CORRIDOR DESIGN ISSUES FOR FLORIDA HIGH SPEED RAIL

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W. Robert Moore
Sr. Project Manager
HNTB Corporation
111 N. Canal St. Suite 1250
Chicago, IL 60606
312-798-0290
bmoore@hntb.com
ABSTRACT

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The State of Florida has attempted to develop high speed passenger rail since 1976, culminating with the current program, led by the Florida High Speed Rail Authority, to introduce an initial high speed rail segment between Tampa and Orlando. The Authority is proceeding to procure a combustion turbine electric powered, high speed rail system under a Design-Build-Operate-Maintain and Finance contract. In advance of the procurement process, consulting engineers working for the Authority evaluated potential routes including existing interstate highway median and freight railroad corridor alternatives. This paper explores the issues associated with designing a system to operate in these constrained corridors. Analysis is both quantitative and qualitative. Key issues including track geometry, barriers and grade separation are addressed based on the Florida experience and existing regulations.

Key words: High speed rail, barriers, track geometry, alignment, spirals, offset
INTRODUCTION AND PROJECT STATUS

The State of Florida has struggled with the development of high speed passenger rail over the past three decades, beginning with the Florida Transit Corridor Study, published in 1976 and culminating with the current program, led by the Florida High Speed Rail Authority, to introduce an initial high speed rail segment between Tampa and Orlando. The program received a great boost with a Constitutional Amendment, passed in November 2000 in a general election by the State’s voters. The Amendment requires that the State construct a monorail, fixed guideway or magnetic levitation system capable of speeds in excess of 120 mph, using dedicated rails or guideway, separated from motor vehicle traffic, and linking the five major urban areas within the State. The language requires the Legislature, Cabinet and Governor to proceed with the program and start construction in November 2003. (Ref. 1)

In response to this mandate, the State formed the Florida High Speed Rail Authority in March 2001 and proceeded to implement a high speed rail program. The Authority adopted a long term vision plan calling for a statewide high speed rail network connecting major communities throughout the state. See Exhibit 1.

In late 2001, a consultant team led by HNTB was selected to prepare initial conceptual studies and serve as General Engineering Consultant. Shortly thereafter, a team led by Parsons Corporation with PBSJ was selected to prepare preliminary engineering and NEPA documents. In late 2002, the Authority issued a Design, Build, Operate, Maintain and Finance Request for Proposal. Four bidders responded in February of 2003 with proposals for steel-wheel/steel rail, monorail and evacuated tube technologies. Two bidders were deemed responsive:

- Global Rail Consortium LLC (GRC), whose principal members are Katherine Beck, ARCADIS, KRTC and Railnet Inc., a subsidiary of Mears Transportation. GRC offered a team of engineers, manufacturers, operators and construction contractors to furnish TGV based, electrified technology modified to meet the standards of FHSRA and FRA.

- Florida High Speed Project Holdings Company (FHSPH), an organization owned by Fluor Daniel Florida Rail, Inc. and Bombardier Transit Corporation. FHSPH offered a team of engineers, manufacturers and construction contractors to furnish JetTrain technology.

In November 2003, the Authority selected the FHSPH team, led by Fluor-Bombardier to furnish its JetTrain and associated infrastructure, a combustion turbine electric powered high speed rail system. At the time of this presentation, negotiations are continuing between the selected proposer and the Authority. During the negotiations, Fluor Bombardier added Virgin Rail and Mears Transportation to its team as the system operators.

High speed rail remains a controversial issue in the State of Florida. The Authority has made substantial progress through the NEPA process, issuing a Draft Environmental Impact Statement in August 2003. The DEIS identified a number of unresolved issues including technology, routing, and agency agreements. Since its publication, the Authority selected a preferred route (I-4 - Greeneway), the preferred technology (JetTrain) and has been seeking to resolve agency agreements and public comments. At the time of this Conference, the Final Environmental Impact Statement has not been published. Under the NEPA process, a Record of Decision follows the publication of the FEIS and receipt of public comments.

Florida’s Governor and Florida’s CFO have expressed opposition to the project and have sought to repeal the November 2000 Constitutional Amendment requiring construction of High Speed Rail. The initiative may appear on the ballot in November 2004 pending resolution of suits and appeals by supporters of the high speed rail program.

Corridor Alternatives

Through the DEIS process, consulting engineers and planners working for the Authority evaluated potential routes for the Tampa-Orlando segment and concluded that the most favorable route will employ the
Interstate Highway - 4 median for much of the 84 mile alignment. Alternative segments in the vicinities of Tampa and Orlando survived the screening process and were presented to bidders in the RFP. The Tampa branches include a highway alignment adjacent to I-275 and a rail alignment parallel to the CSX S-Line and A-Line tracks. Branches in the Orlando area included highway corridor alignments in the Beeline SR 528 and Greeneway SR 417 rights of way.

Alternative routes considered the use of existing CSXT owned freight railroad alignments and adjacent privately owned properties. The selection criteria included a number of environmental factors and two that considered both environmental and cost elements, specifically right of way requirements and structure/embankment requirements. The selected and rejected alignment options resulting from the DEIS are depicted in Exhibit 2.

Based on the analyses performed in previous studies, the DEIS did not consider extensive new segments across privately owned property. As planners and engineers have discovered in transportation corridor studies throughout the USA, it has become increasingly difficult to secure new transportation corridors, particularly where the property has been developed for residential use. As high speed passenger rail systems are likely to be successful only in populated regions or between population centers of sufficient density to provide significant ridership, the likelihood of assembling new contiguous corridors in populated areas is small. This compelling fact has driven transportation planners to take a hard look at using existing corridors, particularly those in interstate highway or freight rail use.

While the purpose of this paper is principally to illuminate the engineering issues associated with designing high speed rail in existing corridors, other institutional challenges exist. In the case of interstate highways, the law (23CFR810.200 Making Highway Rights of Way Available for Mass Transit Projects) allows a publicly owned mass transit authority to submit an application to the State highway agency to utilize land existing within the publicly acquired right of way of a Federal-aid highway. The State agency may request that the Federal Highway Administrator authorize the use of such land, subject to evidence that the transit utilization will not impair future highway improvements or the safety of highway users. The statute states that such land will be provided without charge. (Ref 2)

As noted previously, the selected alignment employs Florida’s Greeneway SR-417 in the vicinity of Orlando. This corridor segment is a tollway, operated by the Orlando Orange County Expressway Authority. This Authority must approve the use of the property and may seek compensation for lost revenues and other costs.

Numerous commuter rail, light rail and high speed rail studies have considered the use of freight rail corridors for new passenger service, so much so, that the Association of American Railroads has issued a formal policy statement on the subject, titled Passenger Service on Tracks Owned by Freight Railroads. The freight railroad industry position is summarized as follows:

- Freight railroads should receive full compensation for use of their assets by passenger trains
- Access by non-Amtrak passenger railroads must be negotiated by the parties without government interference
- There shall be no government mandated access
- Freight railroads should have adequate liability protections
- Agreements must address the adequacy of infrastructure capacity for existing and future passenger and freight operations (Ref 3)

Individual railroads have developed similar position documents, particularly addressing the use of their properties in support of high speed rail operations. Almost uniformly, the freight railroads have requested that operations at 90 mph and above be conducted on tracks separate from those used by freight operations. This paper presumes that the high speed rail planner will undertake studies of freight rail corridors with the cooperation of a willing private railroad owner.
HIGH SPEED RAIL DESIGN CRITERIA

General

In 2002, during the preparation of the RFP and preliminary design documents, it was anticipated that a high speed rail system would be constructed under a design build operate and maintain contract. Preliminary engineering and environmental assessment proceeded on the Tampa to Orlando corridor in order to select a preferred alignment, satisfy the NEPA process and develop tender documents.

Meetings were held with potential proposers representing an assortment of high speed ground transportation technologies, including diesel-electric and electric powered steel wheel/steel rail systems, magnetic levitation systems, monorails and other less service proven strategies. High speed rail systems in use throughout the world offer both conventional and tilt suspensions. As might be expected, the performance and infrastructure requirements of each technology are slightly different. This is particularly true for speed related geometric parameters such as curvature, grades, and spiral length and clearances.

In order to enable the competitive marketplace to present the best option for the citizens of Florida, the Authority did not make a technology selection. This complicated the preliminary engineering task, as the alignments and infrastructure must be designed to allow the application of the range of technologies. The resultant alignment alternatives were designed, so as not to preclude the use of or unjustly penalize the performance of any technology, yet with sufficient curvature and grade to demonstrate the compatibility with the existing infrastructure and topography.

The basic infrastructure design anticipated accommodating a dual ballasted track, grade separated, dedicated use, electrified high speed rail system capable of speeds of 160 mph and complying with existing FRA standards. On award of the contract to a DBOM contractor, it was expected that the contractor would optimize the alignment and infrastructure design for his technology within right of way and other constraints. It may be noted that AREMA’s Manual for Railway Engineering, Chapter 17 High Speed Rail Systems offered limited guidance in 2002.

The Authority’s consultants developed a comprehensive Design Criteria document and Plan Set to guide the proposers in responding to the RFP. The Design Criteria specified design of infrastructure in accord with Florida DOT standards, and railroad track and structures in accord with AREMA’s Manual for Railway Engineering 2002. Track design and maintenance standards must comply with 49 CFR 213 Track Safety Standards. However, in anticipation of bids that might employ European technologies, the RFP allowed deviations from AREMA recommended practice and existing FRA regulations in 49 CFR 200-399. Based on work performed under the previous FOX program, the Authority allowed the proposers to seek a Rule of Particular Applicability or Waiver from the FRA. Documented meetings with the FRA indicated that the Administration would support such a process.

While not attempting to reproduce the entire Design Criteria, this paper summarizes some of the concepts, issues and requirements which are relevant to the route selection.

Horizontal Geometry

Tangent segments of the high speed rail alignment shall be designed to fit within a 44 ft envelope in highway medians and 50 ft envelope within existing railroad alignments, except as required by curves and spirals. Excursions outside the existing median or right of way shall be identified.

Emergency and inspection walkways shall not be required in constrained right of way or highway median construction. Emergency access and evacuation shall be provided along the adjacent track.

The minimum tangent length between curves shall be the greater of 100 ft or three times the design speed, \( L = 3V \), where \( L \) is in feet and \( V \) is in mph. The alignment shall be tangent through the platform area to a distance of 100 ft from platform edges.
Curvature shall not exceed 9 degrees on mainline tracks and 12 degrees on yard tracks. The minimum length of circular curve shall be determined by the formula: \( L = 2.22 \times V \), where \( L \) is in ft and \( V \) is in mph. In no case shall the length of circular curve be less than 100 ft.

Mainline curves shall be superelevated. The maximum design superelevation \( E(A) \) shall not exceed 6 in. FRA permits a maximum superelevation of 7 in (49 CFR 213.329).

Maximum cant deficiency \( E(U) \) shall not exceed 9 in. FRA has permitted a maximum cant deficiency of 9 in on qualified equipment. (Note that the two responsive proposers did not offer tilt technology and limited \( E(U) \) to approximately 4.5 inches for their TPC runs.)

Mainline curves shall be designed with \( E(A) \) established to balance forces on both rails, employing cant deficiency as required to achieve design speeds. The balancing speed in a curve shall be determined by the formula: \( E(A) = 0.0007 \times D \times V \times V \), where \( E(A) \) is in inches, \( D \) is in degrees and \( V \) is in mph. The maximum permissible speed in a curve shall be determined by the formula: \( E(A) + E(U) = 0.0007 \times D \times V \times V \), where \( E(A) \) and \( E(U) \) are in inches, \( D \) is in degrees and \( V \) is in mph. The sum of \( E(A) + E(U) \) shall not exceed 15 in.

Superelevation shall be run off at a constant rate in the spiral. Superelevation shall not be runoff on tangent track.

Mainline curves and tangents shall be connected with a spiral transition. The length of the spiral shall be determined by the maximum value determined by the following formulae:

\[ L(S) = 1.63 \times E(U) \times V, \]  
\[ L(S) = 1.30 \times E(A) \times V, \]  
\[ L(S) = 124 \times E(A), \]  
where \( L(S) \) is in ft, \( E(U) \) is in inches and \( V \) is in mph.

Spiral and curve geometry shall be determined using the formula and notation of AREMA 5-3-2 through 5-3-5.

The application of spirals for high speed operation is anticipated to result in conflicts with existing CSX railroad and highway median alignments, as the original alignments were not constructed with long spirals. Each curve shall be evaluated to determine site specific solutions. Where the cost of realigning existing infrastructure proves prohibitive, the design speed and spiral length shall be reduced as necessary. Highway shoulder pavement width may be reduced to a minimum of 4 ft where necessary to incorporate spirals and curve offset.

**Vertical Geometry**

The vertical alignment shall follow the existing track or highway gradients, wherever practicable. The desired maximum grade shall not exceed 3.5%. Under no circumstances shall the grade exceed 5%. The minimum grade length shall be determined by the formula: \( L = 2.22 \times V \), where \( L \) is in ft and \( V \) is in mph. Yard tracks and station track grades shall not exceed .25%. It is desired to design such tracks at 0% grade.

Where changes in grade occur, gradient lines should be connected by vertical curves, observing the following provisions:

The length of a vertical curve is determined by the difference in grades to be connected and the rate of change adopted. For high-speed main tracks, the rate of change should not be more than 0.05' per station of 100' in sag curves and not more than 0.10' per station of 100' in crest curves.

Where geometric constraints prevail, the following formula shall be used to determine the vertical curve lengths: \( L_{VC} = \Delta g \times V \times V \times K/A \), where
LVC = Length of Vertical Curve (in ft)
Delta g = difference in grades expressed as a decimal
V = speed (in mph)
K = 2.15, constant to convert mph into feet
A = 0.01gc (gc = 32.16 ft/sec/sec)
The minimum vertical curve length, LVC_{(min)}, shall not be less than 70 ft.

**Clearance**

Typical sections were developed and included in the plan set to guide the proposers. Clearances generally comply with AREMA recommended practice and reflect the following strategies.

Main tracks shall be constructed at 14 ft minimum track centers on tangent. This value is greater than the statutory 13.5 ft required by Florida law. Track centers shall be increased to provide clearance for catenary poles.

High speed rail tracks shall be separated from adjacent freight rail tracks by a minimum distance of 25 ft measured between freight and high speed rail track centerlines.

The minimum permissible spacing from track centerlines to adjacent fixed obstructions shall be 8 ft. measured from the track centerline in accord with Florida law.

The standard clearance from track centerline to catenary poles shall be 9 ft 6 in as recommended in AREMA Table 33-4-4. The minimum clearance shall be 8 ft 6 in as recommended in the same table. Minimum clearance shall be used on curves as necessary.

Clearance values shall be adjusted to compensate for curvature. Catenary pole clearance shall be increased 1 inch per degree of curvature. Track centers and clearance to obstructions shall be increased 1.5 in per degree of curvature.

Clearance shall be measured from the centerline of the track, perpendicular to the plane of the top of the rails.

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

The high speed rail alignment shall be designed to provide 19 ft 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. Clearance for existing structures may be obtained by rebuilding the structure or lowering the track elevation.

Highway bridge piers within 25 ft of a track centerline shall be protected with a 6 inch reinforced concrete deflection wall to a height of 6 ft above the top of rail elevation.

**Retaining Walls and Drainage**

Where standard roadbed and ballast section back-slopes intersect existing ground lines beyond the existing ROW, retaining walls shall be designed and constructed within the property with diversion ditches or drains provided behind the retaining wall to divert runoff from adjacent properties toward stabilized drainage outfall structures. Where applicable, profiles may be adjusted to minimize earthwork and reduce or eliminate the need for retaining walls.

In order to minimize right-of-way and excavation requirements, underdrains rather than ditches shall be employed where necessary for drainage. Longitudinal drainage shall be constructed under the highway shoulder. Drainage shall be designed to convey flow from the guideway and adjacent roadway, where the roadway slopes toward the median.

**Barriers**
Systems located in a highway corridor shall be protected against intrusion by unguided automotive vehicles including motorcycles, automobiles, light trucks and over the road trucks. The minimum level of protection shall include the following longitudinal elements:

- Permanent highway barriers meeting the requirements of NCHRP Report 350 Test Level 5 on tangent and adjacent to MSE walls.
- Where the highway is on curve and within 100 feet of a highway curve, reinforced concrete barriers meeting the requirements of NCHRP Report 350 Test Level 6.
- Where the guideway is on pier supported structures NCHRP Report 350 Test Level 5 barriers shall be required to protect guideway piers and the occupants of highway vehicles.
- Curved overhead highway structures to provide highway barriers meeting the requirements of NCHRP Report 350 Test Level 6.

High speed rail systems, which are crossed by overhead highway bridge structures, shall provide protection of highway bridge pier structures in accord with AREMA’s Manual for Railway Engineering Chapter 8 Section 2.1.5.

High speed rail systems shall provide protection against guideway and right of way entry by unauthorized persons, large animals and objects. Such protection shall be provided by 6 ft. chain link fencing installed longitudinally within the guideway between the barrier structure and the track, at a distance of approximately 30 inches from the centerline of the barrier. Fencing shall not be required where the barrier or retaining wall height exceeds the height of the fence. Overhead highway bridge structures shall include chain link fencing across the width of the guideway plus 20 feet on each side to aid in the prevention of acts of vandalism.

High speed rail systems shall include an intrusion detection system, capable of detecting large objects that strike or rupture the chain link fence. Where fencing is not required (at high retaining walls or barriers), the intrusion detection system shall be furnished using electromechanical or other appropriate means of detection. The intrusion detection system shall be tied into the train control system to allow either warning or train stop as determined by the system safety study performed during the design and construction phase by the successful Proposer.

Should the successful Proposer offer a system which provides train operating speeds in excess of 125 mph, during the design and construction phase, Proposer shall meet the requirements of 49CFR213.361, which requires the development of a Right-of-Way Plan for track systems of classes 8 and higher. The Right-of-Way Plan and its implementation shall as a minimum include the base line protection cited herein.

**HIGHWAY CORRIDOR DESIGN ISSUES**

The Tampa-Orlando segment of the high speed rail network considered alignments located within existing highway corridors including I-275, I-75, I-4, Beeline SR 528 and Greeneway SR 417. Based on previous project experience and analyses, in 1993, the State of Florida DOT, anticipating future high speed rail usage of highway corridors established a standard highway median rail envelope and specification for guideway construction suitable for passenger rail operations up to 125 mph. In a February 15, 1999 memo, the DOT directed that a 44 ft wide by 17.5 ft (plus 1 ft for future track raise) high envelope be provided under new highway construction plans where space is reserved for future high speed rail. The 1993 FDOT specification depicted horizontal geometry and clearance issues, but specifically noted that pier protection, visual barriers, wayside or incursion detection methods had not been addressed. The specification also required security measures for overhead roadway bridges and along the adjacent highway including 8 ft high security fencing and “barriers of a strength and configuration to effectively prevent the incursion of an out-of-control vehicle in the railway”. (Ref 4)
It should be noted that the rail and highway regulatory agencies, FRA and FHWA, have not developed extensive regulations addressing the shared corridor use by rail and automotive modes. The industry guidelines are similarly silent. AASHTO’s *A Policy on Geometric Design of Highways and Streets 2001*, notes that the combination of mass transit in freeways provides a means of optimizing transportation services in larger cities and preserves taxable property. (Ref 5) However, the book provides few quantitative recommendations to solve the design issues. As noted previously, AREMA’s *Chapter 17 High Speed Rail Systems* is under development. Similarly, Chapter 12 *Transit*, while addressing track geometry, does not consider highway interfaces. The provisions of NFPA130 *Standard for Fixed Guideway Transit Systems* are generally regarded as not applicable to an intercity passenger railroad transportation mode.

The preliminary engineering work for the Tampa-Orlando program identified the following significant design issues/challenges for constructing high speed rail in the highway corridor:

- Limited median or border (traveled way to ROW limits) dimensions
- Horizontal and vertical curvature designed for highway conditions
- Tangent/curve roadway alignment
- Protective barriers, security fences, intrusion detection and glare screens

Each is discussed to illuminate the issue and define possible solutions.

### Limited Median/Border Dimensions

The conventional passenger/freight railroad is normally constructed on a nominal 100 ft wide right of way. This width provides sufficient space for multiple tracks at typically 14 ft centers, trackside maintenance access by motorized equipment, cost effective ditch drainage and safe clearance to adjacent structures, transportation facilities and right of way fencing. The nominal width is often increased in rolling terrain to allow for embankments and cuts. Right of way width can be reduced in urban areas where property is costly and train speeds are slow.

The Florida DOT policy has mandated that a minimum 44 ft wide corridor (between inside highway shoulder pavement edges, or 64 ft between inside lane pavement edges) be provided in highway medians that may serve as future high speed rail corridors. In many locations, particularly in curves, the existing I-4 highway median exceeds the 44 ft minimum requirement. At other sites, the highway median must be expanded or highway expansion plans altered to provide this space.

As illustrated in Exhibits 3 and 4, the cross section sketches depicted in the FHSRA RFP plan set, produced by Parsons Corp, the Authority’s consultants determined that a two track, electrified high speed rail system could be squeezed within the nominal 44 ft envelope. Similar sketches depict a 44 ft wide bridge section and cut/fill sections with retaining walls. The responsive bidders, FHSPH and GRC, offered Bombardier JetTrain with Acela derived coaches (non-tilting) and French/Korean TGV equipment, respectively. The suppliers stated that the limited envelope was suitable for dual track operations at speeds of 125 mph for JetTrain and 160 mph for TGV. Additionally, the FHSPH team indicated that future electrification could be designed and installed within the envelope.
Having selected a highway corridor, the designer may consider locating the high speed rail alignment in either a border area or within the median. Rural and suburban interstate highway corridors, such as those seen in central Florida, are typically 300 ft wide with construction of the highway facility centered about a relatively narrow median to meet initial construction cost objectives. The border area may offer greater real estate than the constrained median. The border also offers easier station access and connectivity to other modes including the existing street network. However, the border contains interchange ramps, access roads, utilities, drainage structures, and back and fore slopes that challenge the designer. In contrast, the median, where provided, is generally improved to a similar grade to that of the highway and is relatively utility free. However, the median often provides drainage and retention for the adjacent lane and shoulder and serves as a location to land piers to support cost effective grade separated crossing roadways.

In most cases, the designer will determine that an existing median offers a less costly alignment option, due to the cost of structures necessary to clear the existing roadway access elements in the border. In the case of the Tampa-Orlando project, the Authority’s consultants determined that the I-4 median offered the lesser cost. However, the RFP alignments depict highway border construction in the vicinity of Tampa, where a wide median had not been constructed and on segments of the Beeline and Greeneway in Orlando. In each case, construction of the border alignment requires extensive retained earth fills and viaduct structures to provide clearance to existing roadway facilities. The selected proposer, FHSHP, offered a Greeneway alignment within the median to reduce construction cost, but the Expressway Authority had planned to construct future capacity improvements within the graded median, and quite possibly will require compensation for loss of this future facility.

High-speed rail geometric requirements and precise surface maintenance demand close attention to subgrade and embankment construction. The fill must be well compacted and constructed using limited quantities of organic materials or soft clays that may compress over time. In addition, the subgrade must be provided with drainage facilities to remove water to ensure that trainloads do not result in deformation of the structure. Generally, railroads are constructed on a shallow embankment above the surrounding terrain to facilitate drainage. Construction in a highway median will require significant bulk material handling and the construction of new underground drainage facilities sized for the combined highway and railway runoff. Where the median currently provides storm water retention or detention functions, new facilities may be required. In addition, the guideway is considered an relatively impervious surface. Where existing retention ponds are not sized in anticipation of this requirement, additional right of way may be needed to store the additional runoff.

The rather constrained space of the median presents a challenge for fitting all the required components of a two track, electrified high speed rail system. Without belaboring the obvious, the designer must consider drainage pipes and manholes, signal equipment, electrical conduits for signal and communication cables, catenary foundations, feeder cable ducts, catenary poles and foundations, retaining walls, bridge piers, barrier walls and fences. The restricted space, located within the active highway environment, makes access for construction, inspection, maintenance and emergency response more difficult.

**Horizontal and vertical curvature designed for highway conditions**

The alignment of a high-speed rail system can be determined by the mandates of basic physical science, subject to the constraints of the existing natural terrain and man-made infrastructure. Mathematically, an alignment is represented by a series of tangent sections (straight lines) connected by vertical and horizontal curves. The ideal alignment between two points is a straight line in both horizontal and vertical planes. A vehicle traveling through a curve is subject to a centripetal acceleration, which varies as the square of the speed. Rail systems are constructed with superelevated tracks (the outside rail is raised with respect to the inside rail up to 7 inches for Class 3-8 track) to minimize the horizontal component of the centripetal acceleration. However, the superelevation is generally insufficient to totally eliminate the horizontal force component, resulting in “unbalance or cant deficiency”.

Permissible cant deficiency is limited by both passenger comfort objectives and by regulation (49 CFR 213 Subpart G applies to high speed operations) to eliminate the likelihood of derailment. Conventional passenger rail equipment rolls to the outside while traversing a curve, while modern tilt technology trains
roll toward the inside of the curve further reducing the horizontal component of the force felt by the passengers. Tilting passenger coaches, such as those employed on Amtrak’s Acela, offer the capability to improve passenger comfort and enhance the permissible speed through the curve. The FRA defines a procedure to qualify the permissible unbalance of specific rolling stock in Part 213. As the permissible unbalance and superelevation are limited, curves restrict the speed that a vehicle can travel. (Ref 6)

Applying the standard formula of 49 CFR 213.329:

\[ V^2 = E(A) + E(U)/0.0007 \times D \]

where \( V \) is speed in mph, \( E(A) \) is actual superelevation in inches, \( E(U) \) is cant deficiency in inches, and \( D \) is curvature in degrees, we can determine that the JetTrain with a permissible \( E(U) \) of 4.5 inches can achieve its maximum speed of 125 mph through a curve of approximately 1 degree (calculated 0.96 degrees = 58 minutes = 5968 ft radius) with \( E(A) \) of 6 inches.

Similarly, TGV, operating at a cant deficiency, \( E(U) \) of 4.5 inches can achieve its maximum speed of 160 mph through a curve of approximately 0.6 degrees (calculated 0.59 degrees = 35 minutes = 9778 ft radius) with \( E(A) \) of 6 inches.

The reader is cautioned that these computations reflect the performance parameters cited by the proposers in response to the FHSRA RFP conditions. Both technologies are likely to achieve greater peak speeds on unconstrained alignments with different consist configurations. Theoretically, the speeds on this route could be increased by the use of tilt technology equipment, but such equipment was not offered in response to the RFP.

Typical US interstate highways are designed for speeds of 60-70 mph with curves up to 5 degrees. The observed curvature on I-4 from Tampa to Orlando is not overly restrictive to the JetTrain technology, with only two curves exceeding 1 degree, with 1.50 and 1.91 degrees respectively. A slightly larger number of curves impede the TGV performance with 5 curves significantly larger than 0.60 degrees. (The reader may observe that highway curvature is computed using arc definition and railroad in chord definition, but the difference is not significant for these calculations.)

In an attempt to maintain the speed of the high speed rail equipment, the curvature of the roadway and HSR guideway may be reduced. This strategy is likely to result in significant costs for highway reconstruction and possibly right of way purchase. The mathematics of the geometric impacts are similar to those addressed later in the freight railroad corridor analysis.

The vertical alignment can be similarly described as a series of straight grades connected by vertical curves. Due to the limited adhesion of steel wheels on steel rails and generally modest power to weight ratios freight rail systems, grades used in freight rail system design are less than those used for highways. However, the more robustly powered high speed passenger rail systems can operate effectively on grades similar to those of an interstate highway at values up to 5%. The minimum highway vertical curve length is generally established to accommodate comfort and sight distance criteria. Typical vertical curve lengths in highway applications range from 600 to 1000 ft.

Historically, American rail systems have used the classic formula:

\[ r = \frac{(G1-G2)}{LVC} \]

where \( r \) is the rate of change in grade in percent per 100 ft, \( G \) is grade and LVC is vertical curve length in 100 ft stations. AREMA set \( r \) values as 0.10 for crests and 0.05 for sags. Application of this formula results in the classic long vertical curves in use throughout much of the mainline track today.

The new AREMA formula reflects speed and vertical acceleration components. At the time of the FHSRA Tampa-Orlando design, the consultant team used a similar formula with a value of 0.32 for \( A \). The formula is depicted as follows:
**LVC = Δg*V*V*K/A**

where LVC = Length of Vertical Curve (in ft), Δg = difference in grades expressed as a decimal, V = speed (in mph), K = 2.15 constant to convert mph into feet, A = 0.01gc (gc = 32.16 ft/sec/sec). (Ref 7)

A typical application of the new criteria results in a vertical curve length of 2100 ft compared to roughly 800 ft for the adjacent highway, where the grade changes from 0.64 to -1.64%. The difference in profiles between the highway and roadway results in greater use of retaining walls to fit within the narrow constraints of the median. A similar effect is observed as the rail profile is adjusted to provide sufficient clearance for electrification under overhead highway bridges (nominally 19 ft from top of rail to low structure). Often the bridges have been constructed to provide 16.5 ft of clearance above the highway, requiring that the rail alignment be depressed several feet.

**Tangent/curve roadway alignment**

The construction of a railroad in an existing highway alignment is further complicated by the need to build spiral transitions from tangent to curved segments. A spiral may be viewed as a gradual increase in curvature from a straight or tangent line to the circular curve. An interstate highway is generally constructed by connecting tangent sections with pure circular curves, (although short spirals have been employed on occasion). Automotive traffic can enter the curve gradually by steering a spiral path within the travel lane. A rail system must be constructed with spiral transitions to increase the centripetal acceleration gradually (and runoff superelevation).

Construction of a spiral results in an alignment offset (towards the inside of a curve) compared to the path determined by a simple tangent to circular curve transition. The length of the required spiral and resultant offset distance vary directly with speed, curvature and superelevation or cant deficiency as determined employing the standard AREMA formulas, previously referenced in the Design Criteria herein. The Authority’s engineers computed the offset according to Figure 5-3-1 of AREMA’s *Manual for Railway Engineering*, (Ref 8) where the offset is determined as:

\[ D = k*S \]
\[ O = 0.0727 S*S*S \]

where k is the increase in degree of curvature per 100 ft station along the spiral, S is the spiral length in 100 ft stations, and O is offset distance from spiraled curve to simple curve in ft.

Exploring an example found on the I-4 alignment, in curve FLHSR 3-10, we measure 1.5 degrees with a maximum design speed of 100 mph, employing E(U)=4.5 in and E(A)=6.0 in. It can easily be shown that these values satisfy the relationship: E(A)+E(U)=0.0007 D*V*V. The maximum spiral length is computed to be 780 ft employing the formula:

\[ LS = 1.30 E(A)*V \]

The offset, O, is determined to be 6.62 ft, which presents a challenge in the restricted highway median environment with a 44 ft wide guideway and 10 ft shoulder. One option is to reduce the shoulder width from 10 to approximately 3-4 ft. This may not prove acceptable to the highway users due to conflict with the standard minimum inside shoulder width of 10-12 ft per AASHTO’s *A Policy on Geometric Design of Highways and Streets* guideline for freeways of six or more lanes. (Ref 9)

Note that while slight variations to the calculated dimensions may be determined by computing separate alignments for each track, the use of a spiraled high speed rail alignment is likely to require highway alignment modifications where significant curvature exists and the median dimensions are constrained.
Protective barriers, security fences, intrusion detection, glare screens

In steel wheel on steel rail transportation technology, the rails serve to guide and constrain the path of the vehicle. There is little probability that a high-speed passenger train could leave the guideway under normal maintenance and operating conditions. The operating history of high-speed passenger rail systems in Europe and Japan include very few derailments, as a result of conservative design and frequent maintenance. (One incident occurred in Germany, where a wheel failed causing a train derailment and collision with a structure. In addition, freight railroad traffic, while constrained by the track, may derail occasionally due to track defects, equipment defects or train operator error in speed control and braking. The incidence of damaging derailments has diminished in recent years with enhanced rail safety initiatives and improved freight track structure.) Highway traffic is not similarly constrained and may occasionally leave the surface of the roadway for a host of reasons, and principally operator error.

While the FRA requires that passenger trains operating on the general railroad system comply with stringent crashworthiness standards, neither the FRA, nor the Federal Highway Administration (FHWA), has addressed requirements for mode separation of high-speed passenger rail equipment operating in highway medians. Furthermore, while several mass transit systems operate short distances within highway corridors, in most cases the adjacent traffic moves slowly and concrete barriers constructed to various specifications are in place. Few incidents of motorists penetrating the barriers and fences have been recorded, making statistical analysis and well founded recommended practice difficult to develop. As a result, differences of opinion exist on the configuration of such safety and security elements.

The authors of the 1993 FDOT Guidelines were apparently concerned about providing protection to the median guideway, as evidenced by the walls depicted in their sketches and the text in document, “Barriers shall be constructed separating the railroad right of way from the highway right of way. This barrier shall be of a strength and configuration to effectively prevent an out of control highway vehicle from intruding into the railroad right of way.” The standard depicts an embedded concrete structure approximately 2 ft thick, buried 6 ft with 7-8 ft projecting above the surface. Similarly, the authors of the 1993 Guideline observe that successful railroad construction and operation would include “wayside or incursion detection methods.”

TRB’s National Cooperative Highway Research Program (NCHRP) has established standards for roadside longitudinal barriers, issuing NCHRP Report 350 in 1993. This report provides a uniform standard for testing roadside barriers and other roadside safety devices. The typical roadside steel beam, cable or timber barriers meet Test Level – 3 (TL-3), a standard which tests the collision performance of the barrier under the impact of a 1,800 lb car striking the barrier at an angle of 20 degrees at a speed of 60 mph and that of a 4,400 lb pickup truck impacting at 25 degrees also at 60 mph. TL-5 adds an 80,000 lb tractor trailer at an angle of 15 degrees and a speed of 50 mph. TL-6 substitutes an 80,000 lb tractor tanker (high CG). TL-5 and TL-6 barriers have been constructed of reinforced concrete and are depicted in the enclosed photos from AASHTO’s Roadside Design Guide 2002, Exhibit 5. (Ref 10)

Observing that I-4 conveys significant truck volumes at high speeds, the Authority’s consultants recommended common, cost effective concrete TL-5 barriers on at-grade tangent track and more costly, TL-6 barriers on curves. The consultants also specified an intrusion detection system. As noted in the Design Criteria, protection is also required on highway bridges crossing over the rail system. The selected proposer has disputed the need for TL-6 barriers and intrusion detection, noting that existing regulations do not mandate these components and that the proposed technology operating at peak speeds not greater than 125 mph is not subject to the provisions of 49CFR 213.361, which requires submitting a barrier plan for operations at Class 8 and 9 speeds (125+ to 200 mph).

Chain link fencing is specified throughout the system to prevent the intrusion of trespassers and animals. The RFP typical cross sections depict fencing mounted 30 inches inboard from the outer face of barrier walls. The location of the chain link fencing is unresolved, as the FHSPH team has depicted barrier mounted fencing to preserve clearances within the rail envelope. In early project meetings, the FHWA observed that fencing mounted on the barrier walls may present a snagging hazard to motorists and not meet the NCHRP test standards. The NCHRP physical testing allows and usually observes significant
penetration of the barrier by the test vehicle. A barrier mounted, chain link fence is likely to snag a lower mass vehicle, causing an abrupt deceleration.

While the 1993 FDOT specification identifies a need for glare screens, the issue and possible solutions are not fully developed. The FHSRA consultant team held a series of meetings from 2001 through 2003 with the FRA and FHWA to discuss safety issues associated with the design and construction of a high speed rail system in a limited access highway median. The FHWA observed that many American motorists may not be accustomed to the presence of a rail vehicle in close proximity to the highway travel lanes. Accordingly, motorists may be startled by being overtaken by a high speed train or be blinded or confused by the approach of a train’s bright headlamp. This issue was termed the “startle effect”.

It was noted that the preliminary conceptual plans did not enable a thorough analysis of the risk to motorists, due to the difficulty in establishing sight lines with unresolved elevations of the rail and highway pavement. Mitigating factors were recognized, including the generally comfortable separation between train and automotive traffic consisting of shoulder width and railroad clearance dimensions, as well as significant concrete barriers and fencing. The FRA noted that regulations specifying specific headlamp candle power (49 CFR 238.443) could be waived for operation in a highway environment, should the hazard analysis determine that safety would be enhanced by reducing the level of illumination. It was observed that specific segments could benefit from signage and/or higher barrier walls to eliminate headlamp glare and prevent motorists from seeing a train in close proximity.

It is anticipated that these issues will be addressed further in the preparation of the System Safety and Security Plan, a required submittal under the RFP Design Criteria and future contract.

FREIGHT RAILROAD CORRIDOR DESIGN ISSUES

Several passenger rail studies over the past decades have considered alignments on the CSX A Line and S Line corridors between Tampa and Orlando. As an initial task for the FHSRA, HNTB undertook a study to evaluate the feasibility of different route alternatives in the corridor. Interested readers are referred to the Florida High Speed Rail Authority Technical Report, February 4, 2002, which is available on the FHSRA website, www.floridahighspeedrail.org. The study developed a conceptual alignments and capital costs for multiple routes including routes from Tampa Union Station to Orlando International Airport employing the CSX property between MP 882 at Tampa and MP 820 at Davenport. The DEIS eliminated much of the CSX corridor as a feasible alternative, retaining only a short segment from Tampa Union Station to I-75 at MP 874.5.

HNTB met with CSX staff in late 2001 to discuss the potential use of CSX owned property for high speed rail. CSX indicated that it would consider selling a portion of its property for the project, provided that system was on separate tracks, fully grade separated, did not interfere with freight operations and preserved a two track freight system, with tracks realigned as necessary. It was further agreed that the track center spacing between the high speed rail and freight rail would not be less than 25 ft.

Conceptual and preliminary engineering studies identified the following significant design issues/challenges for constructing high speed rail in a freight railroad corridor:

- Narrow right of way
- Historic alignment designed for passenger and freight rail service
- Frequent highway grade crossings
- Frequent industry spurs and sidings

Each is discussed to illuminate the issue and define possible solutions.

Narrow right of way

Freight railroad corridors are generally constructed on a 100 ft right of way with an initial single track centered within the property. Typical alignments in developed regions are characterized by frequent
industry turnouts and sidings and both public and private roadway grade crossings. While densely populated urban areas have invested in constructing grade separations, the great majority of suburban and rural railroads operate at grade through the adjacent communities.

The nominal 100 ft right of way is usually sufficient to fit the necessary embankments and fills that allow a railroad to construct relatively flat grades of 1-2% through rolling terrain. In addition, the 100 ft provides sufficient space to add additional tracks as service grows on the line. In urban areas and town centers, the original 100 ft may have been significantly reduced over the years to provide property valued for other uses including commercial buildings and roadways. Examples of such activity are visible on the CSX alignment at Wheeler St in Plant City, where the right of way narrows to approximately 45 ft, Exhibit 6.

Many historic railroads were constructed to provide passenger and freight service, but most of the intercity passenger service has diminished to the few corridors operated by Amtrak. Outside the Northeast Corridor, most of Amtrak’s service operates on tracks owned by the freight railroads. The reintroduction of passenger service often presents new challenges and possible liabilities to the freight railroad. This is particularly true of high speed rail operations. In several independent discussions with Class 1 freight railroads, the railroads have offered to allow sale or use of their right of way, provided that the new high speed facility was constructed at a track center spacing not less than 25-28 ft from the existing freight main and fully grade separated. This requirement may stem in part from interpretations of 49 CFR 214.7 and 49 CFR 214.335(c). These provisions define adjacent tracks, as tracks separated by less than 25 ft and mandate that large scale maintenance or construction activities be protected against train movements on such adjacent tracks. This requirement disrupts freight operations for work on the adjacent passenger track. (Ref 11)

Railroad corridors often include third party fiber optic lines and railroad signal elements that must be relocated to provide new passenger service. In most cases, utilities that cross the alignment are encased and buried at sufficient depth to be left undisturbed. Evidence of electric and fiber optic use is also visible on the previous Exhibit 6 photo.

At this time, it is not anticipated that barriers between modes would be employed within the railroad right of way, as both the freight and passenger equipment are guided by rails. In the unlikely event of a derailment, commercially feasible barrier systems are not certain to prove effective in constraining the mass and energy of either mode. Fencing has been considered principally to ensure the security of the high speed rail system and discourage trespassers. Barriers and intrusion detection may be warranted in specific cases where the high speed rail alignment is in close proximity to automotive traffic.

CSX had stated that they would sell a portion of its property on the Tampa-Orlando corridor for high speed rail use on the condition that the new tracks be fully grade separated and that the design provide sufficient space for a two track freight main. As is illustrated in the sketch of Exhibit 7, sufficient space exists in the 100 ft right of way to construct both the freight and passenger facilities, but the existing freight main must be relocated from the center. Alternatively, additional right of way must be purchased from adjacent land owners. In many cases, this would be feasible, particularly where the alignment traverses unpopulated ranchlands. In others, the right of way is severely constrained by residential and industrial use. The sketch employs almost all the available right of way for the proposed four track use and it would be possible to construct another siding on the freight property with under drains and fencing as applicable. However, any terrain variation will require retaining walls for cuts and fills or additional property to accommodate embankment and cut slopes.

**Alignment designed for historic passenger and freight service**

Henry B. Plant, a late 19th century railroad magnate, acquired the South Florida Railroad Company in March 1883 and set out to build a railroad line from Kissimmee to Tampa, prior to the expiration of his franchise on January 25, 1884. The project has been described as one of the “most spectacular in the history of American railroad building.” Crews started at each end and built 74 miles across central Florida, joining the rails on a trestle near the present day city of Lakeland on January 23, 1884, a mere two days in advance of the charter’s expiration. Initially, Plant built a narrow gauge track, converting to standard gauge
in 1886. The hectic pace of construction and labor intensive construction procedures of the day did not permit extensive earthworks, resulting in the relatively curvilinear alignment (established to follow favorable and dry terrain) that we find today. (Ref 12)

A quick perusal of the A-Line track chart between Tampa Union Station at MP 882 and our anticipated cut-off to I-4 near Davenport at MP 820 reveals 25 curves ranging from 30 minutes to 3 degrees. However, the relatively flat topography allows gentle grades and long vertical curves, a favorable condition for late 19th Century steam railroading. While the ground profile over this alignment is suitable for modern high speed passenger rail, the curves are another issue. This track segment offers five curves from 2.75 to 3.0 degrees and 8 from 2.0 to 2.5 degrees.

Using the standard formula relating superelevation, cant deficiency, curvature and speed, we can determine that the maximum permissible speeds for rolling stock operating with $E(A)=6$ in and $E(U)=4.5$ in are 86 mph through a 3 degree curve and 71 mph through a 2 degree curve, both acceptable values for passenger trains of that era. However, this alignment provides unacceptable performance for the modern high speed passenger service envisioned for Florida.

The planner may be tempted to straighten some of these curves to yield higher speed limits and reduced travel times. Let’s explore the impact on a typical curve at MP 825.49. Track geometry data reveals spiral lengths of 335 ft and a 1.9 degree circular curve length of 600 ft. The deflection between the tangents is approximately 17.8 degrees. To simplify the math, we will ignore the spirals and consider equivalent circular curves of varying degree to achieve desired speeds, calculating radius, $R$, curve length, $L$, and the external distance from the PI, $E$. Basic formulas are:

\[ E(A) + E(U) = 0.0007 D*V^2 \]

\[ R = \frac{50}{\sin \frac{D}{2}} \]

\[ L = \frac{2 \pi R I}{360} \]

\[ E = R \cos \left( \frac{I}{2} \right) \]

Applying the formulas, we determine that the existing condition employing a 1.9 degree curve, permits a peak operating speed of 89 mph under the previously defined unbalance and superelevation conditions, through a 937 ft curve length, which yields an external distance, $E$, of 37 ft.

We might consider employing a rather standard 1 degree curve. This curve allows a peak operating speed of 122 mph, through a 1780 ft curve with an external distance, $E$, of 70 ft. In order to construct this alignment, we must shift the right of way 70–37=33 ft toward the inside of the curve. If we wish to achieve the nominal TGV speed of 160 mph, we must employ a 35 minute curve, 3038 ft in length with an external distance, $E$, of 119 ft. This application results in a right of way shift of 82 ft.

This concept is depicted in the sketch of Exhibit 8.

In rural regions, it might be possible to buy or swap property to achieve this curve reduction. The work may entail moving the existing freight rail infrastructure depending on the relative positions of the two modes. However, as is seen in the photo for the actual conditions at MP 825.49 in Davenport, Exhibit 9, the impacts on existing property uses are likely to prove problematic. The occurrence of similar conditions throughout the CSX corridor makes geometric alignment improvement a costly endeavor. The reader may note that this analysis ignores the impact of increased spiral lengths, which serves to exacerbate the situation slightly.

**Frequent highway grade crossings**

As noted in Florida’s legislation authorizing the construction of high speed rail and reemphasized in the FHSRA Vision Plan, the high speed rail system must be grade separated from automotive traffic for safe
and reliable operation. Even the most casual motorist will observe that our interstate system has been constructed to be fully grade separated with a limited number of access points and overhead roadway bridges. During the permitting and construction process, many of the crossings are simply closed or rerouted. Our nation’s rail network stands in stark contrast with extensive public and private roadway crossings at grade. The 62 mile track segment from Tampa Union Station to Davenport contains approximately 112 grade crossings. While many could be closed under an aggressive program, working with the adjacent communities, a large number will remain, requiring costly reconstruction of existing roadways to build highway overpass structures or more costly segments of elevated railroad construction.

**Frequent industry spurs and sidings**

CSX stated clearly that the new mode should not interfere with their freight operations. A rough count of industry tracks and sidings along the alignment from Tampa to Davenport reveals approximately 20 sites on the south and 30 sites on the north. While many of these uses are no longer in service a significant number will remain, requiring that high speed rail flyover structures be constructed to achieve grade separation with 23 ft minimum clearance. As most of the facilities are accessed by No. 10 turnouts, freight and industry track realignments and relatively long span, high flyover structures may be required to provide sufficient clearance. The location of customers and connections on both sides of the main track eliminates a simple strategy of selecting the unoccupied side of the track.

**CONCLUSION**

The difficulty of obtaining contiguous properties suitable for the construction of new high speed passenger rail systems forces the consideration of existing transportation corridors, particularly those serving interstate highways and freight railroads. While the obstacles are formidable, as demonstrated in Florida’s Tampa to Orlando project, engineers and contractors are capable of developing the solutions that will enable us to move forward to serve America’s transportation needs in the 21st century. Such solutions are likely to be presented as recommended practice in future editions of AREMA’s *Manual for Railway Engineering*. 
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FHWA
FRA
FTA
AASHTO

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12. Florida’s Great Railroad Men
Exhibit 1: FHSRA Vision Plan (from FHSRA Report to the Legislature 2002)
Exhibit 2
TYPICAL SECTION 1
ELECTRIFIED CENTER POLE RAIL
TANDEM TRACK IN HIGHWAY MEDIAN

Exhibit 3
TYPICAL SECTION 2
ELECTRIFIED CENTER POLE RAIL
CURVED, SUPERELEVATED TRACK IN HIGHWAY MEDIAN
(WITH CRASH WALL)

Exhibit 4
Exhibit 5: TL-5 and TL-6 Barriers

Exhibit 6: CSX A-Line Wheeler St in Plant City
Exhibit 7
Exhibit 8: Original and Flattened Curves

Note that E is measured from the PI perpendicular to the body of the curve.
Exhibit 9 MP 825.49 in Davenport