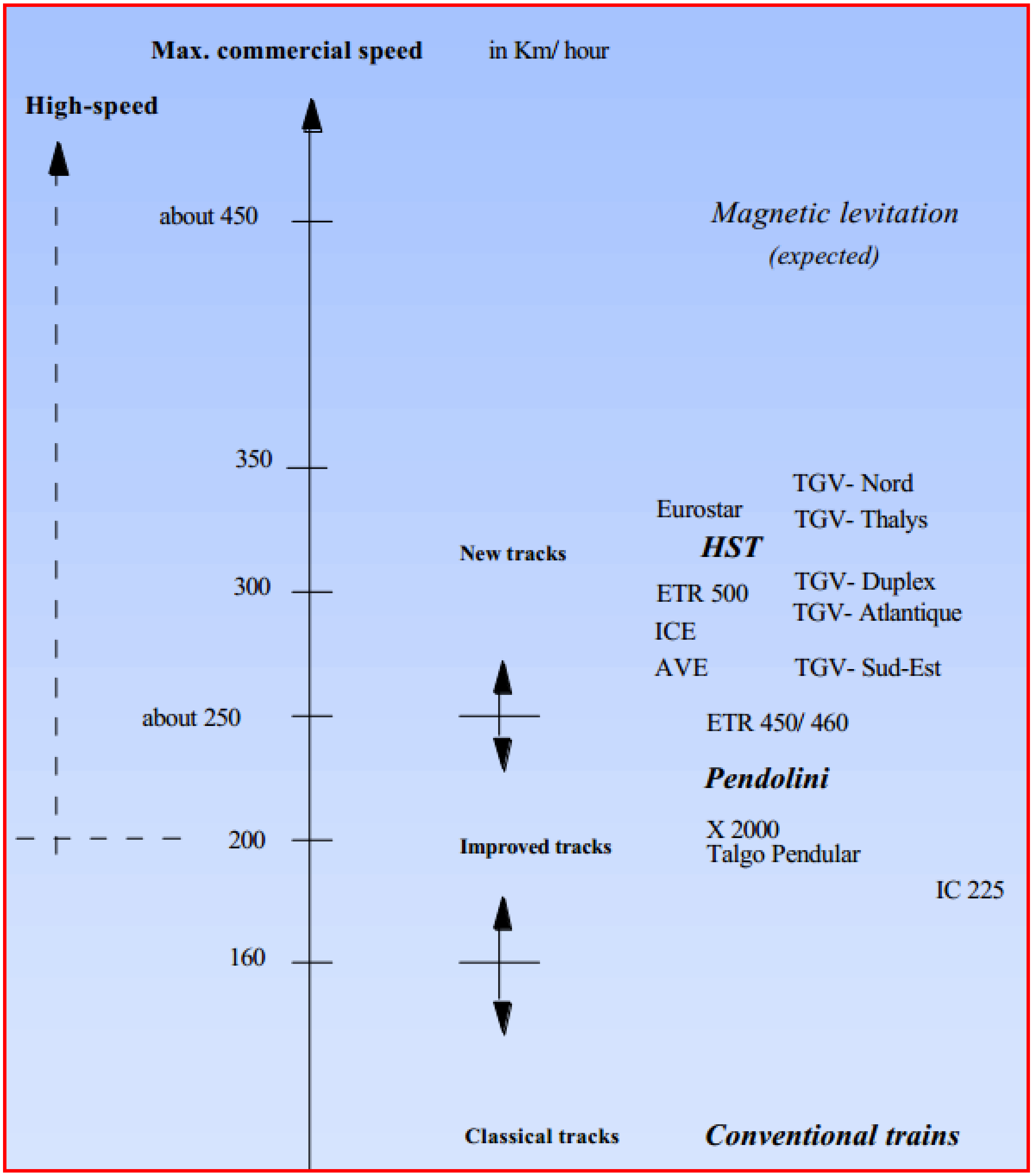
Speed

Table 8 presents speed ranges of the different rail technologies (Transportation Economics & Management Systems, Inc., 2010). SWSR trains cannot reach the higher speeds obtained by maglev technologies because the friction resistance between the wheels and the rail increases as the speed increases. Maglev's experimental, maximum, and operating speeds are much higher than those of other rail technologies because movement of the maglev train does not involve contact between the vehicle and the guideway (see Figure 35).

Table 8. Maximum Operating Speed by Rail Technology Category

Category	Avg. Operating Speed	Max. Operating Speed	Examples of In-Service Operation
 Diesel Rail	30-50 mph	79 mph	Amtrak (shown), New Mexico Rail Runner, Salt Lake City Front Runner
 High-Speed Diesel	50-70 mph	110-130 mph	Spanish Talgo (shown), German InterCity Express-TD
 High-Speed Magnetic Levitation	60-70 mph	125 mph	Japanese HSST (shown), American Maglev
 High-Speed Electric	70-150 mph	120-150 mph	Eurostar (shown) in U.K./ France/Belgium, German InterCity Express-T, American Acela
 Very High-Speed Electric	120-200 mph	150-220 mph	German InterCity Express (shown), French TGV, Japanese Shinkansen
 Ultra High-Speed Magnetic Levitation	250 mph	250-300 mph	Transrapid Maglev (shown) in Germany and Shanghai

(Source: Transportation Economics & Management Systems, Inc., 2010)



Note: 200 km/hr equates to approximately 124 miles/hr

Figure 35. Maximum Operating Speeds of Wheel on Rail and Maglev Technologies

(Source: Widmer, 2002)

Grades

Grades along the route can reduce the operating speed of a train. Maglev can operate at full design speed on grades of up to 10% (Transrapid International, 2003), whereas SWSR is limited to a grade of 3.0% to 4.5%, according to the product literature for the vehicle technologies. Power-distributed SWSR trains are able to operate at full speed at higher grades than are the power-concentrated SWSR trains. The higher grades permitted by maglev offer more flexibility in route alignments.

At the station and yard tracks, grades should not exceed 0.25% (Moore, 2004).

Curves

Curves along the route also limit the speed of a train. Trains experience centrifugal forces while traversing horizontal curves. Too high of a centrifugal force results in a number of undesirable effects, such as the following (Lindahl, 2001):

- possible passenger discomfort
- possible displacement of wagon loads
- risk of vehicle overturning in combination with strong side winds
- high lateral forces on the track
- risk of derailment

The maximum speed of a train traveling on a curve depends on the degree of curvature and the total superelevation (of the track and of the tilting capabilities of the train). Equation 1 is the equation specified by the FRA rules in 49 CFR 213.55; this equation relates train speed with superelevation and degree of curvature of the track curve. Any remaining force acting on the passenger that is not counteracted by the total superelevation created by the track and/or a tilting train is referred to as *cant deficiency*.

$$v_{max} = \sqrt{\frac{e_c}{0.0007D}} \qquad (1)$$

- D is the degree of curvature,
- e_c is the total superelevation, which is the sum of the physical superelevation of the track, the elevation of the train by tilt, and cant deficiency (in inches), and
- v_{max} is the maximum permissible speed in miles per hour (mph).

The formula $R = 5729.58/D$ converts degree of curvature to radius. The American Railway Engineering and Maintenance of Way Association's (AREMA) *2012 Manual for Railway Engineering* provides more information about designing curves for HSIPR systems.

The FRA regulates how much physical superelevation of the track and cant deficiency is permitted. The FRA Track Safety Standards (49 CFR Part 213) do not allow the outer rail of SWSR track to exceed a superelevation of 7 inches and limit cant deficiency to 3 inches unless the FRA qualifies a vehicle for additional cant deficiency after reviewing simulation and test results proving the additional deficiency does not adversely impact safety. The maximum total superelevation permitted by the FRA without approval for use of tilting trains is 10 inches.

The FRA permits tilting vehicles to increase potential cant deficiency if the vehicle qualifies for operation based on performance testing (49 CFR Part 213). Tilting mechanisms allow trains to travel through curves at higher speeds. If the tilting mechanism fails to work on a curve or fails to return to the upright position after a curve, passengers may experience discomfort.

To maintain high speeds in a corridor with curves, it may be advantageous to exceed 10 inches by seeking additional cant deficiency either by loosening passenger comfort criteria (thus allowing for higher lateral acceleration forces on passengers) or using tilt SWSR trains or maglev. Maglev trains do not have the capability to tilt; however, the guideway may be physically superelevated more than a steel-rail track. The maximum total superelevation attainable for maglev is 24 degrees (Transrapid International, 2003) and for SWSR is 18 degrees (Liu & Deng, 2003). Maglev can thus travel through curves faster than SWSR.

Additionally, maglev trains typically have better operating abilities than SWSR technologies when it comes to negotiating curves (Liu & Deng, 2004; Baohua et al., 2008). Figure 36 compares the minimum curve radius requirements of the maglev and the wheel rail technology.

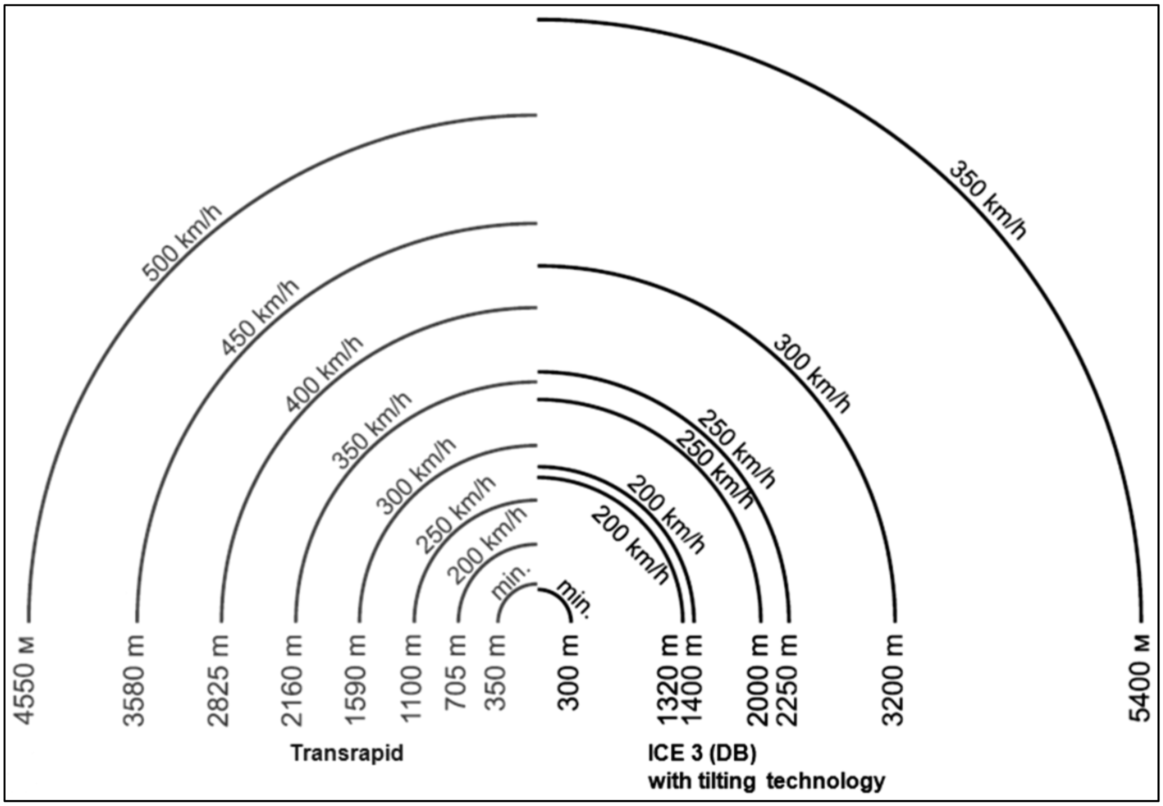


Figure 36. Comparison of Horizontal Radii of Wheel Rail (ICE) and Maglev (Transrapid) High-Speed Trains at Different Design Speeds
(Source: referenced in Retzmann, 2011)

In general, for SWSR trains without tilt mechanisms, the degree of curvature should not exceed one. A tilting train can negotiate curves at full speed with degrees of curvature greater than one, with the maximum depending on the maximum degree of tilt and the amount of permitted cant deficiency (AREMA, 2009). However, to maximize the extent of the route the train is able to travel at high speeds, HSIPR route designers prefer to keep the degree of curvature as small as possible. For instance, for the LGV Sud Europe Atlantique route in France, the minimum degree of curvature was 0.3, with 0.25 considered the optimal, for the design speed of 350 km/hr (218 mph) (Réseau Ferre' de France 2013).

In summary, the maximum allowable speed of the train traveling through a curve may be increased by making the following adjustments to the operation or technology of the train or the track design (Chandra, 2007; Peterson et al., 1985; Profillidis, 2000):

- increasing curve radius (decreasing degree of curvature),
- using tilting SWSR trains,
- using maglev trains,
- transitioning to a circular curve with a spiral curve, and/or
- increasing track superelevation.

Maglev offers the best route alignment flexibility because of its ability to handle higher grades and sharper curves at higher speeds. In fact, the 2005 FRA report on maglev's costs and benefits stated that the estimates for new high-speed SWSR may exceed those of maglev because SWSR route alignment is more constrained than is maglev's, which results in additional costs associated with tunneling or route straightening that would not be encountered with the more flexible route design offered by maglev technology (Federal Railroad Administration, September 2005).

3.1.4 Electric HSIPR Power Supply Facilities

Electric-powered HSIPR (locomotive, EMU, or maglev) requires physical connections to the electric power grid. Propulsion power is delivered to the electric HSIPR from a series of autotransformers and electrical supply substations located along the route. Autotransformers help to maintain and regulate voltage along the line (California and Nevada Departments of Transportation, Federal Railroad Administration, 2009).

A review of the draft EISs for the HSIPR projects in the US furthest along in planning (Florida, California-Nevada XpressWest, Pennsylvania maglev, and the California statewide system) provides some guidance on the sizes and quantity of the substations needed along a route.

Three electric substations were planned for the Tampa-to-Orlando HSIPR route, which provides the benefit of providing a back-up power supply if one of the substations failed (Florida High-Speed Rail Authority, 2005). The amount of land needed and the design requirements for the substations were not provided in the EIR/EIS for the project.

The XpressWest (formerly called DesertXpress) HSIPR EMU planned for operation between Victorville, California (outside Los Angeles), and Las Vegas, Nevada, also would require at least three substations: one near the ends of the rail line and one at the midpoint (California and Nevada Departments of Transportation, Federal Railroad Administration, 2009). The plans are to co-locate the substations with the operation and maintenance facilities for the HSIPR at the endpoints of the line and the maintenance of way facility at the midpoint of the line.

Preliminary engineering for the DesertXpress called for 17 autotransformers at 10- to 12-mile intervals along the HSIPR line, with physical footprints of about one-tenth to one-fifth of an acre (California and Nevada Departments of Transportation, Federal Railroad Administration, 2009).

To connect the DesertXpress HSIPR to the electric power grid, three utility corridors would have to be created with the following characteristics (California and Nevada Departments of Transportation, Federal Railroad Administration, 2009):

- located parallel and along existing roadways (including i-15)
- typical width of 100 feet
- 10-foot wide access road
- electric pole height ranging from 95 to 135 feet
- electric pole spacing between 44 to 940 feet
- electric pole footprint of 24 to 59 square feet (sf)
- typical voltage of 230 kv, with 66kv power distribution

The California EIR/EIS for the Bay Area to Central Valley specified more details regarding the electrical infrastructure needed to support the HSIPR system (California High-Speed Rail Authority, 2008):

- supply substations required about every 30 miles with a footprint of about 20,000 sf (200 feet by 100 feet)
- electric switching stations required about every 15 miles, with a footprint of about 7,500 sf (150 feet by 50 feet)
- booster stations required every 7.5 miles with footprints of about 5,000 sf (100 feet by 50 feet) with a 800 sf (40 feet by 20 feet) control house

Sibal (2011) provides a more detailed description of the electric infrastructure needed for the California HSIPR project.

The Pennsylvania maglev plans five electrical substations, with each one located generally within 2 miles of a passenger station. The EIR/EIS for the Pennsylvania maglev noted the factors affecting the number and location of the maglev electrical substations:

- alignment length,
- minimum vehicle headway requirements,
- maximum load,
- maximum speed,
- maximum gradient, and
- station locations and dwell times.

With maglev, the guideway is divided into propulsion segments of length between 0.3 to 1.2 miles. Electrical switch stations switch the propulsion power from one segment to the next (Federal Railroad Administration, Port Authority of Allegheny County, and Pennsylvania Department of Transportation, May 2010).

When planning for use of existing ROW for electric-powered HSIPR, consideration must be given to the additional utility corridors required to connect the system to the electric grid and to the space for facilities required to support the electric supply (e.g., autotransformers and substations).

3.1.5 HSIPR Station and Maintenance Areas

The environmental impact studies, such as EISs, conducted for HSIPR projects proposed in the US provide useful information regarding the requirements for station and maintenance areas.

Stations

The location depends greatly on the ridership demand forecasts and travel time impacts, and the size of stations depends on the land uses and development surrounding proposed stations. The speed of the train should also influence the station spacing, with greater station spacing recommended for faster trains, to take full advantage of the speed capabilities of the train technology.

For Florida's HSIPR project, an area of 20 acres was assumed as the preferred station size to accommodate parking, station buildings, and bus and local rail access (Florida Department of Transportation, 2009).

Figure 37 and Figure 38 present examples of the stations in Nevada of about 20 acres or more considered as part of the EIS for the DesertXpress HSIPR project.

The size and types of facilities planned for California's statewide HSIPR system stations depends heavily on the existing development around the station. To minimize impacts to travel time, the stations for the statewide California HSIPR system are located about 50 miles apart in rural areas and 15 miles in urban areas (California High-Speed Rail Authority, 2008). Figure 39 presents a map of the maintenance facilities planned for the statewide HSIPR system.

The development constraints around passenger stations required the planners of the system to locate the majority of the operation, storage and maintenance facilities away from passenger stations (California High-Speed Rail Authority, 2008).

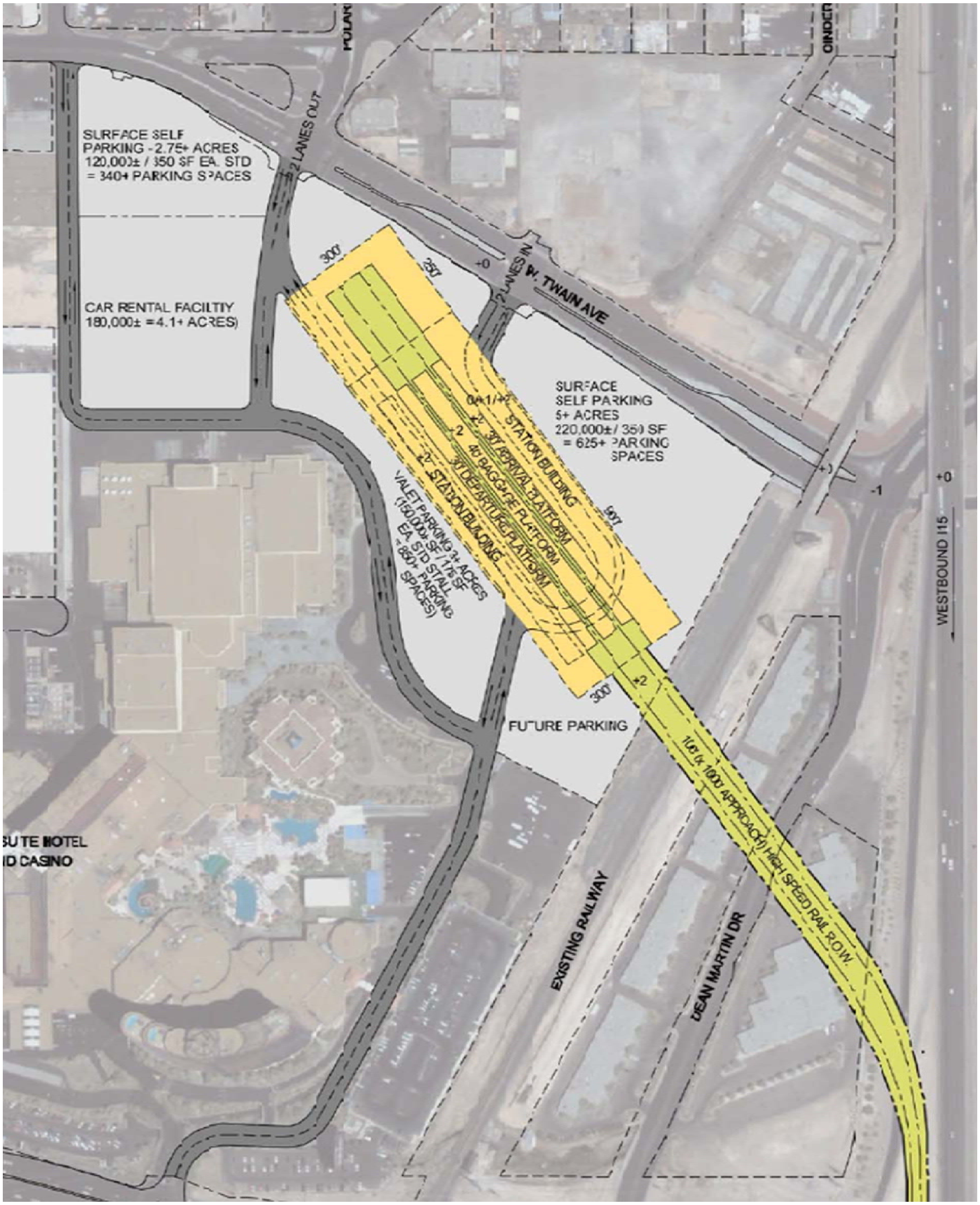


Figure 37. Las Vegas Central Station Option A
(Source: California and Nevada Departments of Transportation, Federal Railroad Administration, 2009)

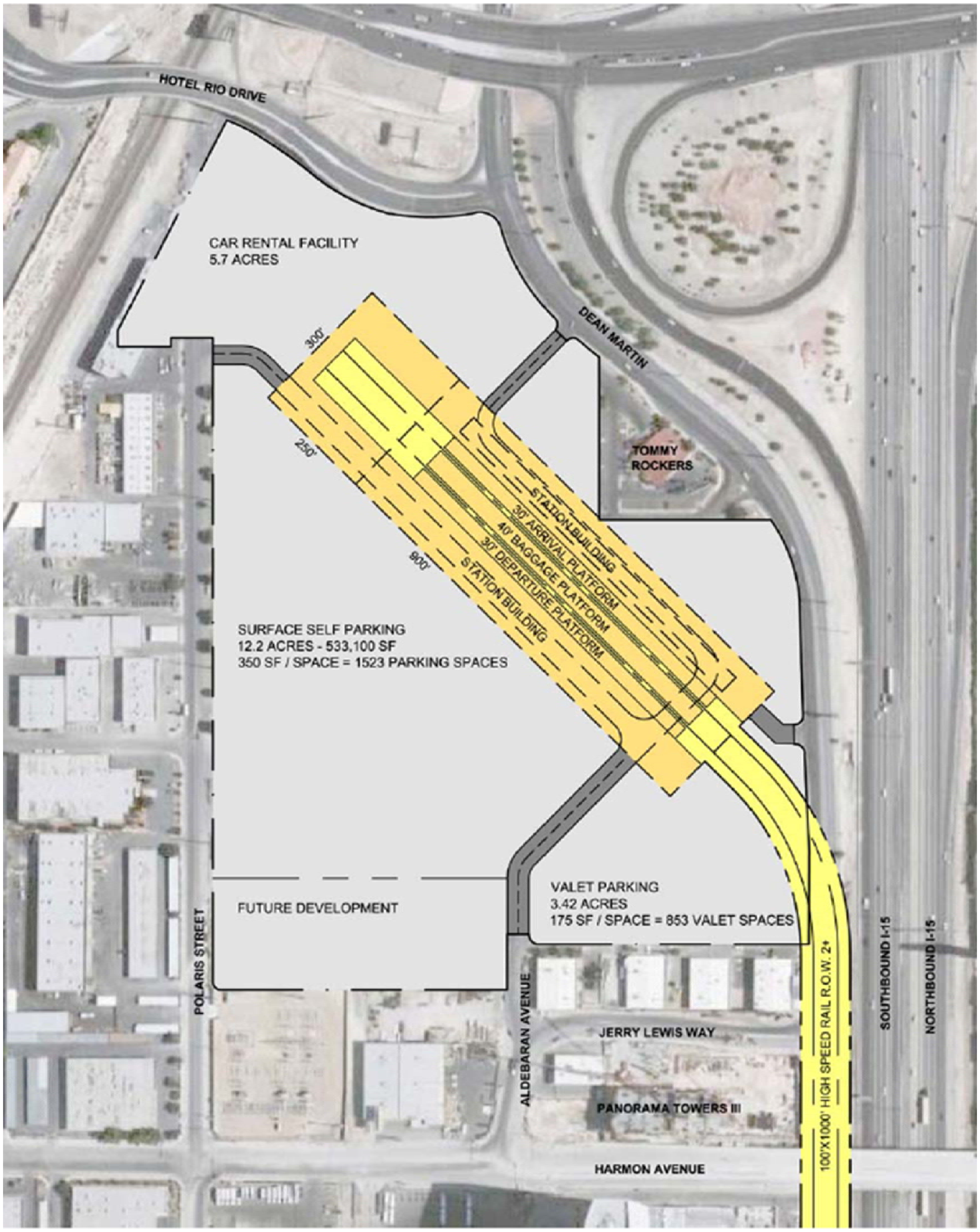


Figure 38. Las Vegas Central Station Option B
(Source: California and Nevada Departments of Transportation, Federal Railroad Administration, 2009)

Operation and Maintenance Facilities

According to the HSIPR planning experiences of other states, this study identifies the following criteria related to station size and maintenance areas:

- Florida's HSIPR project assumed a minimum of 20 acres as the preferred station size to accommodate parking, station buildings, and bus and local rail access (Florida Department of Transportation, 2009)
- California allocated 50 acres for their main maintenance facility and 7 to 10 for light maintenance, storage, cleaning, and inspection facilities
- Pennsylvania allocated 35 acres for their maglev facility (California High-Speed Rail Authority, 2008).

To minimize the cost and travel time associated with moving trains to and from repair and maintenance facilities, the facilities should be located as close as possible to the HSIPR alignment.

California

The California High-Speed Rail Authority's (CHSRA) website includes a report that gives an extensive discussion of the siting and sizing of operation and maintenance facilities (Campbell & Hanakura, Technical Memorandum: Terminal and Heavy Maintenance Facility, 2009). The California statewide HSIPR system planned for only one fleet storage, service, and light maintenance facility for each major branch of the system (i.e., San Francisco Bay Area, Sacramento for Central Valley, and Southern California) located as close to the terminal passenger stations as possible. Only one major repair and maintenance facility is planned for the entire statewide system, located on the portion of the route near Bakersfield, which is the location expected to have the majority of trains pass by (California High-Speed Rail Authority, 2008).

Florida

The 2005 Final EIS for the Florida project recommended two alternative sites for the one major repair and maintenance facility: one south of the Orlando International Airport (at the east end of the HSIPR line) and one north of the airport (Florida Department of Transportation, 2009).

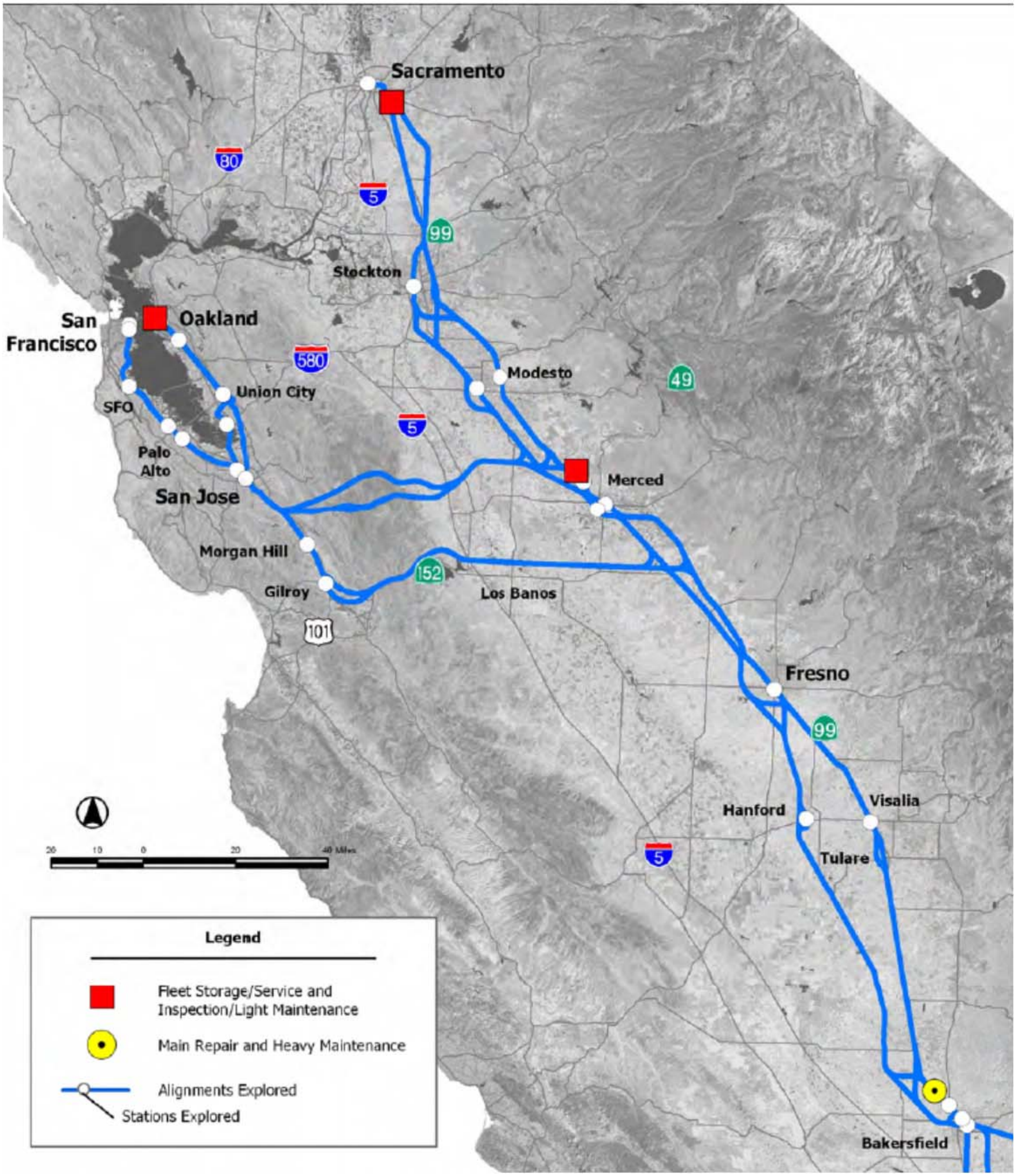


Figure 39. Light and Heavy Maintenance Facilities Planned for California Statewide HSIPR System
(Source: California High-Speed Rail Authority, 2008)

Colorado

The feasibility study for the proposed Colorado HSIPR SWSR system serving Denver noted the importance of knowing the length of the trains to be placed in service to be able to plan for appropriately-sized operations and maintenance facilities (Transportation Economics & Management Systems, Inc., 2008). Additionally, maintenance facilities would most likely rely on turn tables rather than curved track in order to save space.

Transportation Economics & Management Systems, Inc. (2008) in their feasibility study for HSIPR for Colorado referred to the Pittsburgh maglev plans to provide a maglev maintenance facility that requires about 35 acres (Federal Railroad Administration, Port Authority of Allegheny County, and Pennsylvania Department of Transportation, May 2010).

Pennsylvania Maglev

The Pennsylvania maglev 35-acre facility (Figure 40) would consist of the following (Federal Railroad Administration, Port Authority of Allegheny County, and Pennsylvania Department of Transportation, May 2010):

- five vehicle bays with all-weather coverage of a five-section area approximately 420 feet in length.
- multi-story operation and maintenance center building, a visitor center, employee and visitor parking, maintenance vehicle parking and storage, open air vehicle storage, and the guideway, switches, and transfer table.

California XpressWest

The EIS for the DesertXpress SWSR planned for the operations (including the central control room), maintenance, and storage facility to be approximately 50 acres in size and located in the southern end of the route (California and Nevada Departments of Transportation, Federal Railroad Administration, 2009). The light maintenance, storage, cleaning, and inspection facility, located at the northern end of the route in the Las Vegas area, would be approximately 7 to 10 acres in size.

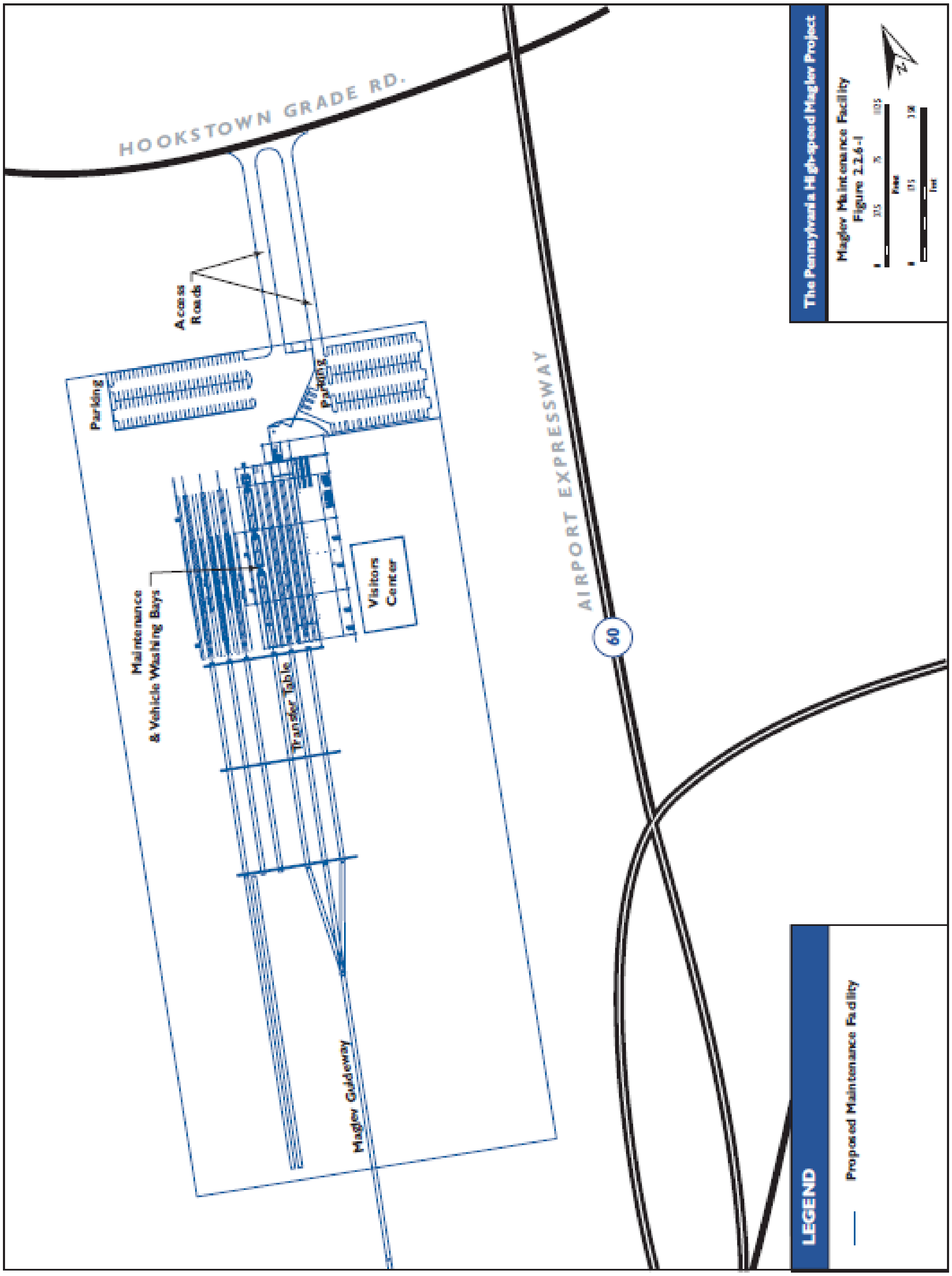


Figure 40. Pennsylvania Maglev Maintenance Facility

(Source: Federal Railroad Administration, Port Authority of Allegheny County, and Pennsylvania DOT, May 2010, pp. 2–9)

3.2 Dedicated Freight Transportation Systems

3.2.1 Freight Pipeline

Freight pipelines convey freight using the buoyant forces of air (pneumatic capsule pipelines) or water (hydraulic capsule pipelines), or the support of wheels or wheel and rail, to transport freight through an underground pipe (Figure 41). Howgego (2000) presented examples around the world of operational freight pipelines such as the 1- and 1.2-meter-diameter Russian TRANSPROGRESS systems constructed in 1971 and 1979, respectively, that transport crushed rock. A 427-meter-long, 0.92-m-diameter prototype system was built by TRANSCO Energy Corporation in Houston, Texas, in 1971 (Goff, Patil, & Shih, 2000).

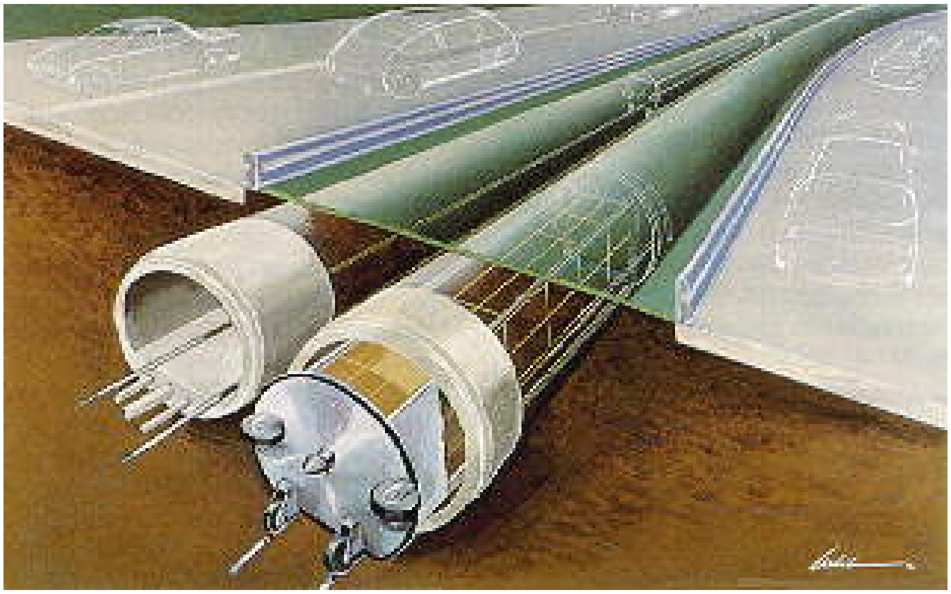


Figure 41. Tube Freight Transport
(Source: http://www.fhwa.dot.gov/publications/publicroads/94fall/p94au21.cfm)

The design requirements tend to be more stringent and complicated for freight pipelines than for the freight shuttle system or the HSIPR technologies because of the need to accommodate the change from underground to aboveground operations and to avoid turns and curves as much as possible. The pipelines need to be as straight as possible for pneumatic conveyance (Egbunike & Potter, 2011).

Egbunike & Potter (2011) noted that most of the actual and proposed freight pipeline systems in Europe focused on deliveries in urban environments, and the applications in other parts of the world focused on deliveries in industrial environments. Vance and Mills (1994) suggested use of federal ROW for implementing freight pipeline.

TTI conducted research in 1997–1998 resulting in a report titled *Feasibility of Freight Pipelines to Relieve Highway Congestion* (Goff, Patil, and Shih, 2000) that described the freight pipeline technologies and evaluated the benefits and limitations of and possible corridors to implement freight pipelines in Texas. Existing and forecasted levels of congestion along both the urban and rural segments of Texas highways prompted consideration of alternatives such as freight pipelines. Goff, Patil, and Shih (2000) performed a qualitative feasibility analysis of adding freight pipelines between San Antonio and Dallas-Fort Worth parallel to I-35 and determined the tube freight concept to be institutionally and technologically feasible, safer, and more reliable than the truck mode.

TTI began a multi-year study investigating the feasibility of a solid freight conveying pipeline system in Texas. Their first year report, titled *The Technical and Economic Feasibility of a Freight Pipeline System in Texas—Year 1 Report*, explained TTI's decision to examine the Dallas-to-Laredo corridor for a potential freight pipeline system because of the potential for the greatest modal shift from highway truck traffic to the freight pipeline, provided a brief history of freight pipelines, and described the system engineering for a freight pipeline system (Roop et al., 2000, p. 20).

By year three, however, Roop et al. (2000) cited concerns about the costs associated with excavation, tunneling, and related infrastructure for an underground freight system such as freight pipelines, and the logistics of transloading pallets between the pipeline and containers used by ships, trucks and rail (Roop et al., 2003). As an alternative, Roop et al. (2003) recommended use of freight shuttle systems instead.

3.2.2 Freight Shuttle System

The freight shuttle system envisioned and patented by TTI (Roop et al., 2003) would transport containers and truck trailers on shuttles operating on a fixed guideway (see Figure 42 through Figure 45), using linear induction motors (LIM) at speeds around 60 mph (Roop 2010). Figure 44 shows the components and benefits of the freight shuttle system. The 6-foot column diameter would allow the shuttle system to fit within existing highway or rail ROW (Roop 2010).

Figure 42. Freight Shuttle System Elevated over Highway Interchange
(Source: TxDOT 2013 TIGER Grant Application for El Paso Freight Shuttle)

Figure 43. Elevated Freight Shuttle System
(Source: TxDOT 2013 TIGER Grant Application for El Paso Freight Shuttle)

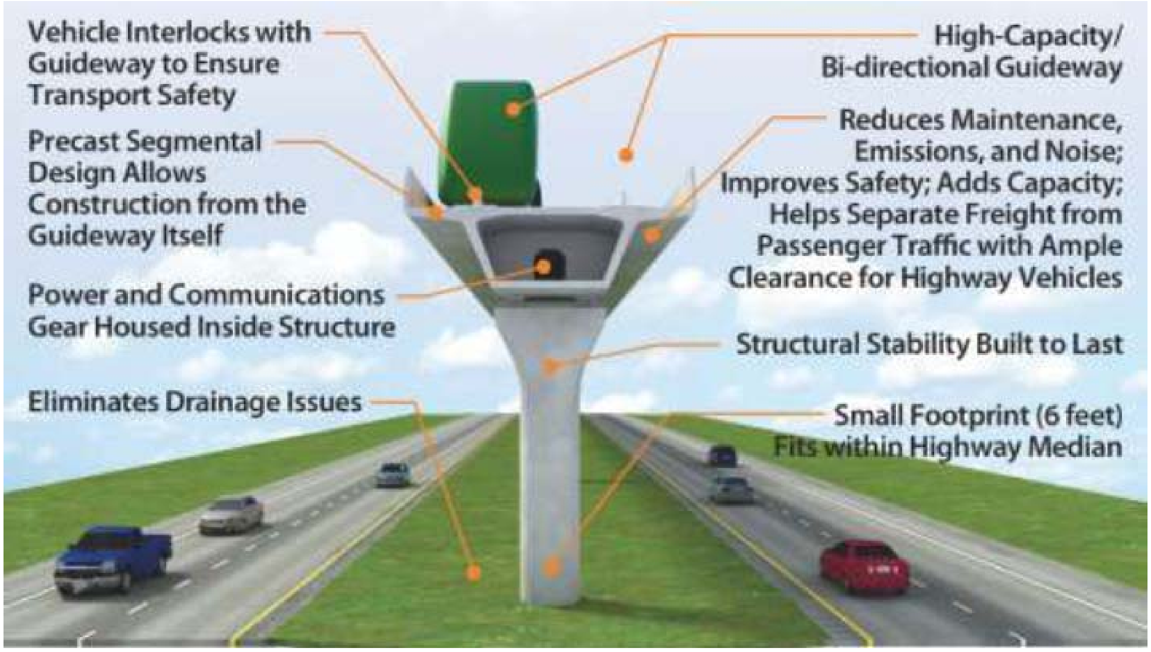


Figure 44. Components of Freight Shuttle System
(Source: TxDOT 2013 TIGER Grant Application for El Paso Freight Shuttle)

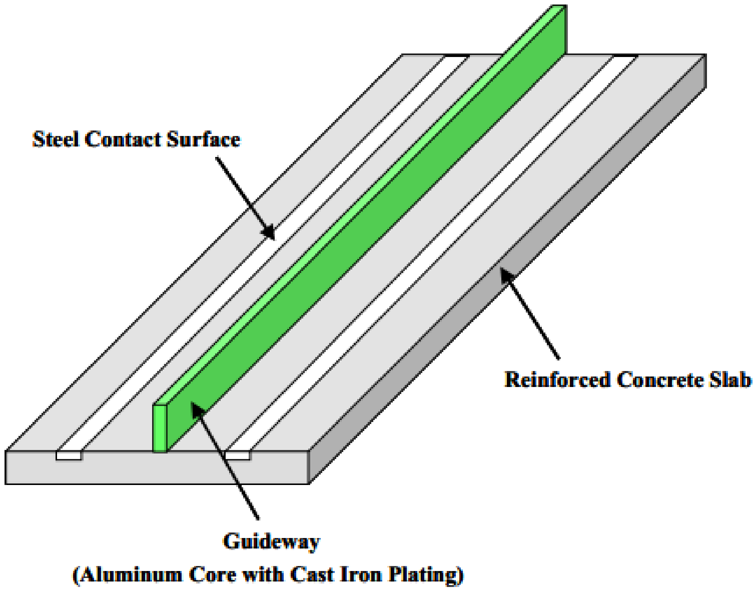


Figure 45. Freight Shuttle Guideway
(Source: Roop et al., 2003)

Figure 46 and Figure 47 present some of the fixed guideway's dimensions and Figure 47 presents the span length ranges. The documentation provided by TTI to TxDOT (Roop et al., 2003) does not include specifications of other design requirements, such as maximum curvature and grades and power supply facility requirements. However, the system shares characteristics with trucks (speed and size) and maglev (LIM) and thus shares design requirements similar to those transportation modes.

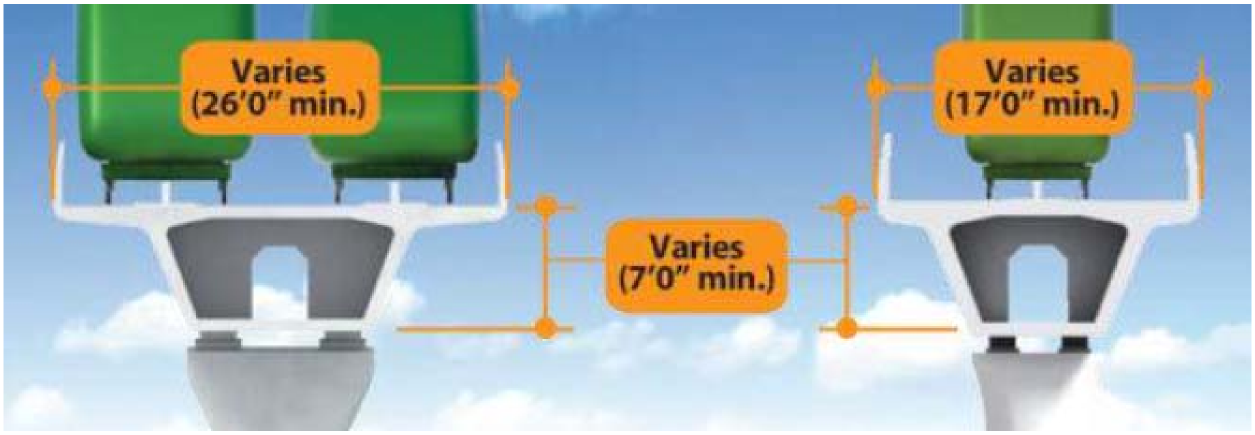


Figure 46. Freight Shuttle Guideway Dimensions
(Source: TxDOT 2013 TIGER Grant Application for El Paso Freight Shuttle)

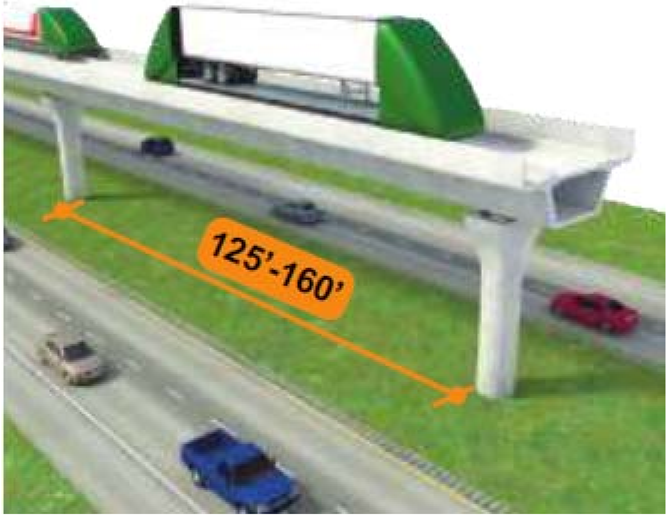


Figure 47. Freight Shuttle Span Length
(Source: TxDOT 2013 TIGER Grant Application for El Paso Freight Shuttle)

3.3 Feasibility Methodology

The methodology for determining feasibility encompasses the data and tools TxDOT can use to determine at a preliminary, sketch-planning level if a highway ROW corridor is suitable for HSIPR or dedicated freight transportation systems. Feasibility is determined by evaluating the characteristics of the ROW that affect HSIPR or freight transportation operations the most:

- curvature
- clearance (lateral and vertical),
- obstructions, and
- grades.

There are, of course, other factors affecting physical design and location, such as stormwater drainage and soils, to consider in more detail after the sketch-planning level.

Section 3.1 described the curvature, clearance, and grade requirements for the HSIPR and dedicated freight transportation technologies. This section describes how to use existing data to evaluate the potential of a ROW corridor using tools such as ArcGIS, the geographic information systems (GIS) software used by TxDOT and by the researchers for this project.

3.3.1 Curve Feasibility

Examining the feasibility of utilizing existing highway ROW at the sketch-planning level requires determining the degree of curvature of all the curves along the ROW route, and the distance between those curves, using maps, DOT curve data, aerial photos, or GIS data.

Curve data can come from the GeoHiNI database maintained by TxDOT. GIS can extract radius-of-curvature data from existing ROW if the GeoHiNI database is incomplete or inaccurate, based on an assessment using aerial images or centerline GIS features. The Florida DOT's curvature extension tool or the ArcGIS COGO tool can correct inaccuracies found with the GeoHINI curve data.

The Florida DOT developed and posted on their website a downloadable ArcGIS extension tool designed to measure simple circular curves from roadway centerline GIS shape files (Figure 50); see http://www.dot.state.fl.us/planning/statistics/gis/. Larsen (2010) evaluated the feasibility of using existing I-35 ROW between Austin and San Antonio by making use of the Florida DOT GIS tool. The Florida DOT GIS curvature extension tool was determined by a recent published article to also be an accurate means of measuring curvature of roadway centerlines in ArcGIS (Rasdorf, et al., 2012).

ArcGIS's COGO (coordinate geometry) capabilities also allow for calculation of the radius of curvature. In ArcInfo and ArcEditor, if the radius of the curve is unknown, the "Curve Calculator" on the COGO toolbar allows the user to select two known parameters to find the radius of the curve. Both tools assume only circular curves are present between the tangent sections.

With either tool, the curve's point of curvature (PC) and the point of tangency (PT) are located visually using the aerial images (see Figure 48). Once the points are located, a curve line feature is drawn in ArcGIS and the radius is measured (using the *ArcGIS COGO* tool or Florida DOT curvature extension tool). The COGO tool requires two values: arc length (automatically generated in ArcGIS and reported as the SHAPE_Length) and chord length (measured using the *Measure* tool). Figure 49 shows the use of the COGO tool to measure the curve radius.

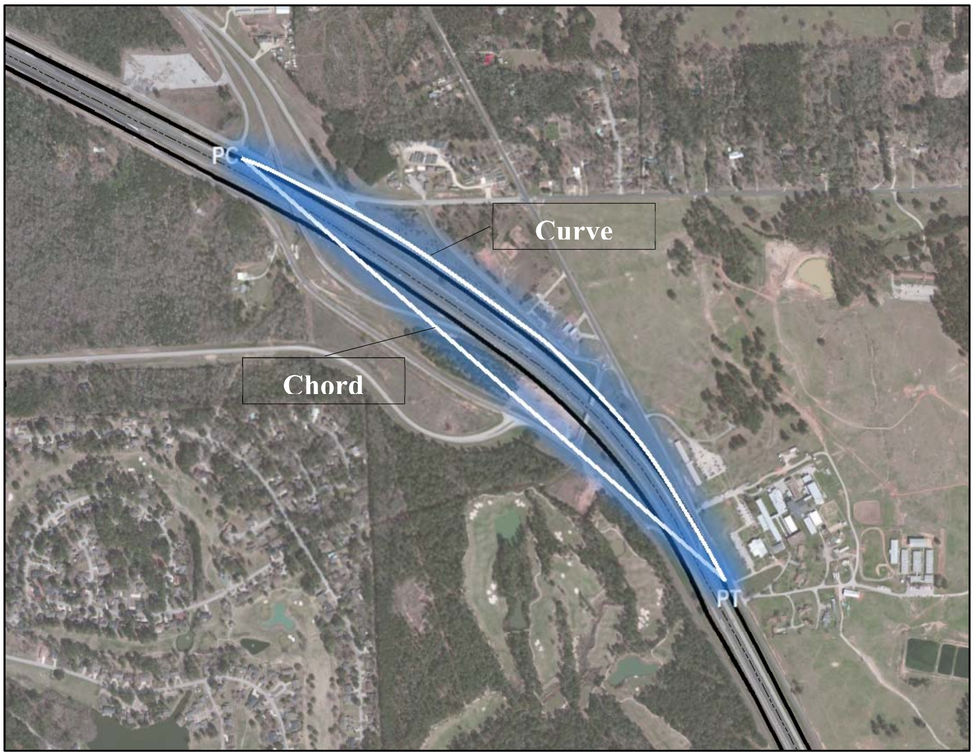


Figure 48. Locating the Circular Curve, PC, and PT in the ArcGIS using Aerial Images

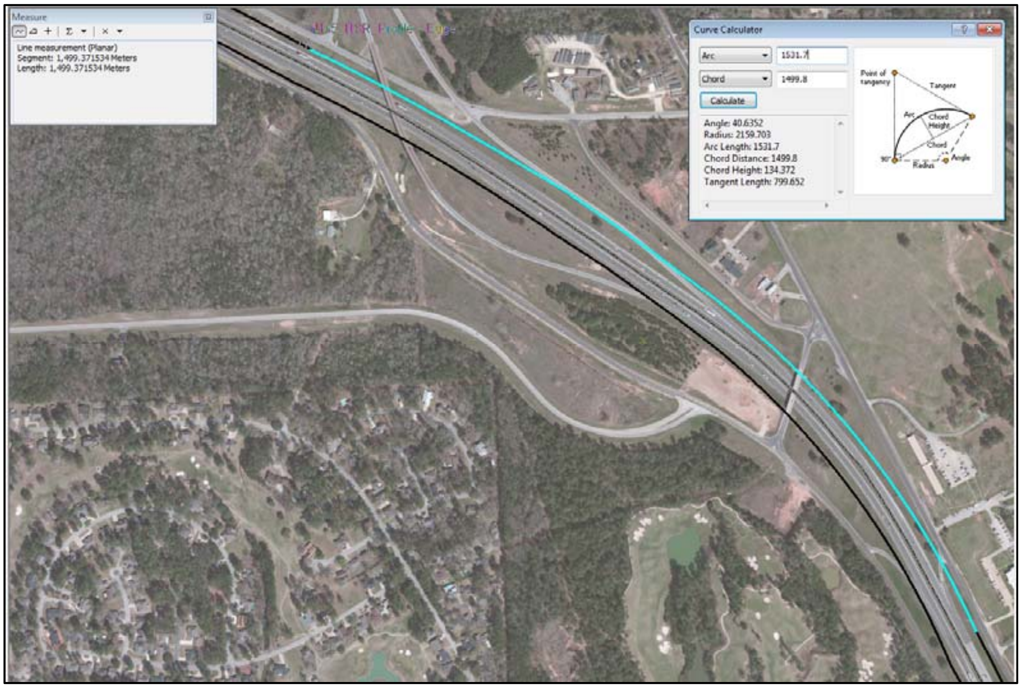


Figure 49. Measuring the Curve Radius Using a ArcGIS COGO Tool

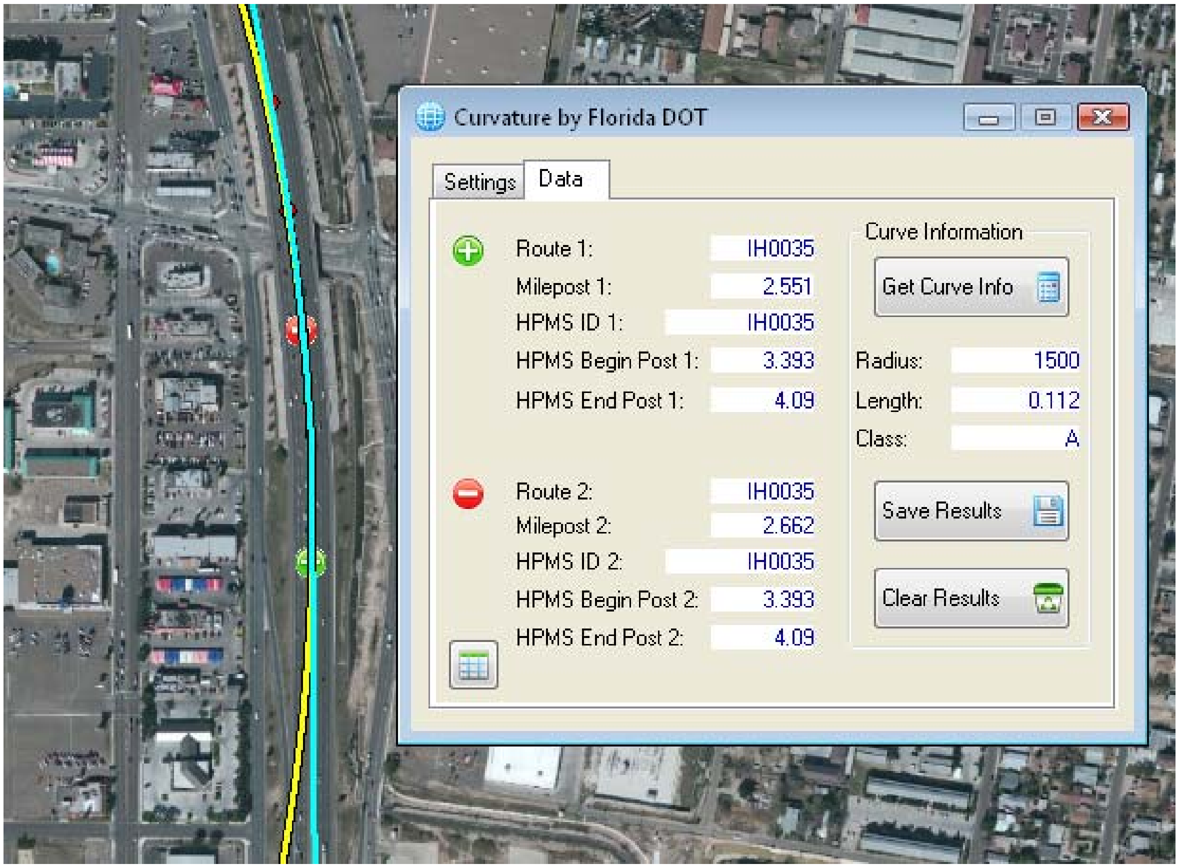


Figure 50. Screen Shot of Florida DOT Curvature Extension Input and Output Window for ArcGIS 10.0

TTI researchers (Kim et al., 2011) also developed a tool using Mathematica to calculate the radius of curvature from a set of three points on a GIS polyline using a Lagrange polynomial to interpolate the curve between the three points. Their methodology and the Mathematica code used to implement the calculation are provided in Appendix D of their report (Kim et al., 2011).

Once the degree of curvature is known, an assessment needs to be conducted to determine if the degree of curvature is too high for the preferred operating speed of the train. The degree of curvature and the combined superelevation of the track determine the speed at which the train can travel in the curved section, subject to passenger comfort criteria. Section 3.1.3 presented the mathematical relationship for allowable speeds, degree of curvature, and superelevation for HSIPR operating on standard gauge track.

In order to stay within the existing ROW, the curves of the existing ROW must not exceed the maximum degree of curvature determined from the preferred travel speed and superelevation. In general, for SWSR trains without tilt mechanisms, the degree of curvature should not exceed one. A tilting train can negotiate curves at full speed with degrees of curvature greater than one, with the maximum depending on the maximum degree of tilt and the amount of permitted cant deficiency (AREMA, 2009).

Methodologies for examining potential deviations from the existing ROW typically assume a maximum superelevation to determine the range of speeds an HSIPR may travel through a curve using simple and transition curves. At a sketch-planning level, the methodology could identify curve “trouble spots” (i.e., high degrees of curvature) and determine amount of deviation from the ROW to obtain a preferred HSIPR speed through the curve. The Peterson et al. study (1985) on utilizing Texas highway ROW performed such an analysis.

The Peterson et al. methodology (1985) was to assume a maximum superelevation for an HSIPR technology, then test out different speeds at which the HSIPR would traverse the segment with the curve to determine the deviation from the ROW. An example provided in their report was of a curve on I-45 curve at US 75. At 160 mph, a one-degree curvature requires the train to slightly deviate away from the highway ROW, but at 185 mph and 227 mph, the alignment must deviate even more from the ROW at 0.75 and 0.5 degrees of curvature, respectively.

To offer a higher level of passenger comfort, some ROW may need to be acquired adjacent to highway ROW to “smooth” out the curves at particular sections of highway. Further complications occur when two curves in close proximity curve in opposite directions, additional departures from the ROW may need to occur to allow for the transition in track superelevation from one curve to another (Peterson, et al., 1985). Potential opportunities for deviation near such curved sections should be examined along the highway corridor, such as freight rail ROW, utility corridors, or publically-owned land parcels. Where ROW cannot be acquired, the other solutions, such as use of tilting trains or decreasing train speed, can be pursued.

3.3.2 Lateral Clearance Feasibility

As discussed in Section 3.1.3, the minimum distance between the main tracks and clearance to track overhead structures influence the ROW width requirements. Florida mandated a minimum 44-foot (13.4 m) median in IH-4 (FDOT, 2009). The earlier Texas feasibility report also stated a minimum 44-foot width is required for two tracks (Peterson et al., 1985). The XpressWest plans to use as little as about 8 feet (2.42 m) of ROW for elevated sections to as much as 84 feet (25.6 m) of highway median for at-grade segments (XpressWest, 2009). The California HSIPR specifies 60 feet (18.3 m) of space for an at-grade dual track with closed drainage, 50 feet for elevated dual tracks, 30 feet single at-grade and single elevated track, and 138 feet (42.1 m) for HSIPR in a shared rail corridor (California High-Speed Rail Authority, 2009b).

Table 9 presents the minimum lateral clearance determined to be needed for each type of track option.

Table 9. GIS Coding for ROW Availability and HSIPR Guideway Suitability

GIS Code	Type of Track	Lateral Clearance (feet)
0	No track	<8
1	Elevated	>=8 AND <23
2	At-grade single track	>=23 AND <44
3	At-grade dual track	>=44

Finding the required minimum width along the corridor involves two sources of data. The median width (in feet) information is obtained from the highway RHINO database maintained by TxDOT. The second source of data must come from manually recording the width of the lateral clearance in non-median spaces (between the ROW property line and each frontage road and the frontage road and main travel lanes). These additional lateral clearance sections are added as new fields to the RHINO database to record the available width.

In order to maintain the cross section homogeneity, highway segments are re-segmented based on uniform cross sectional spaces. The cross sectional width can be measured using the measurement tool in ArcGIS and recorded in the corresponding fields. The recorded width helps in assessing the suitability of laying an elevated track, a single at-grade track, or a dual at-grade track, with suitability determined by width according to Table 9. If the ROW space is neither available nor suitable for a track, possible diversion to railroad ROW parallel to the highway is examined by recording a railroad ROW binary (0/1) field indicator.

3.3.3 Vertical Clearance Feasibility

Concerns about vertical clearance along a highway arise when bridges cross over the highway, especially interchange bridges. TxDOT's bridge inventory records, which are maintained for the National Bridge Inventory (NBI), provide the needed information. However, selecting the bridges within the ROW of a highway unfortunately is not straightforward.

The NBI requires data items for each bridge, including what features the bridge intersects (item 6-1) and what facility the bridge carries (item 7). The coding for those items is not consistent or user-friendly for finding unique roadways (e.g., business versus main interstate highways), and so SQL selection in ArcGIS using the highway name as the features and facilities to search for must be supplemented with a manual search of the bridges within the ROW along its entire length.

Using the "selection by location" option within ArcGIS using a search distance equal to the width of the reported minimum ROW was also insufficient because some of the geographic coordinates of the bridge points did not reside within the ROW buffer even if the bridge resided within the ROW. That problem happened frequently for interchange ramps. The opposite problem, of bridge points residing in the ROW buffer that are not within the ROW, was also observed.

Once the bridges are selected, ideally by combination of name, location, and manual selection, ArcGIS's Linear Referencing tools can be used to route (locate) the bridge events to the centerline of the highway. The routing results provided the distance from origin (DFO) measures (FRM_DFO and TO_DFO) used to locate the bridges along the highway ROW. As with the curve data, since the bridges are points along the route, the DFO values will be the same for the "from" and "to" DFO for a single bridge.

Interchanges

The difficulties of finding a place within interchanges to construct a HSIPR guideway is a concern commonly brought up in response to the idea of placing HSIPR within highway ROW. There are examples internationally of HSIPR traveling through an interchange (see the Shanghai maglev in Figure 51) and planned domestically (e.g., XpressWest—formerly DesertXpress).

Any feasibility analysis of a corridor must involve identifying all the interchanges along the corridor and determining how HSIPR or a dedicated freight transportation system could be threaded through, under, around, or over the interchange.

Figure 51. Shanghai Maglev Traveling through an Interchange
(Source: Google Earth)

3.3.4 Grades

Google Earth provides vertical elevation data. A code written in the Python language can extract many vertical elevation points using Google Earth elevation data. The average grade for a ROW section can be calculated by differencing the elevation between the ends of a section, and distributing it over its length (see Equation 2).

$$\text{Average grade of a section AB (\%)} = \frac{\text{ElevationA} - \text{ElevationB}}{\text{Length of the section AB}} \quad (2)$$

Highway ROW usually has vertical gradients. As discussed in Section 3.3., the maglev can easily overcome uphill gradients and slopes with inclinations up to 10% in comparison to a maximum of 3.5% to 4% for the SWSR trains. In general, the maglev vehicle can climb grades from 2.5 to 8 times steeper than wheel rail trains with no loss of speed (Yaghoubi et al., 2012).

3.3.5 Pipeline

The Railroad Commission of Texas (RCT) website's public GIS map viewer for oil, gas, and pipeline data provides maps for each county showing pipelines that cross the IH-35 corridor

(Texas Railroad Commission, 2013) Although the RCT pipeline database identifies a pipeline's location, status, ownership, and commodity, it does not contain the pipeline's depth at a given location. The detailed design process will require more pipeline information and additional construction strategies and mitigation measures at active pipeline locations.

3.3.6 Existing Rail Lines

In addition to identifying the location of interchanges along the corridor, recording in the GIS RHINO database which segments have rail lines directly adjacent to and parallel to the highway ROW allows for identification of potential locations where freight and passenger rail investments could be made together or where the rail line could provide an alternative route where the highway ROW is not as suitable for HSIPR. For instance, at several locations along the IH-35 route, the parallel rail line continues to travel straight while the highway ROW curves. To avoid having to slow down the HSIPR, the HSIPR could deviate from the highway and on to the rail ROW (again, assuming approval from the owner of the rail track). Figure 52 depicts such a deviation for the UK's HSIPR, High Speed 1.

Figure 52. High Speed 1 in the UK
(Source: http://highspeed1.co.uk/business-updates/hs1-ltd-publishes-freight-access-terms)

3.3.7 Station and Maintenance Location Feasibility Methodology

ArcGIS can be used to evaluate the possible station locations. Some county appraisal districts can provide county parcel GIS shape files that contain the owner information. The selection process uses ArcGIS as an analysis tool, and station selection criteria as guidance.

The GIS analysis process uses two different approaches. The first approach looks for appropriate TxDOT-owned land based on two criteria of land availability and distance to route.

The second approach does not limit the search for parcels to TxDOT-owned land. This approach captures a wider range of candidate locations, and better supports potential ridership. Potential parcels are selected based on the following criteria and described more in-depth following the list of criteria:

1) land availability
2) distance to route
3) intermodal connectivity
4) accessibility
5) population density

Land availability

Land availability serves as the first screening criteria to assess available TxDOT parcels or non-TxDOT-owned candidate parcels; any candidate parcels must meet this minimum size requirement. Following are the size requirements:

- 20 acres for any preferred station
- 20 to 50 acres for the main maintenance facility
- 7 to 10 acres for the light maintenance, storage, cleaning and inspection facilities

Distance to route

Distance to route identifies available TxDOT parcels or non-TxDOT-owned candidate parcels that are within a distance of 0.25 mile, 0.5 mile, or 1 mile of an identified HSIPR route.

Intermodal connectivity

Intermodal connectivity identifies locations that are close to a transit route (within distance of 0.25 miles) and/or close to the major commercial airports (within 30-minute driving distance or 10 miles).

Central location

A central location is preferred for HSIPR stations. Stations that are located in the central cities tend to be more likely to facilitate intermodal connections and encourage supportive, sustainable development nearby (Facchinetti-Mannone, 2009). Thus, this study identified locations that are close to the downtown areas (i.e., have the downtown zip codes) as preferred HSIPR station locations.

Population density

Population density will affect the ridership demand. To capture a wider area of potential ridership, the HSIPR stations should be located close to densely populated areas. This study prefers the locations that have more population within a 30-minute driving distance or 10-mile ring of the potential HSIPR station locations.

3.4 Conditions of Approval

This section presents the conditions that TxDOT should consider imposing, with modifications made as further research and experience suggests changes, in terms of prioritization and safety (e.g., crash protection and spacing).

3.4.1 Passenger and Freight Prioritization

Along highway corridors where both passenger and freight transportation could serve a demand, the highway ROW may not be able to accommodate both technologies. In those cases, criteria are needed to help determine how to prioritize the type of service to provide (e.g., passenger or freight). The 2010 Texas Rail Plan included the results of a TTI research study (research project 0-6467) that developed an evaluation system for prioritizing rail investments. The same or similar evaluation system could help prioritize passenger and freight investment within a constrained highway ROW.

The system consists of three categories of weighted evaluation criteria: sustainability, transportation, and implementation (Table 10). Table 11 through Table 13 explain the evaluation criteria in more detail. For more information about this phase I initial evaluation system, refer to Chapter 7 of the the 2010 Texas Rail Plan. After the completion of the rail plan, in 2013 a phase II evaluation framework was developed and used to prioritize rail projects (Table 14). The framework may benefit from tailoring the criteria to factors specific to use of existing ROW, such as a comparison of the physical feasibility and impacts on access.

Table 10. Evaluation Criteria for Prioritization

Categories	Criteria	Weights
Sustainability	Economic Impacts	10
	Environmental/Social Impact	10
	Asset Preservation	15
Transportation	*Safety & Security*	10
	Connectivity	10
	Congestion Relief	10
	System Capacity	15
Implementation	Cost Effectiveness	5
	Project Development	5
	Partnerships	5
	Innovation	5
Note: Italicized criteria are mostly closely related to TxDOT goals		**100**

(Source: 2010 Texas Rail Plan, Chapter 7)

Table 11. Sustainability Evaluation Criteria

Sustainability	
Economic Impact	The economic impact criterion examines the economic value of the project. A variety of factors to consider include direct and indirect benefits, short- and long-term job creation, shipper savings, tax revenues that could be potentially generated, and long-term economic growth that could be attributed to the project by attracting new businesses and generating redevelopment.
Environmental/ Social Impact	The environmental and social impact criterion evaluates the economic and social impacts that are likely to accrue from the project. Examples of factors include air quality, energy use, natural resources and noise and vibration. Social Impacts also include livability and access to multiple modes of transportation for nearby communities.
Asset Preservation	The asset preservation criterion evaluates the ability of the project to assist in preserving existing TxDOT or state assets with a particular emphasis on existing public sector transportation infrastructure (e.g., highways and associated rights of way) and/or privately-held transportation infrastructure (e.g., freight railroad infrastructure and rights of way). Also included is the preservation of exiting rail lines that might be abandoned. These lines in many cases can provide shipping alternatives to local industries and reduce shipping by truck. Also to be considered is the preservation of buildings that could be used for passenger rail stations and future transit oriented development.

(Source: 2010 Texas Rail Plan, Chapter 7)

Table 12. Transportation Evaluation Criteria

Transportation	
Safety and Security	The safety and security criterion evaluates the safety benefits and security enhancements that will accrue by implementation of the project. This takes into account crashes, fatalities, and injuries that may be prevented; property damage averted; and physical and operational security measures featured in the project. It may also give specific credit for projects that address the ability to handle transportation emergencies, such as those caused by natural disasters, or projects that address specific needs such hazardous materials transportation safety and security.
Connectivity	The connectivity criterion allows for project evaluation based upon its characteristics that relate to the ability to connect to other modes of transportation. Examples of a project attribute include the way in which a proposed intercity or commuter rail service connects with the urban transit services in urban areas or the way in which a proposed new freight rail line or urban bypass route serves existing freight distribution activity centers. Also included is how freight and passenger rail connect to the highway network. Interoperability between rail networks is also an important criterion to consider. Connectivity between rural and urban networks also needs to be considered in the evaluation.
Congestion Relief	The congestion relief criterion accounts for travel time improvements, relief or removal of rail traffic and/or highway bottlenecks, and for alleviation of non-recurring congestion as the result of special events. Example projects include those making rail line improvements to allow improved freight/passenger rail travel times, rail grade separation projects addressing rail congestion, or highway-rail grade separations that remove the delay caused by train activity. Other examples include implementation of new passenger services which reduce roadway congestion by providing an alternative mode of travel.
System Capacity	The system capacity criterion evaluates the project as it relates to overall transportation system capacity needs. Examples of such a project might be rail infrastructure capacity improvement projects, such as adding sidings, double-tracking, or improving signaling in order to increase the daily throughput along a corridor.

(Source: 2010 Texas Rail Plan, Chapter 7)

Table 13. Implementation Evaluation Criteria

Implementation	
Cost Effectiveness	The cost effectiveness criterion looks at the overall benefit derived for the investment applied to the project. It could encompass several methods of calculation (benefit-cost analysis, etc.) or be subjectively scored based on expected costs and outcomes depending on the level of project development at the time the projects are ranked.
Project Development	The project development criterion evaluates the stage of project development in relation to whether detailed engineering plans and environmental compliance documents are completed or in the process of being completed. Projects with major planning studies already completed would score higher than conceptualized projects.
Partnerships	The partnership criterion allows for credit to be given to a project for maximizing the partnership features to produce a more readily implementable project. The partnerships may consist of public-private partnerships, partnerships between multiple government agencies, or other types of partnerships.
Innovation	The innovation criterion provides an additional scoring opportunity for projects that exhibit technological and/or institutional innovation. This could refer to the technology proposed for implementation of a certain service or operation, or innovation related to creative funding methods from a variety of public and private sources.

(Source: 2010 Texas Rail Plan, Chapter 7)

Table 14. TxDOT Railroad Division - Project Prioritization - Phase II Framework

Criteria #	Criteria	Sub-Criteria	Quantitative/ Qualitative	Input Metric	Description
Sustainability					
1	Economic Impact	Job Creation (short term direct)	Quantitative	Project Cost	Number of full-time equivalent jobs (during construction phase typically), number of job-years, dollar wage equivalent, average dollar wages per month
		Shipper Savings	Qualitative	Positive/ Neutral/ Negative	Reduction in transportation costs, reduction in logistics costs (inventory, warehousing, distribution). This is a function of total rail travel time.
		Income Tax Revenues	Quantitative	Project Cost	Corporate and personal income tax
		Property Tax Revenues	Qualitative	Positive/ Neutral/ Negative	Potential for transit oriented development to increase property taxes municipalities/region.
		Import/Export Opportunity	Qualitative	Positive/ Neutral/ Negative	Project increases opportunity to import/export goods to the US through improved rail infrastructure.
2	Environmental/ Social Impact	Non-Attainment Area	Qualitative	Y/N	If project is in non-attainment area, additional weight will be give towards increased or decreased fuel usage.
		Fuel Usage - Programmatic	Qualitative	Positive/ Neutral/ Negative	Reduced fuel usage will result in tons of emissions (CO, NOx, PM, CO2) saved as well as productivity improvement.
		Fuel Usage - Grade Separation	Quantitative	AADT	Reduced fuel usage will result in tons of emissions (CO, NOx, PM, CO2) saved as well as productivity improvement.
		Natural Resources	Qualitative	Significant/ Potential/None	Determination of relative impact on natural resources.
		Noise & Vibration	Quantitative	Population Within 1 Mile Project Limits	Noise and vibration impact level of the project on surrounding population.
		Neighborhood Cohesiveness	Qualitative	Y/N	Impact of project to bring about neighborhood cohesiveness
3	Asset Preservation	Preservation of Rail Infrastructure	Quantitative	Track-Miles	Track miles revitalized, maintained, upgraded, and/or saved from abandonment
		Preservation of Highway Infrastructure	Qualitative	Positive/ Neutral/ Negative	Truck VMT saved or avoided, lane-miles with avoided pavement maintenance/damage costs, or the pavement maintenance/damage savings

Criteria #	Criteria	Sub-Criteria	Quantitative/ Qualitative	Input Metric	Description
Transportation					
4	Safety and Security	Fatalities	Quantitative	Value	Reduction in number of fatalities at grade crossings. Use FRA crossing inventory database.
		Injuries	Quantitative	Value	Reduction in number of injuries at grade crossings. Use FRA crossing inventory database.
		Property Damage	Quantitative	Value	Reduction in property damage at grade crossings. Use FRA crossing inventory database.
		Security	Qualitative	Y/N	Is project critical infrastructure. Use AAR definition of critical infrastructure.
		Hazardous Materials	Qualitative	Y/N	Assess route hazmat characteristics.
5	Connectivity	Connectivity of Transportation Network	Qualitative	1 to 5	Positive impact of the project, e.g., critical connection between existing or planned facilities
6	Congestion Relief	Travel Time - Programmatic	Qualitative	1 to 5	Reduction in travel time delay and costs across rail network
		Travel Time - Grade Separation	Quantitative	AADT, train volumes	Reduction in travel time delay and costs across road network
		Known Critical Locations (Bottlenecks)	Qualitative	1 to 5	Reductions in travel time delay over links with recurring congestion
7	System Capacity	Throughput	Qualitative	1 to 5	Increase in rail throughput
Implementation					
8	Cost Effectiveness	Benefit-Cost Ratio	Quantitative	Benefit Estimate	Benefit derived from the investment divided by the cost.
		Operation and Maintenance Cost	Qualitative	Positive/ Neutral/ Negative	Increase, decrease or no change in operation and maintenance cost on rail and road due to project
9	Project Development	Engineering Design	Qualitative	1 to 5	Design level
		Environmental Documents	Qualitative	1 to 5	Environmental document status
		ROW	Qualitative	1 to 5	Difficulty in acquiring ROW
10	Partnerships	Public-Private Partnerships or Public Agency Partnerships	Qualitative	1 to 5	Support from partnerships
		Public Support	Qualitative	Y/N	General public support

Criteria #	Criteria	Sub-Criteria	Quantitative/ Qualitative	Input Metric	Description
		Likelihood of Other Funding Source	Qualitative	1 to 5	Are other funding sources identified and what is the likelihood of securing funding?
		Magnitude of Other Funding Source	Qualitative	1 to 5	How much funding from other sources is expected?
11	Innovation	Technological Innovation	Qualitative	Y/N	Implementation of institutional, technological or other innovations

3.4.2 General Safety

The co-location of HSIPR with other uses within existing ROW introduces additional considerations for planning, construction, and operation. This section summarizes the guidance available for safely accommodating HSIPR and other uses within existing ROW. Communication systems, in addition to physical design, are used to prevent collisions, security breaches, and other risks, but the former are not included in this section because the systems in general are independent of the type of ROW or land used for the HSIPR or dedicated freight transportation system.

Maglev offers the highest safety because maglev trains wrap around or are contained within their guideway and only move with activated guideway sections; a guideway section can only have one maglev train per section at a time, ensuring safe spacing of maglev trains (Liu & Deng, 2003). In contrast, SWSR rests precariously on two steel rails and relies on communication systems to ensure safe spacing. The July 2011 tragedy in China of a SWSR HSIPR train colliding into another train and the July 2013 tragedy in Spain of a train derailing on a curve are examples of the weakness of the SWSR systems.

Multiple SWSR accidents have occurred, resulting in hundreds of passenger fatalities. Only one maglev accident has occurred, and that accident happened on a test track (the Transrapid Germany test track) under conditions that would not have been acceptable under revenue operation (i.e., insufficient communication systems).

Table 15 lists reported SWSR accidents resulting in derailment and/or passenger injuries and fatalities. If the accident involved an object on the track, the SWSR usually derailed. In the single maglev accident, an object (a maintenance vehicle) was also on the track; however, the maglev vehicle did not derail. The physical design of maglev makes it the safest for operation within existing, constrained ROW.

Table 15. History of Japanese, French, and German HST Accidents

Date	Cause of Derailment	Number of Vehicles Derailed	Speed at Time of Derailment	Number of Fatalities
Alvia (Spain)				
July 2013	Excessive speed on curve	All eight cars	95 mph	79
Shinkansen (Japan)				
Oct. 23, 2004	Earthquake	Eight of the ten cars	unknown	None
TGV (France)				
Sept. 23, 1988	Truck stranded on grade crossing	One leading power unit, remainder did not derail	68 mph (110km/hr)	2
Dec. 14, 1992	Flat wheel caused one bogie of trainset to derail	One passenger car	168 mph (270 km/hr)	None
Dec. 21, 1993	Sink hole underneath track	Last four passenger car and rear power unit	182 mph (294 km/hr)	None
Sept. 25, 1997	Asphalt paving machine stranded on grade crossing	Leading power unit and four passenger cars (two of which completely left the trackbed)	81 mph (130 km/hr)	None
May 9, 1998	Truck at grade crossing	Leading power unit and first two passenger cars	Info not available	1
June 5, 2000	Reaction link to bogie on leading power car detached from bogie frame and caused transmission assembly parts to impact the track	Cars with bogie 2, 3 and 23 (numbering starting from the front) derailed, but stayed upright	(290 km/hr)	None
Jan. 5, 2001	Mudslide covered tracks	Leading power car	(120 km/hr)	None
ICE (Germany)				
June 3, 1998	Failed wheel rim became embedded in passenger trailer and hit guard rail as train passed over a switch, setting off a chain reaction	All but three	125 mph (200 km/hr)	101
April 1, 2004	Tractor on track	Leading power unit	Info not available	None
March 1, 2008	Tree on track	Info not available	Info not available	None
April 26, 2008	Sheep on track	Leading power units and ten of the twelve cars	Info not available	None

Date	Cause of Derailment	Number of Vehicles Derailed	Speed at Time of Derailment	Number of Fatalities
July 2008	Cracked axle	Info not available	Info not available	None
Transrapid Maglev (Germany)				
Sept. 22, 2006	Maintenance vehicle on test track	None (debris of first vehicle fell from guideway)	125 mph (200 km/hr)	23
China				
July 2011	Lightening caused communication system failure and track damage, resulting in train behind hitting stopped train	Several fell off viaduct	125 mph	100+

(Source: Larsen, 2010; updated for 2011)

Japan's Shinkansen, which has moved billions of riders, has had a few derailments since the start of operations in 1964, but no reported passenger fatalities. To further protect against derailment, JR Central installed derailment prevention guards on their rails in earthquake-prone areas (see Figure 53) in October 2009.

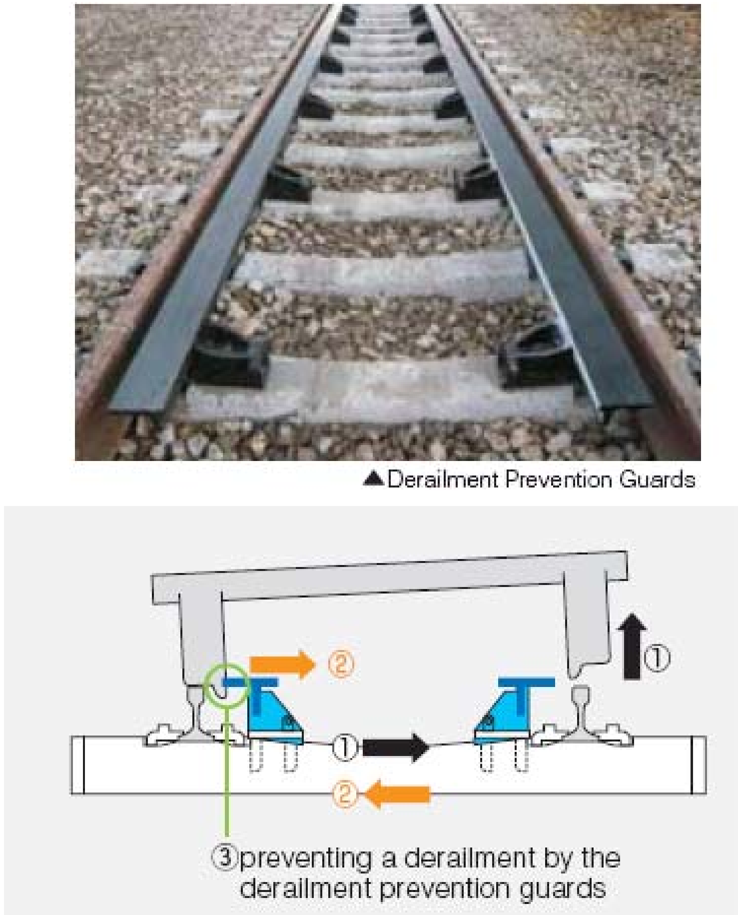


Figure 53. Derailment Prevention Option for SWSR Technology
(Source: JR Central, 2010)

Compared with other HSIPR technologies, the maglev technology appears to be the best designed for safety. Although the derailment prevention guards used in Japan may help reduce the risk of derailment for SWSR technology, they appear unlikely to make derailment impossible. The attraction-based EMS maglev vehicle wraps around the guideway, making derailment almost impossible. A repulsion-based EDS maglev vehicle is contained within the walls of the guideway, which also reduces the risk of the train leaving the guideway.

This section presents the safety and design requirements for co-locating HSIPR with automobiles.

3.4.3 Crash Protection

Barriers are needed between the HSIPR and dedicated freight transportation systems and the highway to protect the users of both systems. Several reports about US HSIPR projects note that NCHRP Class 6 barriers should be used on curves between the highway and HSIPR track structure (e.g., Colorado 2010 business plan, Florida HSIPRA Final EIS [2005]) and Class 5 barriers on tangent sections (Florida High-Speed Rail Authority 2005). The FRA requires barrier plans for HSIPR systems operating at speeds of more than 125 mph.

Other than the barrier requirements stated in the EISs, neither the USDOT nor other organizations that usually provide guidance for transportation facilities have developed manuals or regulations specifically providing guidance for safely designing HSIPR within existing highway corridors to protect both the trains and the automobiles.

The American Association of State Highway and Transportation Officials (AASHTO) commissioned the creation of an interim guide titled *Geometric Design Guide for Transit Facilities on Highways and Streets—Phase 1*; however, the scope of the guide is limited to buses and HOV lanes (Fuhs, 2002). AASHTO's "Policy on Geometric Design of Highways and Streets" (AASHTO, 2011) and "Policy on Design Standards Interstate Systems" (AASHTO, 2005) provide guidance for sight distances and horizontal and vertical clearances applicable to designing an HSIPR facility in close proximity to a highway. The same guidance specific to Texas roadways is found in TxDOT's *Roadway Manual*.

AREMA's chapter on HSIPR in their *Manual for Railway Engineering* does not include guidance on how to design HSIPR operating within highway corridors (except for rail-highway crossings). AREMA provides guidance for vertical and horizontal track geometry, heights and distances needed for electric SWSR train technology components along the track, and recommended safety measures, such as fencing and barriers—nothing specific to designing near existing roadways. AREMA's 2002 *Manual for Railway Engineering* offered "limited guidance" at the time Florida developed highway alignments for their EIS (Moore, 2004). Larsen's (2010) summary of the design requirements extracted from the EIRs/EISs and Moore (2004) guides the assessment of the feasibility of using existing highway ROW in Texas.

Though there is a lack of guidance domestically in the US, crash protection research and measures can be found internationally. In Italy, several HSIPR lines parallel highways (e.g., the Milano-Torino and Milan-Bologna sections of Italy's HSIPR line operates close to the A4 and A1 motorway respectively). Buzzetti et al. (2005) identified the areas along the Italian highways with the potential for interference from automobiles traveling off the highway and developed several possible mitigation measures (see Figure 54 and Figure 55). In those figures, the A1 refers to the motorway, AI refers to the enclosed area between the HSIPR tracks and the highway, and the AV refers to the HSIPR tracks.

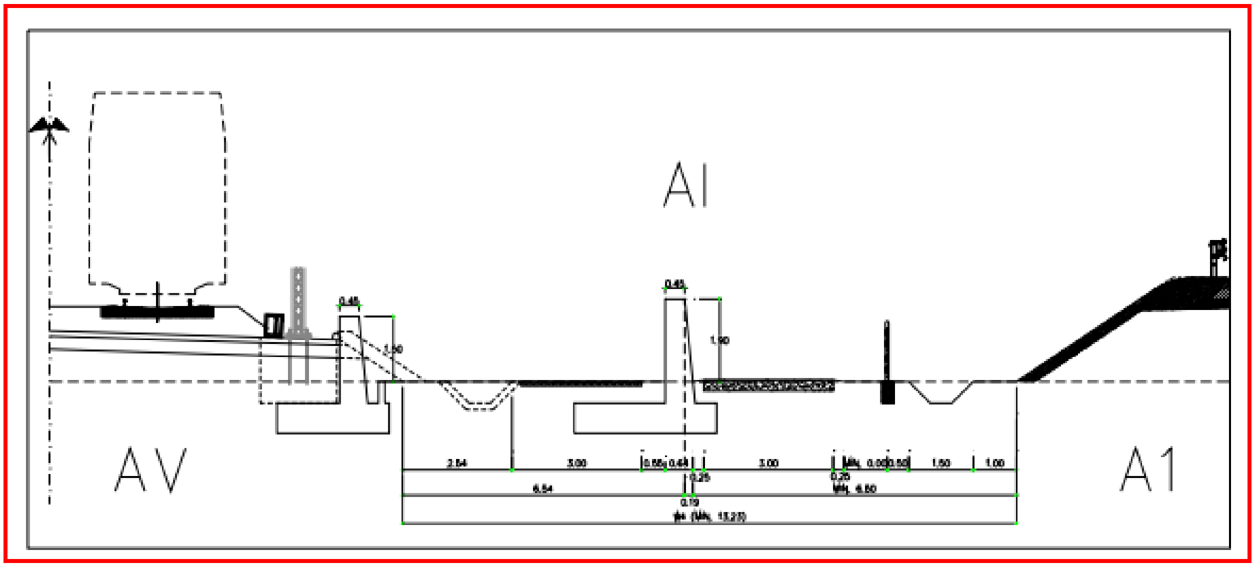


Figure 54. Barrier Design to Prevent Encroachment of Vehicles into HSIPR Tracks
(Source: Buzzetti et al., 2005)

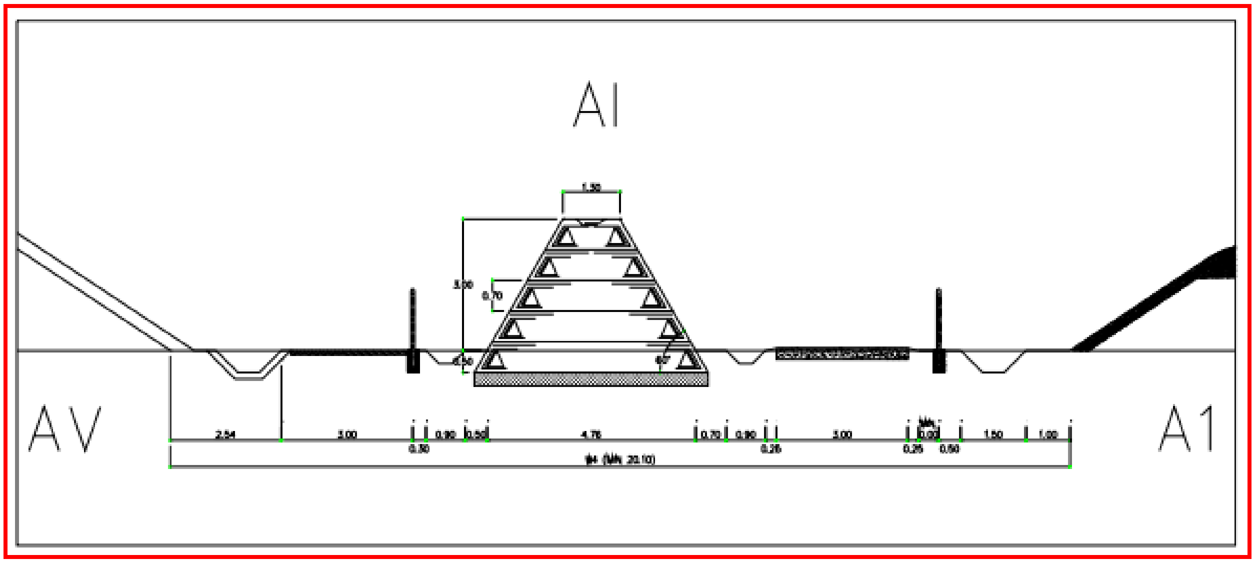


Figure 55. Pyramid Design to Prevent Encroachment of Vehicles into HSIPR Tracks
(Source: Buzzetti et al., 2005)

3.4.4 Highway Emergency and Maintenance Access

Barriers are needed for protection, but highway emergency and maintenance access must not be impeded. Emergency crossovers are needed to allow emergency and maintenance vehicles to travel from one side of the highway to another. The crossovers cannot be at the same grade as the HSIPR and dedicated freight systems for obvious safety reasons, however. If the HSIPR and dedicated freight system are at-grade, either the guideway needs to be elevated where crossovers are needed, or the crossovers should be depressed underneath (or if enough room, possibly elevated above) the guideway. Figure 56 shows the XpressWest HSIPR plan for an emergency crossover (with a 28-foot turning radius) depressed underneath the guideway (with the double-track guideway on a bridge shown as 70 feet long).

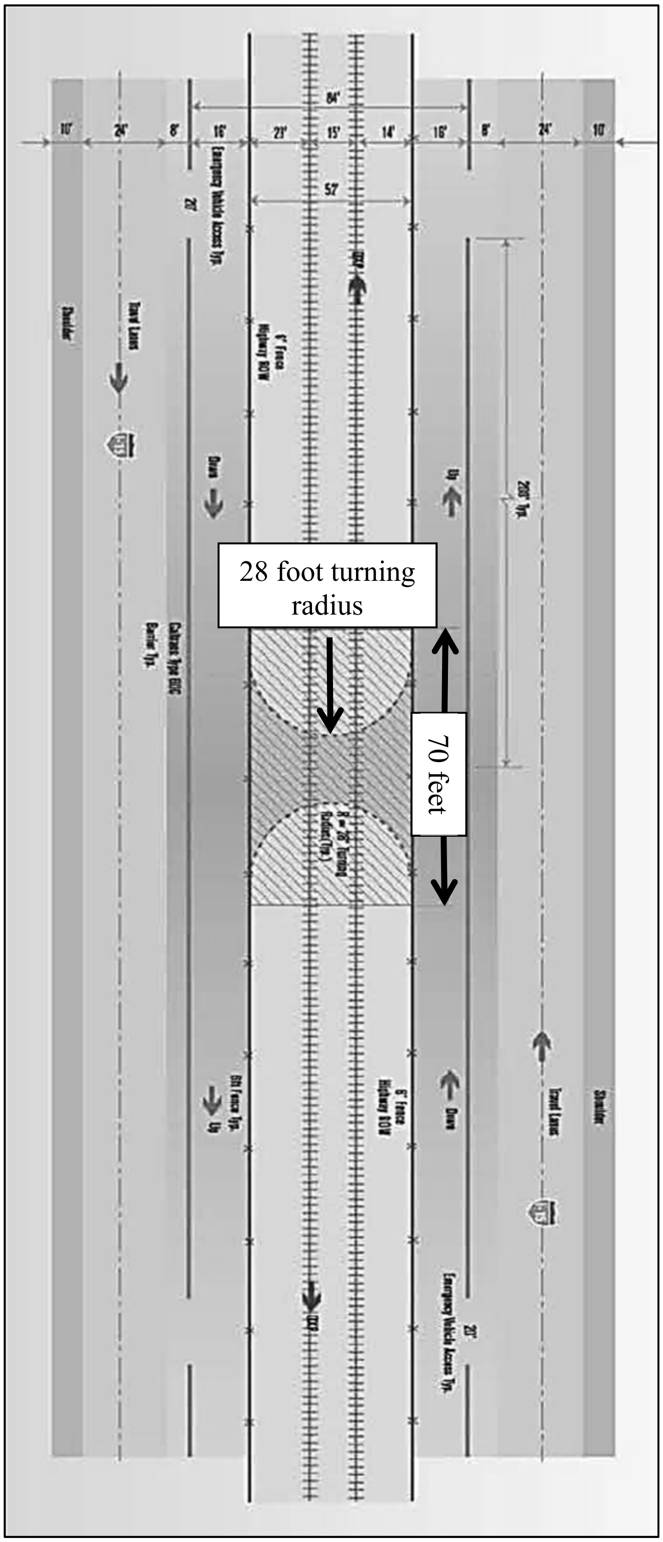


Figure 56. Diagram of Elevated Emergency Median Crossover over XpressWest HSIPR Tracks along IH-15

(Source: USDOT Federal Railroad Administration, 2011)

TxDOT issued a memo giving guidelines for the preferred location and construction of highway emergency crossovers that may also need to be applied in planning for the HSIPR or dedicated freight system. As outlined in the TxDOT memo (Barton, 2011), emergency crossovers should

- not be installed in urban locations. Interchanges are closely spaced and provide opportunities for making needed turn movements.
- be spaced at approximately 2-mile intervals, except where coordination with local and state law enforcement has identified a need for spacing of crossovers of less than 2 miles to address local issues.
- be placed at reasonable intervals based on engineering judgment and safety, generally no closer than ½ mile between crossovers.
- not be located within 1500 feet from any ramp terminal or other access connection.
- not be located within curves requiring superelevation, unless field engineering determines the location is safe and reasonable for emergency use.
- be located where more than minimum stopping sight distance is provided.
- be approximately 20 feet wide with turning radii of 10 feet (see Figure 57), be constructed with an all-weather surface, and, if possible, be depressed below the road shoulder level (see Figure 58).

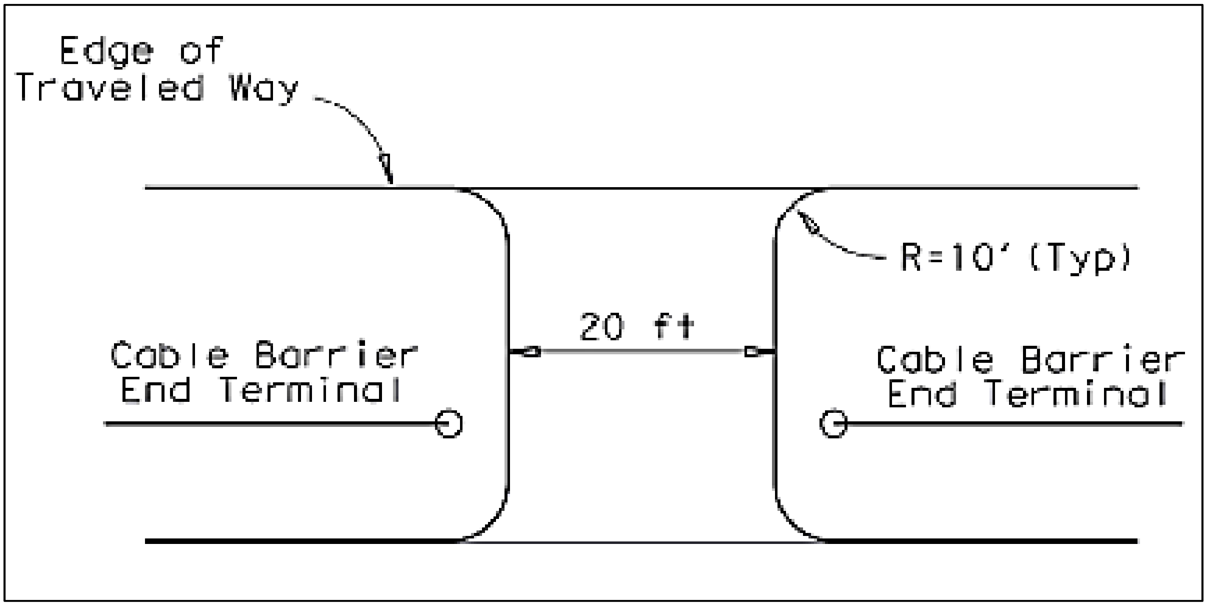


Figure 57. Emergency Crossover
(Source: Barton, 2011)

Figure 58. Emergency Crossover
(Source: Barton, 2011)

Section 4. Accommodating High-Speed and Dedicated Freight Transportation Systems

4.1 Introduction

The purpose of Section 4 is to develop highway and road design criteria that accommodates potential co-location with HSIPR or dedicated freight transportation systems, such as minimum curvature and maximum grades. Section 1.3 described two projects, the Trans Texas Corridor and SH 130 east of Austin, where the design of the highway considered potential inclusion of rail in the ROW at a future date.

This section defines the highway and roadway geometrical design requirements necessary to provide a safe environment to operate HSIPR or dedicated freight transportation systems. The general HSIPR design criteria follow the best recommended practices of the existing European and Japanese high-speed lines. The guidance of International Union of Railways, AREMA, and CHSRA are also taken into account. Design criteria place greater emphasis on SWSR technologies, because uniform guidelines are more widely available, given the existing wheel-based systems. Freight technologies follow the guidelines of steel-wheel-based technologies for speeds lower than 125 mph.

This section provides general guidance on major geometric considerations, and does not provide a set of rules that cover all situations. These guidelines are not the only rules available; good engineering judgment always governs the highway design. Specific guidance is provided in the standards described in the AASHTO document *A Policy on Geometric Design of Highways and Streets*, TxDOT's *Roadway Design Manual*, the AREMA *Manual for Railway Engineering*, and local regulations.

Chapter 8 of the 2010 TxDOT *Roadway Design Manual* explains the *mobility corridor (5R)* design criteria. Mobility corridors are defined as (TxDOT, 2010) "the corridors intended to generate, or produce very long term transportation opportunities including multiple modes such as rail, utilities, and freight and passenger characteristics. These modes may occur within a single corridor alignment or the modes may be separated for some intervals."

According to the manual, the following list gives the controlling criteria that dictate the design:

- lane width and number
- shoulders
- pavement cross slope
- vertical clearances at structures
- stopping sight distance
- grades
- curve radii
- superelevation
- vertical curves

Whenever the specified controlling criteria are not met, a design exception is required. The following sub-sections cover controlling criteria on minimum segment lengths, curve radii, superelevation, grades, vertical curves, and clearances when a potential HSIPR coexists with the highway in ROW.

4.2 Definition of Terms

The following terms are used throughout this section and are drawn from the CHSRA's reports (CHSRA, 2009a).

Attenuation Time	The time required for the vehicle motion to stabilize after crossing a point of change in the nature of the alignment.
Degree of Curve	Railroad curves are defined by the chord definition. The central angle turned by a 100 foot long tangent between two points on the arc of the curve. It is closely approximated by $D_c = 5730 / R$ or more precisely by $D_c = 2 \sin^{-1}(50/R)$ where R is the radius expressed in feet.
Design Standards	
Desirable	The standard, which shall be equaled or exceeded where there are no constraints on the alignment.
Minimum/Maximum	The standard, which shall be equaled or exceeded where constraints on alignment make use of desirable standards impractical or significantly more expensive than if minimum standards are used.
Exceptional	The standard, which shall be achieved at the absolute minimum and only where minimum standards are either unobtainable or excessively expensive.
Equilibrium Superelevation	The calculated superelevation that exactly balances the lateral force of the train on the curve at the defined speed. Also called balancing cant or equilibrium cant.
Design Speed	Maximum permissible speed along a segment of alignment based on the design specification of the track infrastructure, signaling system characteristics, and the maintenance specifications for that class of track.
Operating Speed	The highest in-service speed that is achievable by a trainset technology on a segment of alignment that conforms to all of the requirements specified for that class of track.
Spiral	A curve of variable radius used to connect a straight section of track with the radius of the body of the curve. Sometimes called a transition or a transition spiral.
Clothoid	Constant rate spiral where the radius increases at a linear rate over the length of the spiral.

Superelevation	The difference in elevation between the outside rail of the curve and the inside rail of the curve measured between the highest point on each railhead. Also called a cant.
Unbalanced Superelevation	The difference between the superelevation and equilibrium superelevation. In European publications, unbalance is called cant deficiency if the actual superelevation is less than the equilibrium superelevation and excess cant if the actual superelevation is greater than the equilibrium superelevation.
Grade or Gradient	The slope of changes in elevation, defined in percentage, as feet of rise in 100 feet.

4.3 Minimum Segment Lengths

Compared to a highway alignment, the HSIPR requires very long alignment elements. The alignment elements, like vertical and horizontal curves, spirals, and lengths of grades, should have a minimum length sufficient to satisfy changes in the motion of the rolling stock. A smooth alignment has minimal changes in both horizontal and vertical direction, and has infrequent and gentle changes in direction. More than four changes in direction per mile is considered to constitute an exceptional condition for HSIPR (CHSRA, 2009a).

Unless the design criteria require longer elements, minimum segment lengths should govern the geometry. Limiting or exceptional design requirements are used where desirable requirements cannot be met due to field constraints.

The minimum ROW segment lengths are based on attenuation times. According to the CHSRA (2009a), attenuation times are the following:

- For design speeds less than 186 mph (< 300 km/h)
  - Desirable attenuation time: not less than 2.4 seconds
  - Minimum attenuation time: not less than 1.8 seconds
  - Exceptional attenuation time: not less than 1.5 seconds
- For design speeds greater than or equal to 186 mph 186 mph (≥ 300 km/h)
  - Desirable attenuation time: not less than 3.1 seconds
  - Minimum attenuation time: not less than 2.4 seconds
  - Exceptional attenuation time: not less than 1.8 seconds

The length of ROW segment is calculated using L_{seg} (feet) = V(mph) × 1.467 × attenuation time (sec). Table 16 and Table 17 list segment lengths by design speeds and attenuation time.

Table 16. Minimum Segment Lengths at Speeds of 186 mph (300 km/h) and Higher

Design Speed		Minimum segment lengths for attenuation time					
		3.1 seconds		2.4 seconds		1.8 seconds	
miles per hour	km/h	feet	meters	feet	meters	feet	meters
250	400	1137	346	880	268	660	201
220	355	1000	305	774	236	581	177
200	320	909	277	704	215	528	161
186	300	846	258	655	200	491	150

(Source: CHSRA, 2009a)

Table 17. Minimum Segment Lengths at Various Speeds up to 186 mph (300 km/h)

Design Speed		Minimum segment lengths for attenuation time					
		3.1 seconds		2.4 seconds		1.8 seconds	
miles per hour	km/h	feet	meters	feet	meters	feet	meters
175	280	616	188	462	141	385	117
150	240	528	161	396	121	330	101
125	200	440	134	330	101	275	84

(Source: CHSRA, 2009a)

4.4 Horizontal Curvature

Highways can be designed with minimum curve radii too small for high-speed operation of a train. Horizontal curvature represents one of the most significant challenges to the use of an existing highway ROW. Existing highways typically have smaller curve radii than those recommended for HSIPR because they are designed for lower speeds: 80 mph for interstate highways and as low as 55 mph for the US and state highway systems (AASHTO, 2004; Caltrans, 2012; Florida DOT, 2013). Typical US interstate highways may have curves up to five degrees (Moore, 2004).

For highway design, Equation 3 gives the minimum curve radii for highways (American Association of State Highway and Transportation Officials, 2004).

$$R_{min} = \frac{V^2}{15\,(0.01e_{max} + f_{max})} \tag{3}$$

- V - speed in mph
- R_{min} - radius of curve in feet,
- e_{max} - maximum physical superelevation, expressed as a percentage
- f_{max} - maximum side friction factor

As the allowable automobile speed increases, the radius increases. For highways with a design speed of 80 mph, a curve with 8% superelevation will have minimum curve radii of about 2,670 feet, resulting in a degree of curvature greater than one. At lower speeds, the radius would be much smaller, resulting in even larger degrees of curvature incompatible with HSIPR operations.

In order for a HSIPR to stay within existing highway ROW, the highway curves must not exceed the maximum degree of curvature determined from the preferred travel speed and superelevation. In cases where the highway curves are too small, the train can slow down or the total superelevation can be increased.

Track diversion may be necessary if the available ROW space is not adequate to accommodate a curve, or a sharper curve may demand the extensive highway alignment modifications (see Figure 59). The HSIPR tracks running through a median may need diversion to the available lateral space between the travel lanes and frontage roads to accommodate the design curvature. In some cases, the proposed curve alignment may necessitate a modification to the frontage roads.

Figure 59. Horizontal Curve Diversion and Re-alignment

When a train travels on a curve, it experiences two accelerations: horizontal centrifugal acceleration (v^2 / R), and gravitational acceleration (g). One of the resultants of the acceleration vectors is the lateral acceleration. Superelevation counters the effect of lateral acceleration and provides a safe and smooth riding quality. Rail track superelevation is defined as the difference in the levels of two rails over a standard railroad track width at a curve. The relationship between the superelevation (SE_{inch})(in inches), speed (v)(in mph), and radius (R) of the curve (in feet) is given in Equation 4 (AREMA, 2004):

$$SE_{inch} \cong 4 \cdot \frac{v^2}{R} \quad (4)$$

The achievement of a fully compensated lateral acceleration for different train technologies (having a variety of speeds) using the same track is not practically possible; therefore, the superelevation applied in the field is maximized to the existing field conditions. An unbalanced superelevation arises when the applied superelevation is less than the equilibrium superelevation.

4.4.1 Minimum Curve Radius

Curves with larger radius than the minimum required provide better riding quality and may ease superelevation requirements. Due to practical field limitations, desirable radius may not be achieved. Therefore, superelevation and unbalanced superelevation are introduced at curves to satisfy the passenger comfort requirements. For a given line speed (v_{mph}), and maximum superelevation ($SE_{max,inch}$), the radius (R_{ft}) is calculated using Equation 5.

$$R_{ft} = \frac{4 \cdot v_{mph}^2}{SE_{max,inch}} \tag{5}$$

The maximum superelevation and unbalanced superelevation requirements for HSIPR are presented in Section 3. The horizontal curvature on highway ROW should meet the requirements given in Table 18.

Table 18. Minimum Curve Radii

Design Speed		Minimum Radii Based on Superelevation Limits					
		Desirable		Minimum		Exceptional	
miles per hour	km/h	feet	meters	feet	meters	feet	meters
250	400	45,000	13,700	28,000	8,500	25,000	7,600
220	355	35,000	10,700	22,000	6,700	19,500	6,000
200	320	30,000	9,200	18,000	5,500	16,000	4,900
186	300	25,000	7,600	16,600	4,700	14,000	4,250
175	280	22,000	6,700	14,000	4,200	11,200	3,400
150	240	16,000	4,900	10,000	3,100	8,200	2,500
125	200	10,500	3,200	7,000	2,100	5,700	1,750

(Source: CHSRA, 2009a)

4.5 Spiral Curves

The spiral, generally, introduces a linear rate of change in both radius and superelevation with length. In order to reduce the entry and exit jerks, especially for higher speeds, the need of increased transition lengths arises. There are two types for introducing the changes in radius and superelevation through spiral curves, either by using a linear rate or variable rate. Clothoid spirals introduce a constant rate of transition, whereas half-sine spirals provide a variable rate of transition.

Half-Sine Spirals (variable rate transitions) should be used for curves having design maximum speeds of 80 mph or more (CHSRA, 2009a). Clothoid spirals are used on very large radius curves that require small amounts or no superelevation and have very small unbalanced superelevation.

The length of the spiral should be *the longest length determined* by calculating the various length requirements (CHSRA, 2009a):

a) Length needed to achieve attenuation time

b) Length determined by allowed rate of change in superelevation
c) Length determined by allowed rate of change in unbalanced superelevation
d) Length determined by limitation on twisting over vehicle and truck spacing length

The highway ROW should consider providing spiral curves and satisfy the length requirements as per Table 19, in addition to the AASHTO manual criteria.

Table 19. Minimum Length of Spiral (feet)

Clothoid (Linear Change) Spirals			
Spiral Design Factor	Desirable	Minimum	Exceptional
Superelevation	1.47 E_a V	1.17 E_a V	0.98 E_a V
Unbalance	1.63 E_u V	1.22 E_u V	0.98 E_u V
Twist	90 E_a	75 E_a	62 E_a
Minimum Segment	2.64 V	2.20 V	1.47 V
Half-Sine (Variable Change) Spirals*			
Spiral Design Factor	Desirable	Minimum	Exceptional
Superelevation	1.63 E_a V	1.30 E_a V	1.09 E_a V
Unbalance	2.10 E_u V	1.57 E_u V	1.26 E_u V
Twist**	140 E_a	118 E_a	98 E_a
Minimum Segment	2.64 V	2.20 V	1.47 V

Note: E_a = Actual superelevation in inches; E_u = Unbalanced superelevation in inches; V = maximum speed of the train (mph)
* Longer lengths of half-sine spirals are due to the variability in the ramp rate.
** Provides maximum twist rates identical to clothoids.

(Source: CHSRA, 2009a)

4.6 Reverse Curves

Wherever feasible, reverse curves should be straightened or avoided. The spirals may be extended to provide a reverse curve, if adequate distance is not possible to provide sufficient tangent section lengths between the curves.

4.7 Grades

Vertical grades on highways should be less than the 2% recommended grade for passenger rail service, with exceptional values between 2 to 4% (TSI, 2000; CEN, 2001; CHSRA, 2009a; AREMA, 2009). Minimum grade in cut and tunnel sections should be at least 0.25% (CHRSA, 2009a). The average grade for any 6 km (3.7 mile) long section of the line should be under 3.5%, and the average grade for any 10 km (6.2 mile) long section of the line should be under 2.5% (CHRSA, 2009a), if planning to use SWSR at-grade. For other options, such as elevated SWSR and elevated maglev, the highway grades may be more.

4.8 Vertical Curves

Parabolic vertical curves are generally practiced in the US due to their simple mathematical characteristics. Vertical curvature in railroad is defined as the change in the grade per 100 feet of length. Vertical curves on passenger rail lines are designed to provide a comfortable vertical acceleration (a_v) rate. The AREMA manual (2012) recommends the use of a vertical acceleration of 0.6 ft/sec/sec for passenger service (1.86% g) and a vertical acceleration of 0.1 ft/sec^2 for freight service (0.31% g).

The following acceleration values are used for vertical curves (CHSRA, 2009a):

- Desirable: 0.60 ft/ sec^2 (1.86% of gravity)
- Minimum: 0.90 ft/ sec^2 (2.80% of gravity)
- Exceptional: 1.40 ft/ sec^2 (4.35% of gravity)

The AREMA manual (2012) sets the value of rate change in grade (*r*; % change (Δ g) per 100 ft) as 0.10 for crest vertical curves and 0.05 for sag vertical curves.

4.8.1 Radius of Vertical Curves

The radius of vertical curve (in feet) is determined using vertical acceleration ($a_{V,}$ ft/sec^2) and maximum speed (*V*, mph) of the line. The following formula (Equation 6) is used for the calculation of the radius (CHSRA, 2009a):

$$R_{min} \geq \frac{(V \cdot 1.467)^2}{a_v} \quad (6)$$

In addition, CHSRA (2009a) establishes the relationship between vertical curve radius and rate of change based on the review of existing HSIPR geometry, as in Equation 7:

$$\text{Rate of change (\%/100 feet)} = \frac{3048\%}{\text{Radius in meters}} \quad (7)$$

For a given speed, Equation 6 establishes the minimum required vertical curve radius and Equation 7 gives the recommended rate of change in the vertical curvature. Table 20, Table 21, and Table 22 list the desirable, minimum, and exceptional values of rate change and vertical curve radii, respectively. In essence, highway ROW vertical curvature should at least meet the minimum requirements of rate of change, and vertical curve radii.

Table 20. Desirable Vertical Curves (a_v = 0.60 ft/s^2) – Rates of Change and Equivalent Radii

Speed mph	Speed km/h	% change per 100 feet	feet per % of change	Radius feet	Radius meters
300	480	0.03%	3250	325,000	100,000
250	400	0.05%	2250	225,000	70,000
220	355	0.06%	1750	175,000	53,000
200	320	0.07%	1450	145,000	44,000
175	280	0.09%	1100	110,000	33,000
150	240	0.12%	810	81,000	25,000
125	200	0.18%	560	56,000	17,000

(Source: CHSRA, 2009a)

Table 21. Minimum Vertical Curves ($a_v = 0.90\ ft/s^2$) – Rates of Change and Equivalent Radii

Speed mph	Speed km/h	% change per 100 feet	feet per % of change	Radius feet	Radius meters
300	480	0.05%	2150	215,000	66,000
250	400	0.07%	1500	150,000	46,000
220	355	0.09%	1160	116,000	36,000
200	320	0.10%	960	96,000	30,000
175	280	0.13%	740	74,000	22,500
150	240	0.18%	540	54,000	16,500
125	200	0.26%	375	37,500	11,500

(Source: CHSRA, 2009a)

Table 22. Exceptional Vertical Curves ($a_v = 1.40\ ft/s^2$) – Rates of Change and Equivalent Radii

Speed mph	Speed km/h	% change per 100 feet	feet per % of change	Radius feet	Radius meters
300	480	0.07%	1400	140,000	43,000
250	400	0.10%	970	97,000	30,000
220	355	0.13%	750	75,000	23,000
200	320	0.15%	620	62,000	19,000
175	280	0.20%	480	48,000	15,000
150	240	0.25%	350	35,000	11,000
125	200	0.40%	250	25,000	7,500

(Source: CHSRA, 2009a)

4.8.2 Length of Vertical Curves

Typical vertical curve lengths in the highway applications range from 600 to 1000 feet, but the vertical curve length requirements for HSIPR are almost twice as long (Moore, 2004). Length of vertical curves is calculated using Equation 8:

$$LVC = (K*V*V*\Delta\ g) / a_v \qquad (8)$$

Where *LVC* is length of vertical curve (feet), Δ g is change in grade (Δ % / 100), *V* is the speed (mph), a_v is the vertical acceleration (ft/sec^2), and *K* (= 2.15) is a constant to convert mph into feet. The highway ROW vertical curves should satisfy the following requirements:

- For design speeds greater than or equal to 186 mph (CHSRA, 2009a):
    - Desirable VC Length: The longer of $LVC_{feet} = 4.55\ V$ (for 3.1 seconds attenuation time) or $LVC_{feet} = 2.15\ V^2 (\Delta\% / 100) / 0.60\ ft/sec^2$, but not less than 400 Δ%
    - Minimum VC Length: The longer of $LVC_{feet} = 3.52\ V$ (for 2.4 seconds attenuation time) or $LVC_{feet} = 2.15\ V^2 (\Delta\% / 100) / 0.90\ ft/sec^2$, but not less than 200 Δ%

- Exceptional VC Length: The longer of LVC_{feet} = 2.64 V (for 1.8 seconds attenuation time) or $LVC_{feet} = 2.15 V^2 (\Delta\% / 100) / 1.40$ ft/ sec^2, but not less than 100 Δ%

- For design speeds less than 186 mph (CHSRA, 2009a):
  - Desirable VC Length: The longer of LVC_{feet} = 3.52 V (for 2.4 seconds attenuation time) or $LVC_{feet} = 2.15 V^2 (\Delta\% / 100) / 0.60$ ft/sec^2, but not less than 400 Δ%
  - Minimum VC Length: The longer of LVC_{feet} = 2.64 V (for 1.8 seconds attenuation time) or $LVC_{feet} = 2.15 V^2 (\Delta\% / 100) / 0.90$ ft/ sec^2, but not less than 200 Δ%
  - Exceptional VC Length: The longer of LVC_{feet} = 2.20 V (for 1.5 seconds attenuation time) or $LVC_{feet} = 2.15 V^2 (\Delta\% / 100) / 1.40$ ft/ sec^2, but not less than 100 Δ%

4.9 Combination of Vertical and Horizontal Alignment

Vertical and horizontal curves can overlap. According to the *2010 TxDOT Roadway Design Manual,* to obtain a proper combination of horizontal and vertical alignment, "the design speed of both vertical and horizontal alignment should be compatible with longer vertical curves and flatter horizontal curves than dictated by minimum values. Design speed should be compatible with topography with the roadway fitting the terrain where feasible." Generally, the horizontal curves near the highest point on the crest vertical curves and the lowest point on the sag vertical curves are avoided.

4.10 Minimum ROW Width Required for HSIPR

The minimum width requirements guide TxDOT on how much median or lateral clearance space should be left in the highway ROW to accommodate HSIPR. Based on the reviewed dimensions in Section 3, a 10- to 22-feet ROW width is recommended for elevated-only tracks, 22 to 44 feet for single at-grade tracks, and at least 44 feet for dual at-grade tracks. Florida's DOT mandated 44-foot-wide medians in the I-4 corridor to preserve space for the planned HSIPR (Moore, 2004).

4.11 Clearance and Barriers

TxDOT may consider keeping the reserved space in the highway ROW to meet the track and clearance requirements of HSIPR. According to Moore (2004), the HSIPR clearance requirements generally comply with AREMA recommended practice and include the following strategies for horizontal and vertical clearances.

4.11.1 Horizontal Clearance

a) Main tracks shall be constructed at 14 feet minimum track centers on tangent. Track centers should be increased to provide clearance for catenary poles.

b) HSIPR tracks should be separated from adjacent freight rail tracks by a minimum distance of 25 feet measured between freight and HSIPR track centerlines.

c) The minimum permissible spacing from track centerlines to adjacent fixed obstructions should be 8 feet measured from the track centerline.

d) The standard clearance from track centerline to catenary poles should be 9.5 feet as recommended in AREMA manual. The minimum clearance should be 8.5 feet as recommended in the same manual.

e) Minimum clearance should be used on curves as necessary. Clearance values should be adjusted to compensate for curvature.

f) Catenary pole clearance should be increased 1 inch per degree of curvature. Track centers and clearance to obstructions should be increased 1.5 inches per degree of curvature.

g) The minimum horizontal clearance and track spacing should be increased 1.5 inches per degree of curvature. Where superelevation is applied, the horizontal clearance should be increased on the inside of the curve as measured from a centerline perpendicular to the plane of the tracks at a distance 23 feet above the top of the rail plane.

4.11.2 Vertical Clearance

Consideration should also be given to providing sufficient vertical clearance for bridges, interchanges and other obstructions in the ROW (e.g., electric utility lines). Generally, considering a standard SWSR HSIPR technology:

a) The HSIPR alignment should be designed to provide at least 19 feet of clearance between the top of rail and the low point of the bridge. This clearance value allows the installation of a catenary system with sufficient electrical clearance to the bridge for a 25kV power system.

b) Clearance for existing structures may be obtained by rebuilding the structure, or elevating or lowering the track elevation.

c) Highway bridge piers within 25 feet of a track centerline should be protected with a 6-inch reinforced concrete deflection wall to a height of 6 feet above the top of rail elevation.

4.11.3 Protective Barriers

Crash protection between the HSIPR and dedicated freight transportation systems and the highway was discussed in Section 3.4.3 and should be referred to for selection of barriers for multimodal highway ROW. Additionally, chain link fencing is an option to prevent the intrusion of trespassers and animals. Another consideration is that motorists may be blinded (in what is called the *startle effect*) by the train's bright and fast-moving headlamp (Moore, 2004). Mitigating factors, such as a comfortable separation between train and highway traffic and significant concrete barriers, may minimize that effect.

4.12 Summary

Highway alignment should be the smoothest possible under the given constraints. The design guidelines lay a foundational framework for providing better alignment. Initial planning is key to an efficient alignment, and should include keeping grades low and radii large and providing sufficient spiral curve lengths and vertical and horizontal clearances. Wherever constraints exist, limiting design values can be used. This section only supplements the engineering judgment and existing TxDOT Roadway Design manual recommendations in designing the alignment.

Section 5. Procedures for Review and Approval

Following are the purposes of Section 5:

- Identify procedures used by other state DOTs for use of ROW for HSIPR and dedicated freight transportation systems, and
- Review the procedures used by TxDOT for similar requests.

5.1 Other DOT Procedures

As mentioned in Section 2, none of the state DOTs have manuals or documents specifically documenting procedures used for locating HSIPR or dedicated freight transportations within ROW, with the exception of Florida's ROW Manual (revised May 30, 2013), which states in section 10.9.1.3 that "consideration of any proposed lease involving rail, aviation, or mass transit shall be coordinated with FDOT's State Freight & Logistics Administrator prior to advertisement soliciting additional joint use proposals" (10-9-3). Their explicit mention of rail pertains to an agreement to use the ROW between a public and private entity.

5.2 TxDOT's *Use of Right of Way by Others* Manual

TxDOT has a manual titled *Use of Right of Way by Others* with three chapters that cover the following types of uses of ROW:

- utilities,
- long-term uses (e.g., mailboxes, parking areas, access driveways, hiking and biking trails, and boat ramps), and
- short-term uses (e.g., temporary signage, coffee rest stops, and haul road agreements).

For long-term uses TxDOT may enter into a multiple use agreement (TxDOT Form 2044), authorized by Minute Order No. 65169, with a political subdivision or federal agency to use portions of the highway ROW for public facilities other than highway purposes. Projects on the Federal-Aid highway system may require FHWA approval. The multiple use agreement should be prepared and administered by TxDOT in coordination with the Maintenance Division and the Design Division.

TxDOT must inspect multiple use sites regularly during construction, within 30 days of completion of construction and once per year thereafter and enforce compliance with the terms of the agreement.

Interestingly, TxDOT must audit any entity that charges a fee for parking to cover the cost of construction, maintenance, and operation of the facility to assure the entity is not making a profit. TxDOT will need to make policy decisions regarding how charges for use of HSIPR or dedicated freight transportation systems would be handled if considered a multiple use agreement.

An alternative to a multiple use agreement is a lease agreement (Section 5 of Chapter 2 of the manual). TxDOT may lease highway ROW if it is not needed for highway purposes. The requesting entity must submit a written request to lease to the district engineer. The procedures are outlined in the Texas Administrative Code, Title 43 §21.606.

A possibility for TxDOT is to include HSIPR or dedicated freight transportation systems as a long-term use in a multiple-use agreement or as a lease agreement.

Section 6. Guidelines and Procedures for Leveraging Use of Existing ROW

The purpose of Section 6 is to synthesize information from state DOTs, past reports, and published literature regarding capturing revenue, matching grants, or entering into private-public partnerships for use of state DOT ROW for HSIPR and dedicated freight transportation systems.

This section explains the factors and conditions that may affect value capture opportunities in TxDOT ROW along corridors and in TxDOT-owned property for stations. These guidelines do not present absolute opportunities, but provide a framework to consider revenue generation opportunities. Of course, specific market dimensions will greatly impact the development potential of any given site or corridor.

This review does not cover broad legal and policy issues related to the leasing or sale of TxDOT owned property. However, this section addresses specific issues of policy in some circumstances.

6.1 Corridor Value Capture

Current TxDOT policies provide mechanisms for entities to "lease" ROW (Texas Transportation Code §202.052). In allowing other uses, a variety of pricing mechanisms have been explored in the literature. The most directly relevant example is a recently signed lease that allows Florida East Coast Industries, which will operate the All Aboard Florida passenger rail project between Miami and Orlando, to use Florida DOT owned ROW for a reported $250,000 per year for a 15-mile segment. The lease term is 50-years with a 49-year extension option and includes an inflation clause (Bowen 2013). Importantly, the lease also encumbers All Aboard Florida to return the property to its original condition or deed the rail infrastructure to the Florida DOT upon lease termination (Florida Department of Transportation 2013). We would expect the average lease fee per mile to be lower for a longer segment. However, given that operating finances for HSIPR remain uncertain, the reliability of such a revenue stream remains unproven.

The State of North Carolina takes another approach. North Carolina owns a 317-mile rail line from Charlotte to Morehead City. Norfolk Southern pays the state more than $11 million per year for trackage rights on this line (Morgan, C. et al., 2005), but that is for existing rail line and not directly comparable to the corridors examined in this analysis.

The main restrictions on the leasing of TxDOT ROW are the determinations that 1) the property will not be needed for a highway purpose during the lease term, and 2) the lease will be valued based on fair market prices. Clarification may be required as to what constitutes a "highway purpose." The sale of TxDOT ROW property has additional requirements. Section 202.021 of the Transportation Code notes that the priority of buyers for such property is 1) a governmental entity with condemnation authority; 2) abutting or adjoining land owners; and 3) the general public. That section of the Transportation Code does not require subdivision of property that is to be sold; therefore, the market of potential buyers would be limited.

Leasing ROW property for alternative uses appears to be a more flexible option and may better protect TxDOT's long term interests. Still, each corridor or property will require detailed analysis that should be conducted by, or under the guidance of, highly experienced real estate market experts.

6.2 Station-Based Value Capture

6.2.1 Freight Rail

Our review of current TxDOT-owned property that potentially could be used for development surrounding a freight rail station found no properties of the size and configuration that would support a critical level of activity to justify development. Such properties would need to be roughly symmetrical (meaning that the property could not be long and narrow) and would likely need to be 100 or more acres in size to support the development of transfer stations, intermodal operations, or industrial properties. Such developments may occur with the presence of freight rail services operating in TxDOT ROW, but the vast majority would be developed on private property.[1] Similar to techniques that will be presented in the following section, TxDOT could partner with local taxing jurisdictions to participate in tax increment financing revenue or development fee revenue associated with industrial development sparked by the presence of freight rail services operating on TxDOT property. However, market conditions for economic development incentives for the foreseeable future do not favor sharing a meaningful portion of these revenues with TxDOT. There appears to be little opportunity for TxDOT to gain significant revenue streams from existing ROW land that would be associated with a freight rail terminal.

6.2.2 High-Speed Intercity Passenger Rail

HSIPR stations share much in common with traditional rail stations, commercial airports, and tourist destinations. Stations may be used as an interchange between routes, as the sole destination before switching to another mode of transportation, or merely a place to visit. Although individual stations are unique, numerous factors may affect determination of the effectiveness of revenue generation or value capture strategies in certain contexts. This section will focus on how size, setting, parking, visitors, and ridership, different types of amenities, and transportation connectivity may impact the ability of HSIPR stations developed in TxDOT ROW to generate additional revenues. In addition, we provide some guidance on quantifying decision boundaries for these factors, though we caution that since available case studies in the US are not HSIPR, and the non-US cases are in markets not directly comparable to Texas, these are not precise estimates but rather convey a sense of magnitude.

1) Population in Region
    a. < 200,000: may not be a critical market mass for ancillary development
    b. 200,000–500,000: some market potential if there is a destination attraction nearby
    c. 500,000–2,000,000: station location within metropolitan area will affect development potential
    d. > 2,000,000: best opportunity for development, options available.
2) Parcel size
    a. > 20 acres: more developable property.
    b. 10–20 acres: development density is more important.
    c. Parcel < 10 acres. Need to be able to do vertical development

[1] This analysis did not include examining the possibility of TxDOT purchasing property to augment currently owned parcels.

    d. Parcel size may not apply if the station is underground.

3) Urban/Suburban/Rural
    a. Closely related to population, but affects development type
    b. Urban: office uses, higher end retail
    c. Suburban: some office, retail, household services
    d. Rural: passenger services
4) Parking facilities
    a. If needed, will displace other revenue opportunities.
    b. High demand for parking (Central Business District): high revenue potential.
    c. Moderate demand for parking: suburban, displaces commercial development but still creates revenue potential.
    d. Low demand: low volume stations, displaces commercial development without substantial parking revenue.
5) Ridership/Visitors
    a. These factors are combined because each represents foot traffic for commercial activities. Some stations are "destinations" in themselves.
    b. Ridership < 20,000/week: low levels. Low market opportunities.
    c. Ridership 20,000–60,000/week: moderate levels generating market demand for retail and attracting office uses.
    d. Ridership >60,000/week: Good market potential; station may attract non-rider visitors.
6) Transportation Connectivity
    a. Closely related to ridership and visitors.
    b. If co-located with transit services, effectively increases the number of riders.
    c. Roadway network: for suburban locations, proximity to existing/future road networks may boost activity in the station area to justify commercial development.
7) Presence of Existing Commercial Development
    a. No nearby development: Increases market risk of development, lowering revenue potential.
    b. Moderate nearby development: Allows market development complementary to existing development that lowers risk and raises value.
    c. Substantial nearby development: Development can feed off of economies of scale and the attraction of other development. Highest revenue potential.

The mechanisms for capturing the value of development on TxDOT ROW used for HSIPR include direct revenue opportunities as well as establishing partnerships with public and private entities. The nature of the partnership revenue will depend on the specific characteristics and market conditions of specific parcels. Revenue generation opportunities include the following:

- Ground leases: Direct lease of grounds to a developer. Market conditions will affect value and the nature of the lease agreement.
- Air leases: Leasing of development rights above ground (vertical development).
- Advertising: Leasing advertising space.
- Concessions: Diversion of a portion of concession fees in developments on TxDOT owned land. (Share fees between property managers, developers, and TxDOT in a public-private partnership.)
- Tax Increment Financing Districts: Requires participation with city and/or county government since the revenue will be for property taxes. This technique effectively encumbers the funds to be used within the district.
- Development Impact Fee: Requires participation of local taxing jurisdictions, which could include more exotic entities such as Municipal Utility Districts. Fund generally cannot be used for overall operations expenditures.

For suburban and urban developments, it is almost certain that multiple public entities will be involved, and private entities may become involved as well. For example, given sufficient space availability, higher-density transit-oriented development may be an especially attractive option. However, for most communities this would require special mixed-use zoning and extensive public interactions through the planning and zoning process, which effectively means that local government(s) would be active partners in the development program. Where multiple government agencies are involved, the agencies should enter an intergovernmental agreement designating a Master Developer to clearly designate authority and responsibilities. The Master Developer should focus on the success of the planned development. In addition, leave property management of commercial spaces to industry experts through partnership arrangements or outsourcing services.

The nature of the development and the scope of interagency agreements, as well as public-private partnerships, may vary greatly across different station sites. Therefore, a key recommendation for TxDOT, if it decides to pursue station-area development projects, is the creation of a department within TxDOT that would focus on market analysis, partnership building, and ongoing management of TxDOT properties. This would be a separate function from administering and managing TxDOT properties used to fulfill operations and department administration.

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