California High-Speed Train Project

TECHNICAL MEMORANDUM

Automatic Train Control and Radio Systems: Requirements, Solutions and Radio Frequency Spectrum Challenges
TM 300.04

Prepared by:	*Signed document on file*_________ Bradley Banks, PE, Communications Manager	_05 May 11_ Date
Checked by:	*Signed document on file*_________ Rick Schmedes, Systems Manager	__10 May 11 Date
Approved by:	*Signed document on file*_________ Ken Jong, PE, Engineering Manager	13 May 11 Date
Released by:	*Signed document on file*_________ Hans Van Winkle, Program Director	_16 June 11 Date
Reviewed by:	*Signed document on file*_________ Kent Riffey, Chief Engineer	_20 June 11 Date
Accepted by:	*Signed document on file*_________ Roelof Van Ark, Chief Executive Officer	_23 June 11 Date

Revision	Date	Description
0	04 May 11	Initial Release, R0

Note: Signatures apply for the latest technical memorandum revision as noted above.

Prepared by PB

for the California High-Speed Rail Authority

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

The California High-Speed Rail Authority (CHSRA) is commissioning the California High-Speed Train Project (CHSTP) which is an 800 mile high-speed rail system that will connect California's major metropolitan centers with completely new dedicated tracks and infrastructure.

One of the engineering and regulatory challenges to implementing the CHSTP is the lack of available radio frequency spectrum. Because the trains and personnel are mobile, radio systems must provide voice and data communications to mobile users. Critical communications needs include voice communications, safety-critical Automatic Train Control (ATC) data, train health telemetry, passenger information, closed circuit television (CCTV) images, and automatic vehicle location (AVL) data. The CHSTP cannot operate without radio spectrum in which to provide radio services.

The CHSRA has the mandate to provide safe, high-speed train service and has developed project and technical requirements to deliver the CHSTP with low risk, low cost and a high and compliant level of safety. A key commitment of the CHSRA design approach is to use service-proven technologies and components in all critical applications. This entails specification and selection for mission-critical and safety-critical systems of equipment already successfully proven in high-speed rail service at or near the intended operating speeds of the CHSTP.

The project has identified multiple Automatic Train Control (ATC) and Radio System technologies which fully or partially meet all of the project and technical requirements. These fully and partially compliant ATC and Radio System technologies are discussed briefly within this paper, including the Japanese Shinkansen DS-ATC signaling system which uses coded track circuits and has not been ruled out as applicable to the CHSTP. The sole technology that is fully compliant with all of the CHSRA project and technical requirements is the European Rail Traffic Management System (ERTMS) European Train Control System (ETCS) Level 2 with Global System for Mobile Communications – Railway (GSM-R). ERTMS is service-proven and its attributes are highly applicable to CHSTP automatic train control and radio communications requirements and because the train control element is integrated within the radio communications system, ERTMS places the highest demands on spectrum and quality of service for the radio network.

This assessment makes several recommendations including that the CHSRA seek the allocation of sufficient radio spectrum for exclusive and/or primary use of a GSM-R system to support ETCS Level 2 for CHSTP operations.

2.0 PURPOSE

The purpose of this paper is to present the project and technical requirements that apply to the interrelated alternatives for Automatic Train Control (ATC) and radio communications. This paper also presents the pros and cons of solutions for CHSTP and presents the impacts of frequency spectrum availability on CHSTP implementation.

3.0 BACKGROUND

3.1 OVERVIEW OF CHSTP

The CHSTP is an 800-mile high-speed rail transportation network that will serve the present and future transportation needs of California, using proven high-speed passenger train technology to achieve the same transportation benefits as current Asian and European systems. The CHSTP will connect the cities of San Francisco, San Jose, Los Angeles, Anaheim, San Diego, and the cities in the Central Valley region with the capitol in Sacramento. Sixteen-car trains will travel at up to 220 mph and provide reduced travel times for passengers. The CHSTP will have a top operating speed of 220 mph while being designed for 250 mph capability.

Train storage yards adjacent to equipment maintenance facilities will be located along the two-track main line right-of-way. These will be strategically placed near selected initial terminal stations, San Francisco and Anaheim / Los Angeles with future considerations for sites near San Diego and Sacramento. The major repair facility will be located in the Central Valley. Maintenance-of-way storage yards and facilities will be positioned across the system to provide daily maintenance access to CHSTP infrastructure. Twenty-four stations will provide access to the CHSTP to the intercity travelers and commuters.

3.2 SPECTRUM AVAILABILITY

RF spectrum availability is a crucial need for the implementation of the CHSTP. Radio communication between trains, operators and maintainers in the field, and the central and distributed control centers is essential for the safe and efficient operation of a high speed passenger railway; without RF spectrum, the CHSTP cannot operate.

Internationally, radio frequency (RF) spectrum is allocated by the International Telecommunication Union (ITU) to various classes of service in regions of the world. Within the United States and its possessions, the RF spectrum is further allocated to non-Government and Government users by different agencies. The Federal Communications Commission (FCC) allocates and assigns frequencies to non-Government users. The National Telecommunications and Information Administration (NTIA) allocates and assigns frequencies to departments and agencies of the U.S. Government.

RF spectrum is a limited natural resource which is used, desired, and demanded by many individuals, government agencies and commercial entities. Increasing demand for services such as mobile cellular broadband has required changes in spectrum management in the US. For many bands and uses, the former practice of licensing discrete bands to groups of similar services has giving way to an auction model that is intended to speed technological innovation and improve the efficiency of spectrum use (spectral efficiency). The sale of spectrum is also a significant revenue earner for the Federal Government.

RF bands of interest to the CHSTP are both allocated and auctioned. Engineering assessment indicates there is a financial or regulatory obstacle to CHSTP’s acquisition of adequate spectrum in every band suitable to the CHSTP. Accordingly, the CHSRA has approached the FCC for assistance in identifying appropriate bands and acquisition strategies that will give the CHSTP necessary radio spectrum, without causing the FCC to lose significant income at the same time keeping CHSRA spectrum licensing costs within a reasonable budget.

4.0 REQUIREMENTS

4.1 PROJECT REQUIREMENTS

A major task in bringing high speed rail technology to the US is establishing engineering standards and specifications which ensure safe and reliable operation of the trains at speeds significantly higher than those currently in service in the country. To do so, the CHSRA has identified the best practices from high speed rail systems around the world and planned to adapt the technologies for use in California. The CHSRA engineering team is currently developing standards for all components of the civil infrastructure, track, electrical systems, and rail vehicles to enable high speed operations.

To minimize project risk, a key commitment of the CHSRA design approach is to use service-proven technologies and components in all critical applications. This entails specification and selection for mission-critical and safety-critical systems of equipment already successfully proven in high-speed rail service in Europe and Asia. The project criteria require that all technologies and implementations proposed by design bidders be proven in passenger service, under similar conditions, at or near CHSTP speeds, in other rail systems for a minimum of five years. This requirement is intended to minimize CHSTP implementation risk. Furthermore, this requirement will make proving safe operation and securing safety approval from the Federal Railroad Administration (FRA) and other US regulatory bodies much easier compared to deploying an unknown and unproven technology.

A mandated objective of the CHSTP is to be at least revenue–neutral; operations and maintenance costs must be balanced by fare and other revenue. As such, the CHSRA requires that it is not locked into a single source for procurement, bidding, and supply. Interoperable, interchangeable, open standard and multi-vendor solutions are required and will provide the CHSRA with several sources of supply for extensions, upgrades, and maintenance spare parts in the present and future, thereby lowering risk and cost.

4.2 RELATIONSHIP BETWEEN ATC AND RADIO

A primary driver of radio requirements is the choice of Automatic Train Control (ATC) technology and the surrounding procurement issues because the leading ATC and Radio System candidate for CHSTP application consists of an integrated ATC and radio solution.

The European Rail Traffic Management System (ERTMS) is a primary candidate for train control and wireless communications for CHSTP. The International Union of Railways (UIC) began development of ERTMS specifications in the 1990s to create a safe, reliable, efficient and interoperable rail traffic management system for high-speed and conventional rail networks. The ERTMS specifications describe the ATC system which allows trains to travel across political borders without the need for multiple on-board train control and voice radio systems or to force a change of locomotive or trainset. ERTMS is now a proven technology being implemented in a widespread manner across Europe and has also been installed on high-speed systems outside of Europe, including China and South Korea. ERMTS systems are in service or under construction in India, Algeria, Saudi Arabia, New Zealand, Kazakhstan, Turkey, and Mexico.

The ATC component of ERTMS, the European Train Control System (ETCS) defines different levels to delineate functionality, ranging from Level 1: track to train communications, to Level 2: continuous communications between the train and the radio block center (RBC), and Level 3: moving block technology (which is in a conceptual phase and still not available as a proven technology).

ETCS level 1 is designed as an add-on to or as an overlay on a conventional line already equipped with wayside signals, and possibly as a fallback solution from ETCS level 2. Communication from the track to the train is ensured by dedicated balises located on the trackside adjacent to the wayside signals at required intervals, and connected to the nearby interlocking and/or wayside signals.. The balises have a data connection to the ATC equipment which provides movement authorities for transfer to the train. Receiving the movement authority through balises, the ETCS onboard equipment automatically calculates and indicates to the train engineer maximum permitted speeds of the train and the next braking points if needed, taking into account the train braking characteristics and the track description data. This information is displayed to the train engineer through a dedicated screen in the cabin. The speed of the train is continuously supervised by the ETCS onboard equipment.

Siemens has reported their ETCS Level 1 implementation is operating at a top speed of 217 in China (Beijing - Tianjin) using ETCS Level 1 which began operation in 2008.

Similarly, ETCS Level 1 is in use on several Spanish high speed train lines at 186 mph. Spain began implementing ETCS Level 1 on selected high speed train lines in 2006.

As opposed to ETCS level 1, ETCS level 2 does not require wayside signals. The movement authority is communicated directly from a RBC to the onboard unit using GSM-R. The balises are only used to transmit “fixed messages” such as location, gradient, speed limit, etc. A continuous stream of data informs the train engineer of the movement authorities and line-specific data on the route ahead, allowing the train to reach its maximum or optimal speed but still maintaining a safe braking distance factor. While enabling greatly reduced maintenance costs through the removal of wayside signals, ERTMS Level 2 also presents the possibility for substantial line capacity increase of more than 50% with optimized block sections by enabling higher operational speeds and offering reduced headways comparing to the level 1 solution with the conventional approach as reported in the UIC Report from the Annual Conference 2007. More capacity means more trains moving, thus more benefits. The Railway authorities in Switzerland are reporting a significant decrease in average delay per train after introducing the level 2 system on certain lines. ETCS Level 2 with GSM-R is becoming the dominant global de-facto train control and communications standard for high-speed rail and has been verified to be a reliable technology which has been tested and proven at speeds up to 310 mph.

GSM-R, the wireless component of ETCS Level 2, is a multi-function radio solution supporting critical train control data, train to wayside voice communication, multiple voice channels for all railroad personnel and passenger information including various special railroad requested services such as emergency, group or broadcast calls, functional or location dependent addressing, call prioritizing, paging, telemetry, and other data in a single, integrated radio solution.

Research and study of various wireless solutions has resulted in the determination that an integrated voice, data, and Automatic Train Control (ATC) radio system is the most suitable for the CHSTP because integrated systems are lower in capital and ongoing expenditures as fewer individual systems and equipment need to be managed. The ETCS Level 2 with GSM-R integrated system has proven itself to provide safety critical functionality to deliver reliable passenger train service when suitably high Quality of Service required to meet the high availability thresholds is provided. The attributes of ETCS Level 2 with GSM-R position the technology as the ideal to deploy for CHSTP train control and radio. It is proven at CHSTP speeds and has been in operation for five years (Rome–Naples high-speed line). Because the primary candidate for CHSTP ATC relies on an integrated, multifunction radio solution, the choice of safety-critical ATC technology is driving the radio system design. Other alternatives are not technically compliant, not compliant with the project requirements, or present too much risk to implementation. These alternatives will be discussed later in this paper.

4.3 RADIO REQUIREMENTS

Based on project requirements previously discussed, ETCS Level 2 is the preferred technology that is fully compliant and suitable to implement the CHSTP with a minimum of risk. However, the project team is investigating other reasonable paths to implementation to understand potential solutions if ETCS Level 2 with GSM-R is not possible.

The CHSTP has radio requirements ranging from mandatory to desired. Table 1 lists the CHSTP radio requirements for a CHSRA owned / operated radio system:

Table 1: CHSTP Radio Requirements

Requirement	Traffic	Location / Scenario	Classification
1	Voice	Train to Wayside	Mandatory

Requirement	Traffic	Location / Scenario	Classification
2	Low bit rate data (telemetry, passenger information, etc)	Train to Wayside	Mandatory
3	High bit rate stationary data offload	Train to Wayside when train is stationary in yard or facility	Desired
4	Mobile CCTV video	Train to Wayside	Desired
5	Automatic Train Control	Train to Wayside	Mandatory*
6	Voice	Mobile / Portable O&M Personnel to Fixed	Mandatory
7	Low-bit rate data (short text message or similar)	Mobile / Portable O&M Personnel to Fixed	Mandatory
8	Voice	Mobile / Portable CHSRA Police Personnel to Fixed	Mandatory
9	Low-bit rate data	Mobile / Portable CHSRA Police Personnel to Fixed	Mandatory

** This technical requirement is tied to the project requirements. The only technology fully compliant with the project requirements has integrated ATC. Therefore, integrated ATC is a mandatory technical requirement.*

The desired requirements apply to functionality that is not absolutely necessary for the operation of the CHSTP. Without these requirements provided by a radio solution, the CHSRA would need to use a non-radio technology (applies to req. 5) or operational procedure (applies to req. 3) to accomplish the functionality, or simply not meet the requirement (applies to req. 4).

Radio related requirements for non-CHSRA owned / operated systems include: Global Positioning System (GPS) radios, interoperability between first responders and shared corridor trains and infotainment services provided by a third-party. These requirements are out of the scope of this paper.

Depending on the bandwidth available and the technology, radio systems can satisfy these communications requirements including voice communications, safety-critical ATC data, train health telemetry, passenger information, CCTV images, and AVL data. To meet all of the CHSTP requirements, including the desired requirements, a suite of different radio solutions will need to be deployed.

4.3.1 Traffic Planning, Capacity and Required Spectrum

To determine how much spectrum is required for each radio technology, calculations must be done based upon the number of users of the radio system, their usage profile and geographic density. Depending on radio system, these calculations may depend on number of global or local users. Local users depend on geographical radio coverage per site and the worst case number of users who would be within that coverage area. The number of local users applies to capacity estimates for multicast and frequency reuse radio technologies.

Capacity calculations depend upon estimates of worst case number of radio system users including trains, operations and maintenance personnel, CHSRA security personnel and accounting for growth, expansion and the provision of a redundancy strategy.

Currently, operational estimates of worst case number of users are being developed which will drive the required spectrum calculations for each potential radio solution.

5.0 SOLUTION CONCEPTS

As part of the design process, the CHSRA is investigating multiple train control and radio system technologies to support the requirements of the CHSTP. The potential radio solutions can be grouped by their integration of Automatic Train Control technology: ATC-Integrated and non-ATC-integrated.

5.1 ATC INTEGRATED SOLUTIONS

ETCS Level 2 with GSM-R is a broadly service-proven, certified, multiply-sourced integrated ATC and radio solution which complies with project and technical characteristics suited to implement the CHSTP with low risk and cost, if suitable radio frequencies can be acquired.

5.1.1 ETCS Level 2 / GSM-R

Because it is a proven high-speed train technology, ETCS Level 2 with GSM-R is an attractive and viable low-risk path for implementing the ATC and voice and data radio service for CHSTP if suitable radio frequencies can be acquired. GSM-R is an international wireless communications standard for railway communication and applications. A sub-system of ERTMS, it is used for communication between train and railway regulation control centers. The system is based on GSM and EIRENE - MORANE specifications, managed by the International Union of Railways (UIC) which guarantees safe performance at speeds up to 310 mph. GSM-R is a secure platform for voice and data communication between railway operational staff, including train engineers, dispatchers, shunting team members and station personnel. It delivers features such as group calls (VGCS), voice broadcast (VBS), location-based connections and call pre-emption in case of an emergency.

GSM-R in most of the world is allocated 2 x 4 MHz blocks, in some countries this has been enhanced with additional 2 x 3 MHz neighboring blocks. Channel spacing is 200 kHz and the modulation used is GMSK modulation (Gaussian Minimum Shift Keying). GSM-R is a TDMA (Time Division Multiple Access) system. Data transmission is made of periodical TDMA frames (with a period of 4.615 ms), for each carrier frequency (physical channel). Each TDMA frame is divided in 8 time-slots, named logical channels (577 µs long, each time-slot), carrying 148 bits of information.

ETCS Level 2 with GSM-R would satisfy radio requirements 1, 2 and 5-9. Separate systems would need to be deployed to satisfy requirements 3 and 4.

To satisfy desired radio requirement 3 (High bit rate data offload from train to wayside while train stationary in yard or facility) a known radio solution like 802.11 (Wi-Fi) can be deployed. 802.11 variants operate in unlicensed bands 2.4, 3.6 and 5 GHz. Since this technology can operate in sufficiently available unlicensed bands under Part 15 of the US Federal Communications Commission Rules and Regulations, detailed discussion of this technology and these unlicensed bands is outside of the scope of this paper.

To satisfy the optional radio requirement 4 (CCTV Video while train is travelling at top speed) a radio solution must be found. Based on research done by CHSRA as of 2011, a radio technology that may eventually deliver this capability at CHSTP speeds is Long Term Evolution (LTE) (See Section 5.3.1 for more detail on LTE). Another technology being investigated by the CHSRA engineering team is Wireless Mesh networks which may support radio requirement 4. More detail about Wireless Mesh networks can be found in Section 5.3.9.

5.1.2 Capacity and spectrum

GSM-R is allocated 2 x 4 MHz total in most installations based on worst-case projected capacity of users by the UIC. Our current assumptions are that CHSTP radio communications needs will require at least the same amount of bandwidth.

5.1.3 ETCS with General Packet Radio Service (GPRS) technology

The current version of GSM-R relies on circuit switching to carry ETCS data, which in essence requires one time slot to be dedicated for each train within each cell contained within the given movement authority. The UIC is investigating more spectrally efficient modulation schemes and packet switched radio networks. With packet-switched schemes, multiple mobile data users can share a time slot and the overall capacity of a fixed number of channels is increased compared to a circuit switched scheme.

Enhanced Data rates for GSM Evolution (EDGE) and LTE are considered “future” technologies by the UIC, and current focus is on investigating the suitability of General Packet Radio Service (GPRS) for ERTMS. Just as GSM-R leveraged GSM commercial cellular technology for railroad usage, the UIC’s investigation follows that trend with the investigation of GPRS. GPRS is a packet oriented mobile data service on the 2G and 3G GSM systems. GPRS standards are maintained by the 3rd Generation Partnership Project (3GPP) and are a widely deployed wireless data service, available now with most GSM networks. EDGE was deployed on GSM networks beginning in 2003 initially by Cingular (now AT&T) in the United States. It is available in most major metropolitan areas today.

By 2012, the UIC expects to solve issues related to GPRS for high-speed critical train operation and have the service approved and incorporated into the ERTMS specifications to provide ETCS Level 2 ATC data via GPRS, while standard voice traffic is handled by the legacy GSM-R technology. This type of deployment would operate in the same GSM-R spectrum.

Until GPRS is standardized for ETCS train control data, GPRS can still be used as an overlay on a traditional GSM-R system for non-ATC data transmissions like telemetry, passenger information or similar.

A GSM-R system with GPRS would satisfy radio requirements 1, 2 and 5-9. Separate systems for stationary high bit rate data and mobile video as described in the previous section would need to be deployed to satisfy requirements 3 and 4. The bit rate available with GPRS is not suitable to carry video data and neither is it expected that UIC will include video transmission within the system requirements for GPRS within GSM-R.

5.1.4 Capacity and Spectrum

GPRS, which extends GSM to support packet switching of data, is a more spectrally efficient technology compared to GSM circuit switched data and therefore, less spectrum is required to support the same number of users. The spectrum issues applicable to GSM-R also apply to GSM-R with GPRS.

5.2 NON-ATC-INTEGRATED SOLUTIONS

Because it is a proven high-speed train technology, ETCS Level 2 with GSM-R (circuit switched data or GPRS) is an attractive, compliant and viable low-risk path for implementing the ATC and voice and data radio service for CHSTP if suitable radio frequencies can be acquired. Other train control and communication alternatives do not meet the project requirements, are less desirable or not suitable for CHST’s 220 mph operation. These solutions would introduce many unknowns and risk to the implementation of the CHSTP.

If the CHSRA is forced into a non-ATC integrated radio solution the ATC and radio technology deployed would become more fragmented. In this case, ATC would be handled by a track circuit technology. Most of these technologies are not fully compliant or completely non-compliant with the project and technical requirements of the CHSTP. These technologies include the Shinkansen DS-ATC, TVM-430, PTC at 220MHz and ETCS Level 1. In the event that one of these non-ATC integrated radio solutions is selected as a solution, radio spectrum is still needed for voice and other data. Section 5.3.1 begins the discussion of the radio solutions that would need to be deployed to support these following ATC solutions.

5.2.1 Shinkansen DS-ATC

The Japanese Shinkansen high-speed DS-ATC train control technology utilizes a non-radio based ATC system offered by a single supplier and is non-compliant with all of the CHSTP project and technical requirements. A key concern is that it is a proprietary solution offered by a single supplier, with the procurement of the system, extensions, upgrades, and maintenance parts constrained to a single source representing sourcing risk and potentially increased cost. However, the CHSRA project team has not ruled out the Shinkansen system for ATC for CHSTP. The Shinkansen train control technologies operate up to speeds around 200 mph and have been proven in operation for five years. If CHSRA was forced into this position and waived project requirements and the technology could be adapted to 220 mph operation, the CHSTP would still require a voice and data radio solution and therefore radio spectrum would still be necessary.

5.2.2 TVM-430

Transmission Voie-Machine (TVM, English: track-to-train transmission) is a form of in-cab signaling originally deployed in France and used on the Lignes à Grande Vitesse (LGV) high-speed railway lines. The TVM-430 transmits more information than traditional signaling would allow, including gradient profiles and information about the state of signaling blocks further ahead and permits operating speeds up to 250 mph. TVM-430 uses encoded track circuits to transmit ATC data to trains within blocks. The most recent TGV line is equipped with ETCS Level 2 signaling together with TVM-430 signaling.

However, the CHSRA has eliminated TVM-430 from consideration. It is predominantly a French geography only system and is effectively obsolete as new lines and signaling upgrades in France will be ERTMS equipped. The CHSRA determined this during the technology study and confirmed by the European suppliers during the request for information process in the summer of 2010.

5.2.3 Positive Train Control at 220MHz

Design for the emerging Positive Train Control (PTC) technology as per the mandate of the Railway Safety Improvement Act (2008) at 220MHz is focused on positive train control at speeds below 110 mph. This technology is currently in development and it is uncertain whether 220MHz PTC systems could be adapted to safely operate at 250 mph representing significant risk to implementing CHSTP using the technology. Furthermore, the freight railroads have already identified that the channel availability in the 220 MHz band is insufficient by itself to support all of their needs for PTC especially in built-up areas such as the Los Angeles basin through which CHSTP will also operate. If capacity is inadequate for freight, it cannot support the added demand of CHSTP service.

Wabtec has been developing their Electronic Train Management System (ETMS) to fill the PTC needs for US freight railroads and was contracted by the Class 1 freight railroads to work with their consortium to develop an interoperable PTC system that can be deployed nationally. As well as interoperability enhancements, Wabtec are developing a vital (safety critical) version of the system. ETMS provides wireless digital packet communication between locomotives, waysides and dispatch for PTC.

MeteorComm are still developing the radios that will deliver digital track authorities, track database updates, consist information from dispatch, and real-time wayside status to the locomotive. The radio development schedule has slipped significantly since its inception and it was recently disclosed that usage of MeteorComm technologies will require users outside of the Class 1 Railroad consortium (including CHSRA) to pay licensing fees for hardware, software, and broadcasting rights and be tied long term to a sole supplier for procurement of the system, extensions, upgrades, and maintenance parts. This monopoly on the 220 MHz PTC technology adds sourcing risk and additional cost to the CHSTP and is not compliant with the CHSTP project or technical requirements. If a 220MHz PTC solution could be developed for safe high speed rail operations and the five year demonstration requirement and sole source prohibition was waived, a voice and data radio solution, and radio spectrum, would still be needed.

5.2.4 ETCS Level 1

ETCS Level 1 is a potentially viable position for the CHSTP ATC. It has been implemented in China at speeds close to CHSTP's target. Even if ETCS Level 1 is accepted and adapted for CHSTP voice and data radio coverage with critical spectrum requirements will still be needed.

If one of these train control solutions were deployed for the CHSTP, one of the following radio solutions would need to be deployed.

5.3 POSSIBLE RADIO SOLUTIONS TO SUPPORT NON-RADIO BASED ATC TECHNOLOGIES

If the project was forced into a situation with one of the ATC solutions described in Section 5.2, then a radio solution would need to be deployed to support the Radio Requirements excluding Requirement 5. The following radio solutions have the following complications not present with GSM-R:

1. The technology may not be in proven service at or near CHSTP speeds at the time of this writing. Most manufactures are not designing or testing radio systems specifically for high-speed function which makes evaluating the suitability of these technologies for high-speed operation difficult. Handoffs, Doppler and other radio issues may require increased development time, demonstration time and added risk.
2. Since the following radio technologies were not specifically developed for the high-speed train operational environment the features and functions of the radio system may not be suitable for the high-speed train operations resulting in hampered capabilities and increased development time.

5.3.1 Private Land Mobile Radio - P-25

Federal Communication Commission (FCC) rules define a land mobile radio (LMR) system as a regularly interacting group of base, mobile, and associated control and fixed relay stations intended to provide land mobile radio communications service over a single area of operation. Private land mobile radio systems (PLMR) are used by companies, local governments, and other organizations to meet a wide range of voice and low speed data communication requirements. Public safety agencies, utilities, railroads, manufacturers, and a wide variety of other businesses rely on PLMR radio systems.

The land mobile frequency spectrum is very crowded and additional frequencies are difficult to obtain. More efficient use of spectrum is being instigated by narrowbanding mandates and wider use of trunked radio systems. Trunking systems use access control schemes to share channel capacity among many users based on the principle that not all users will be using the system at the same time.

APCO Project 25, or "P-25" for short, is the public safety industry standard developed by the International Association of Public Safety Communications Officials (APCO) to provide a radio solution so agencies using different radio systems can interoperate per a public safety industry standard. P-25 is becoming the broadly used standard for trunking system for public safety use; it is a major contender to partially satisfy CHSTP radio requirements. Along with providing trunked voice services, P-25 can provide 9600 bps total channel throughput.

P-25 is currently being used by the Korea High Speed Train which is designed for speeds of 217 mph and has been in service since 2004.

Depending on spectrum acquired, P-25 could satisfy radio requirements 1, 2 and 6 - 9. Separate systems for stationary high bit rate data and another technology for mobile CCTV video as described below could satisfy requirements 3 and 4.

5.3.2 Capacity and Spectrum

As early as 1992, the FCC began identifying the desire to more efficiently utilize the frequencies in the PLMR spectrum allocations below 512 MHz, through a process known as narrowbanding. Narrowbanding generally entails replacing wideband (25 kHz channel) equipment with 12.5 kHz narrowband equipment. In December 2004, the Federal Communications Commission mandated that all private LMR users operating below 512 MHz move to 12.5 kHz narrowband voice channels and highly efficient data channel operations by December 31, 2012. In public communications, the FCC has mentioned a future 6.25 kHz Narrowbanding mandate, but has yet declined to specify a date for it to take effect.

Phase 1 P25-compliant technology would be deployed in a 12.5 kHz channel environment. P25 is being deployed in two phases. Phase 1 radio systems operate in 12.5 kHz analog, digital or mixed mode. Phase 1 radios use Continuous 4 level FM (C4FM) modulation for digital transmissions at 4800 baud and 2 bits per symbol, yielding 9600 bits per second total channel throughput. Receivers designed for the C4FM standard can also demodulate the "Compatible Quadrature Phase Shift Keying" (CQPSK) standard, as the parameters of the CQPSK signal were chosen to yield the same signal deviation at symbol time as C4FM while using only 6.25 kHz of bandwidth.

P25 is appropriate for any of the LMR bands that are allocated in 25 kHz or 12.5 kHz channels.

5.3.3 Private Land Mobile Radio - NXDN

Similar to P25, NXDN is a PLMR standard developed jointly by Icom and Kenwood. The proprietary names are IDAS for Icom's system and Kenwood uses NEXEDGE. The NXDN standard is of interest to the CHSTP because NXDN has been selected by the Association of American Railroads (AAR) as the radio technology to migrate toward primarily because there are multiple vendors supporting it today. Furthermore, the AAR has recommended that all railroads implement the very narrowband (VNB) 6.25 kHz channel size and skip 12.5 kHz narrowbanding. CHSTP may get access to the AAR coordinated frequencies in 160 MHz and therefore this technology is presented here.

NXDN is appropriate for most LMR bands but is included for consideration here for specific use in the 160 MHz band allocated by the AAR.

5.3.4 Private Land Mobile Radio - Terrestrial Trunked Radio (TETRA)

Terrestrial Trunked Radio (TETRA) is an open digital trunked mobile radio standard developed by the European Telecommunications Standards Institute (ETSI).

Similar to P25, the ability for full interoperability between different manufacturer's products is a distinct advantage of open standards developed by ETSI. The TETRA standard is supported by several independent manufacturers which increases competition, provides second source security and allows a greater choice of terminal products for specific user applications. TETRA has been widely deployed around the globe — by public-safety agencies, militaries, utilities and transportation companies — that the technology has attracted numerous vendors, which in turn has reduced the price of network and radio equipment. TETRA is generating interest among oil and gas, utilities and railroad companies in the US. TETRA operates at high speeds (greater than 248 mph). Sepura TETRA was used for voice and data transmissions during the French TGV train speed record on 3 April 2007 at 357 mph. TETRA did not transmit any ATC data during this demonstration.

There are intellectual property rights issues, regulatory approvals and technical issues related to spectrum use which are seen as obstacles to TETRA's adoption in the US. Recently a waiver was submitted to the FCC to permit the use of TETRA in the US. Most comments opposed the TETRA waiver which would permit deployment of TETRA in the US. Based on the comments received, standards bodies indicated that the TETRA standard must be altered to be applicable to the US regulatory environment. If the standard is altered there is concern that the outcome of the alteration may be unique and not have all of TETRA's cost benefits.

A TETRA based radio system is available in the US under proprietary name PowerTrunk-T. Further information is being sought on this technology and its link to ETSI TETRA and suitability to CHSTP applications.

Depending on spectrum acquired, TETRA could satisfy radio requirements 1, 2 and 6 - 9. Separate systems for stationary high bit rate data and another technology for mobile CCTV video as described below could satisfy requirements 3 and 4.

5.3.5 LTE for voice and data

LTE is a 4G wireless technology considered next in line in the GSM evolution path after Universal Mobile Telecommunications System (UMTS) / High Speed Packet Access (HSPA) 3G technologies. LTE is currently being developed by the 3GPP, aimed at evolving 3GPP's third generation system towards an all-IP network optimized for high speed data transmission.

Rather than further developing current HSPA and modulation schemes based on the Wideband Code Domain Multiple Access (W-CDMA) used in third generation UMTS cellular systems today, LTE uses Orthogonal Frequency Division Multiplexing (OFDM) as its radio access technology, together with advanced antenna technologies.

UIC's investigation into LTE to for ERTMS is planned to start in 2020; however, LTE will most likely be a commercially dominant technology before then. Furthermore, public safety agencies including Association of Public-Safety Communications Officials (APCO), the National Emergency Number Association (NENA) and the National Public-Safety Telecommunications Council (NPSTC) have endorsed LTE as the preferred technology for a proposed national broadband network for first responders in the 700 MHz spectrum band. Even though LTE has not been completely defined as of this writing, for the above reasons, LTE is a technology to investigate to support the CHSTP radio requirements.

The LTE specification provides downlink peak rates of at least 100 Mbps, an uplink of at least 50 Mbps and Radio Access Network round-trip times of less than 10 ms.

Huawei, the network infrastructure provider, has demonstrated an LTE system on board a train that has a top speed of 268 mph and averages 156 mph that covers 19.25 miles in only 7 minutes and 20 seconds. When the train first leaves the station it supports an LTE network speed of 46 Mbps, and when the train is at top speed the data speed drops to 36 Mbps.

5.3.6 LTE for Voice and Data

Depending on spectrum acquirable, LTE could possibly satisfy radio requirements 1 – 4 and 6 - 9. It may be beneficial to remove radio requirement 3 from the LTE's system and shift this to a stationary (Wi-Fi) system depending on predicted usage and capacity. It is theoretically possible that LTE could support ATC (requirement 5), however until LTE is incorporated into an internationally adopted, integrated standard for safety critical ATC, LTE alone will not be considered herein as meeting requirement 5.

5.3.7 LTE for Exclusive Mobile CCTV Use

It is more likely that LTE would be a solution deployed in conjunction with GSM-R to provide mobile CCTV for trains to satisfy radio requirement 4.

5.3.8 Capacity and Spectrum

LTE aims to offer a 100 Mbps download rate and 50 Mbps upload rate for every 20 MHz of spectrum. Support is intended for even higher rates, to 326.4 Mbps in the downlink, using multiple antenna configurations.

LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD). This can result in paired spectrum blocks for FDD and single spectrum blocks for TDD implementations. LTE is currently planned for 1900 MHz, 1.7/2.1 GHz, 850, UMTS1700 and 700 MHz A, B, C and D block bands in the US.

5.3.9 Wireless Mesh Networks

A wireless mesh network is a radio communications network made up of radio nodes geographically organized in a mesh topology. Wireless Mesh networks offer redundancy and resistance to single points of failure as they are often configured in an ad-hoc manner with multiple paths of communication and a level of intelligence to route communications around failures. Wireless mesh networks can be implemented with various wireless technology including 802.11, 802.16, cellular technologies or combinations of more than one type.

Initial CHSRA research into Motorola Mesh Network technology found evidence that data connectivity and handoff has been demonstrated at 240 mph at a race track. More detailed information is being sought to determine the suitability of the Motorola Wireless Mesh network and wireless mesh in general for CHSTP. Wireless mesh is being included here as a notation for future consideration. If compliant with technical requirements, Wireless Mesh Technology could be deployed to satisfy CHSTP radio requirements 1 – 4 and 6 - 9 however, it would likely only be focused on providing mobile CCTV video data: radio requirement 4.

5.3.10 Wireless Mesh for Voice and Data

Depending on spectrum acquirable, Wireless Mesh could possibly satisfy radio requirements 1 – 4 and 6 - 9. It may be beneficial to remove radio requirement 3 from the system and shift this to a stationary (Wi-Fi) system depending on predicted usage and capacity.

5.3.11 Wireless Mesh for Exclusive Mobile CCTV Use

It is more likely that Wireless Mesh would be a solution deployed in conjunction with GSM-R to provide mobile CCTV for trains to satisfy radio requirement 4.

6.0 SPECTRUM ACQUISITION

The preferred integrated ATC radio solution is ETCS Level 2 with GSM-R. In the US, including California, the native spectrum that GSM-R uses (876 MHz — 880 MHz for uplink and 921 MHz — 925 MHz for downlink) is designated as Specialized Mobile Radio (SMR) service. The lower portion of the 800 MHz band is not appropriate for a GSM-R technology due to the strict narrowband channel plans adopted for both the public safety (NPSPAC) and non-cellular land mobile systems deployed in the lower portion of the 800 MHz band (post re-configuration). Similarly, the 900 MHz band is allocated with interleaved channel plans that are not conducive to the GSM-R network envisioned.

The upper portion of the 800 MHz band (post re-configuration) could be suitable for GSM-R since sufficient bandwidth can be aggregated on an area-wide basis. However, this band is significantly utilized by the existing Sprint Nextel's iDEN system and other companies' cellular-type systems. Most of the bandwidth is in use in the major California markets that have significant traffic demand. Unless Sprint transitions these users to their other licensed bands, this band segment would probably not be a viable option for the high-speed train corridor.

For the ideal solution, ETCS Level 2 with GSM-R, the bands considered the least likely for the CHSRA to acquire and use for the high-speed transportation corridor include:

- 220MHz band
  - Channelization generally consists of non-contiguous 5.0 KHz channels and because of licensing rules, it would not be possible for the CHSRA to acquire and group channels to amass the approximately 8 MHz total needed to support a GSM-R system.
- 450 MHz LMR channels
  - Similar to the obstacle with 220 MHz, the CHSRA would not be permitted to aggregate these 25 kHz or 12.5 kHz channels to amass the approximately 8 MHz total needed to support a GSM-R system.
- 700 MHz public safety band narrowband channels
  - Similar to the obstacle with 220 MHz, the CHSRA would not be permitted to aggregate these 12.5 kHz channels to amass the approximately 8 MHz total needed to support a GSM-R system.
- The commercial 700, 800 and 900 MHz bands
  - These bands are significantly utilized by existing commercial cellular-type systems. Most of the bandwidth is in use in the major California markets that have significant traffic demand. It is highly unlikely that these companies will transition users to their other licensed bands.
- 1.9 GHz PCS band
  - Similar to the 800 and 900 MHz bands, the 1.9 GHz band has been heavily used by the main wireless carriers since the mid 1990's. The majority of the PCS spectrum in California and across the major US markets contains large deployed networks, especially in the dense market areas of Los Angeles, San Francisco, and San Diego. It is unlikely that any of the PCS licensees in the high-speed transportation corridor would vacate their licenses.
  - It is unlikely that GSM-R equipment can be ported to this higher frequency and still function at high speed. Section 6.1 discusses details on porting GSM-R away from native frequencies for use at other frequencies.

- AWS bands
    - o The AWS bands that are licensed to the well-known wireless carriers have similar obstacles found with the 1.9 GHz band. Further, it is unlikely that GSM-R equipment can be ported to this higher frequency and still function at high speed.

The bands that are potentially viable for a GSM-R solution include the 700 MHz broadband segment; 700 MHz guard band. As discussed in Section 6.1, technical obstacles are expected with porting GSM-R technology above 925 MHz. The 1.4 GHz band, 1.5 / 1.6 GHz L-band, yet to be auctioned AWS bands, and a portion of the WCS band could be appropriate for another non-GSM-R radio system as these incumbent license holders do not have a massive infrastructure in place and numerous revenue generating users and are more likely to part with radio spectrum.

For the radio solutions discussed above, LTE, P-25, NXDN, Wireless Mesh, and others not listed, each technology requires narrowband, very narrowband or broadband spectrum. The CHSTP is currently reaching out to appropriate spectrum holders and frequency coordinators to determine how CHSRA can acquire radio spectrum.

6.1 PROCUREMENT AND VENDOR PERSPECTIVES

Procurement for the CHSTP including train control and radio system is planned to be issued in 2012. The CHSTP team has discussed several procurement scenarios with vendors regarding acquisition of spectrum and has considered the risks and opportunities of various spectrum procurement options used by Metrolink, Caltrain and the Florida High Speed Rail Project.

Some vendors have expressed concern over a procurement requiring them to identify and acquire frequency spectrum as part of their design task. Clearly these vendors see the challenges and risks that the CHSRA have identified in acquiring frequency spectrum. Since certain radio bands are suitable for specific radio technologies, by acquiring spectrum suitable only for a certain solution before the procurement, this will preclude another solution unless additional spectrum is acquired.

The CHSTP team also met with several suppliers experienced in the supply and deployment of ERTMS and GSM-R. They indicated that GSM-R systems can be ported to operate at alternative frequencies. The vendors reported that GSM-R can be operated at frequencies as low as 450 MHz, yet their upper frequency limit did not extend past 925 MHz for a train travelling at 250 mph. According to Kapsch Carrier Com (KCC, a GSM-R system supplier) Doppler shift for a train travelling at 250 mph is too great for a GSM-R radio system operating above 925MHz. More investigation is needed into this limitation.

450 MHz was not included in the original spectrum study commissioned by CHSRA. However, it is known that 450 MHz is used extensively by public safety entities for LMR systems and is unlikely to be available for acquisition by CHSRA. Furthermore, this band is strictly channelized into 25 kHz / 12.5 kHz channels and not permitted to be utilized at the GSM-R 200 kHz channelization.

A bi-band system can be deployed as a possible work-around of spectrum availability issues. In densely populated areas, near the terminals at San Francisco and Los Angeles, it is expected that the CHST will be travelling at relatively low speeds, thereby allowing the use of a higher frequency and avoiding the heavily used native GSM-R frequencies. KCC suggested to use 1800 MHz for these segments, upon the train's transition to the high-speed segment of track where the CHST will be travelling at 220 mph, the system can switch to native, 800 - 900 MHz frequencies. In these more remote areas, it is possible that there is less contention for 800 - 900 MHz frequencies by commercial operators thereby making CHSRA's acquisition of spectrum possible and less expensive.

Other suggested work-arounds involving use of commercial GSM channels and / or infrastructure for train control and voice and data communications are not suitable for the safety-critical radio requirements of the CHSTP. The CHSRA must have exclusive / primary use and ownership of the spectrum used by the CHSTP radio system. This proposal can be a good consideration for a fallback solution for emergency radio functions if a CHSRA GSM-R radio network is unavailable.

Pushing the acquisition of frequency spectrum past the procurement only serves to postpone risk to the project. The CHSRA is approaching the FCC for assistance in identifying appropriate bands and acquisition strategies that will give the CHSTP the frequency spectrum to support ETCS Level 2 with GSM-R before the procurement thereby reducing risk to the bidders and project.

7.0 TIMELINE ASSUMPTIONS

The CHSRA is charged with building out a high-speed rail system with the first deployment of running trains and supporting technology on an approximately 100 mile section of track scheduled for 2017; six years from today.

The preliminary engineering of the CHSTP is currently underway and must be completed by mid-2011. The procurement of design/build contracts for all the civil elements of the rail network will begin in late 2011, and construction of the first section of CHSTP track in the Central Valley is scheduled to begin in mid-2012. This first section of track is anticipated to be the proving ground for trains and supporting systems. System integration, testing and verification (including for the radio system) would begin in 2017 requiring radio operations. A radio communications and spectrum solution must be deployed and operational by the beginning of 2015. It is anticipated that passenger services will begin in an incremental fashion as major sections of construction are completed, culminating in the start of San Francisco to Los Angeles/Anaheim passenger service in 2020.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The CHSRA has the mandate to deliver a safety-critical high-speed train system to the citizens of California and has developed project and technical requirements to deliver the CHSTP with the lowest risk, lowest cost and the highest level of safety. The attributes of ETCS Level 2 with GSM-R position the technology as the ideal to deploy for CHSTP train control and radio. Other alternatives are not fully technically compliant, not fully compliant with the project requirements, or present too much risk to implementation. The challenge to implementing ETCS Level 2 with GSM-R is the lack of available radio frequency spectrum. Engineering assessment indicates there is a financial or regulatory obstacle to CHSTP's acquisition of adequate spectrum in every band suitable to the CHSTP. Based on research and vendor input, the most suitable bands for a GSM-R radio system in the CHSTP right-of-way are the 700 MHz broadband segment and the 700 MHz guard band.

The CHSRA engineering team has identified several ATC and radio system solutions that may be suitable for the CHSTP if project and technical requirements are waived or loosened if ETCS Level 2 / GSM-R could not be implemented.

In order to develop a compliant radio system to support high-speed CHSTP operations, the following actions are recommended:

1. CHSRA to continue interfacing with the FCC, with FRA support, to determine appropriate spectrum and best means of spectrum acquisition.
2. CHSRA to continue to search for innovative ways to acquire available spectrum appropriate for CHSTP use.

3. CHSRA to continue to interface with incumbent spectrum license holders to determine whether an agreement to buy, lease or sublicense spectrum is possible.
4. CHSRA to continue to explore infotainment services partnerships and shared infrastructure with incumbent spectrum license holders.

More detail on RF Spectrum acquisition tasks are detailed in TM 300.03 EMT Radio Frequency (RF) Spectrum Acquisition Strategy. Ideally, sufficient spectrum can be allocated to the CHSRA for exclusive / primary use to deploy a GSM-R system to support high speed train operations in the State of California.