Tehama County, California and Tehama Rural Area eXpress (TRAX)

Alternatives & Recommended Solution Report for the Integrated Public Safety Communications Project

STATUS: FINAL

Prepared and Submitted by:

CDX WIRELESS INC
TECHNOLOGY CONSULTANTS

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1. Executive Summary

This Alternatives & Recommended Solution Report describes alternative radio-system technologies that are available to improve the capabilities of the two-way radio communications systems in use by the Tehama County Sheriff's Office (TCSO), Tehama County Public Works (TCPW), and the Tehama Rural Area eXpress (TRAX). It provides recommendations for which of those alternatives best meet the needs of TCSO, TCPW, and TRAX as collected and presented our prior report, the Inventory and Needs Assessment Report. It assembles the recommended alternatives into a conceptual-level system design and provides a budgetary estimate for that design. It is expected that this report will allow stakeholders from TCSO, TCPW, and TRAX to agree on a strategy and arrange funding and other resources for pursuing a solution to refresh/replace the existing systems.

In preparation for this report, our project team of staff from CDX Wireless and TCSO/TCPW/TRAX completed and accepted an Inventory and Needs Assessment Report that documents the condition and performance of the public safety and public service two-way radio communications systems and computerized dispatch as well as user needs for improvements to those systems. That report listed the needs of users for improvements as follows:

System Attribute	User Needs
Sites	Sites improved or constructed to standards for grounding, line routing, power, and rack bracing.
Coverage	Existing coverage maintained and improvements made to "corners" of county.
	Also, coverage be as countywide as possible (minimize channel-changing based on location).
Inter-operability	Maintain existing high levels of interoperability among TCSO and its neighbor/partner law-enforcement agencies.
	Increase interop between TCSO, TCPW, and TRAX, if possible.
Features	Deploy/support GPS-based location services.
	Add Radio ID, Emergency, and Encryption for TCSO.
	Add Scan for TCPW.
	Add Short/Canned Messages for TRAX.
Capacity	Add a 2nd countywide/repeated channel for TCSO (for tactical operations) and for paratransit (separate from fixed-route).
	Add a "local government" channel.

System Attribute	User Needs
User Eqpt	Replace the existing TCSO dispatch consoles with supported equipment that meets needs for features.
Support	Support any new system with an appropriate and cost-effective set of maintenance services.

For this report, we categorized each agency's requirements into five distinct operational needs:

1) TCSO's dispatch needs which include wide-area coverage to portable radios and a high level of interoperability with neighboring/partnering agencies (which use analog VHF technologies)
2) TCSO's inquiry needs which require compliance with the California Department of Justice's requirements for protecting personal information over radio calls
3) TCPW's needs which include wide-area coverage to mobile radios and interoperability with neighboring/partnering agencies (which use analog VHF technologies)
4) TRAX's needs which include wide-area coverage to mobile radios and the possibility for future addition of data transmissions for intelligent transit applications
5) Local government's needs which include wide-area coverage to portable and/or mobile radios and interoperability with TCSO and TCPW.

The detailed listing of needs and their categorization based on agency operations is included in Section 3 of this report (pages 1-5).

To meet these operation needs with a conceptual design, our process involves:

- First, reviewing the available technologies and selecting those that best fit user requirements
- Second, identifying radio sites based on their ability to provide coverage where it is needed
- Third, creating combinations of the selected technologies and the identified sites that pair our choices for each in a conceptual design that can be modeled for its performance, its ability to reuse existing equipment, and its estimated costs.

Step 1: Selecting Technologies

To complete that first step in our process, we looked at the basic technologies used in designing two-way radio systems, each of which have different options for their "building blocks". For example, radio systems can use various frequency bands and the "building block" choices include VHF, UHF, and 7/800MHz, each of which have different advantages and disadvantages to meeting the operational needs of TCSO, TCPW, and TRAX.

We evaluated the building-blocks available for seven system-level technologies and identified those building-blocks that best address the operational needs of each agency. The following table summarizes the options, our selections for the various operational needs, and our justifications for those selections.

For the technology of	From the building-block choices of	We chose	For the purposes of	Because
Ownership	Private, Shared, or Subscription	Private or shared	All agencies' operations	Subscription based systems do not (currently) meet TCSO's, TCPW's, or TRAX's operational needs (primarily coverage)
Frequency Band	VHF, UHF, or 7/800MHZ	VHF	All TCSO, TCPW, Local Government operations	VHF has good propagation characteristics in rural areas and it supports interoperability with neighbors that also use VHF
		UHF	TRAX's operations	UHF has good propagation characteristics in rural areas and it allows the possibility of equipment reuse
Modulation	Analog, P25 Digital, or Other Digital	Analog	TCSO's Dispatch, TCPW, and Local Government's operations	Analog, with bursty-data signaling, meets the needs for basic radio calling with some features (radio user ID, emergency, etc.) and it supports interoperability with neighbors that also use analog
		P25 Digital	TCSO's Inquiry operations	P25 supports encryption which can meet the need to protect personal information during inquiry radio calls
		Other Digital (DMR)	TRAX's operations	DMR allows the possibility of equipment reuse and it supports more robust data signaling (for GPS-based location services and/or intelligent transit applications)
Site Configuration	Single Site, Voting & Multicast, or Simulcast	Simulcast	TCSO's Dispatch operations	Simulcast provides wide-area coverage, especially to portable radios, while simplifying the selection of sites
		Single Site	TCSO's Inquiry, TCPW's, and TRAX's operations	Single site systems deliver sufficient coverage to mobile radios
		Voting	Local Government's operations	Voting will support coverage to a mixed use of mobile and portable radios

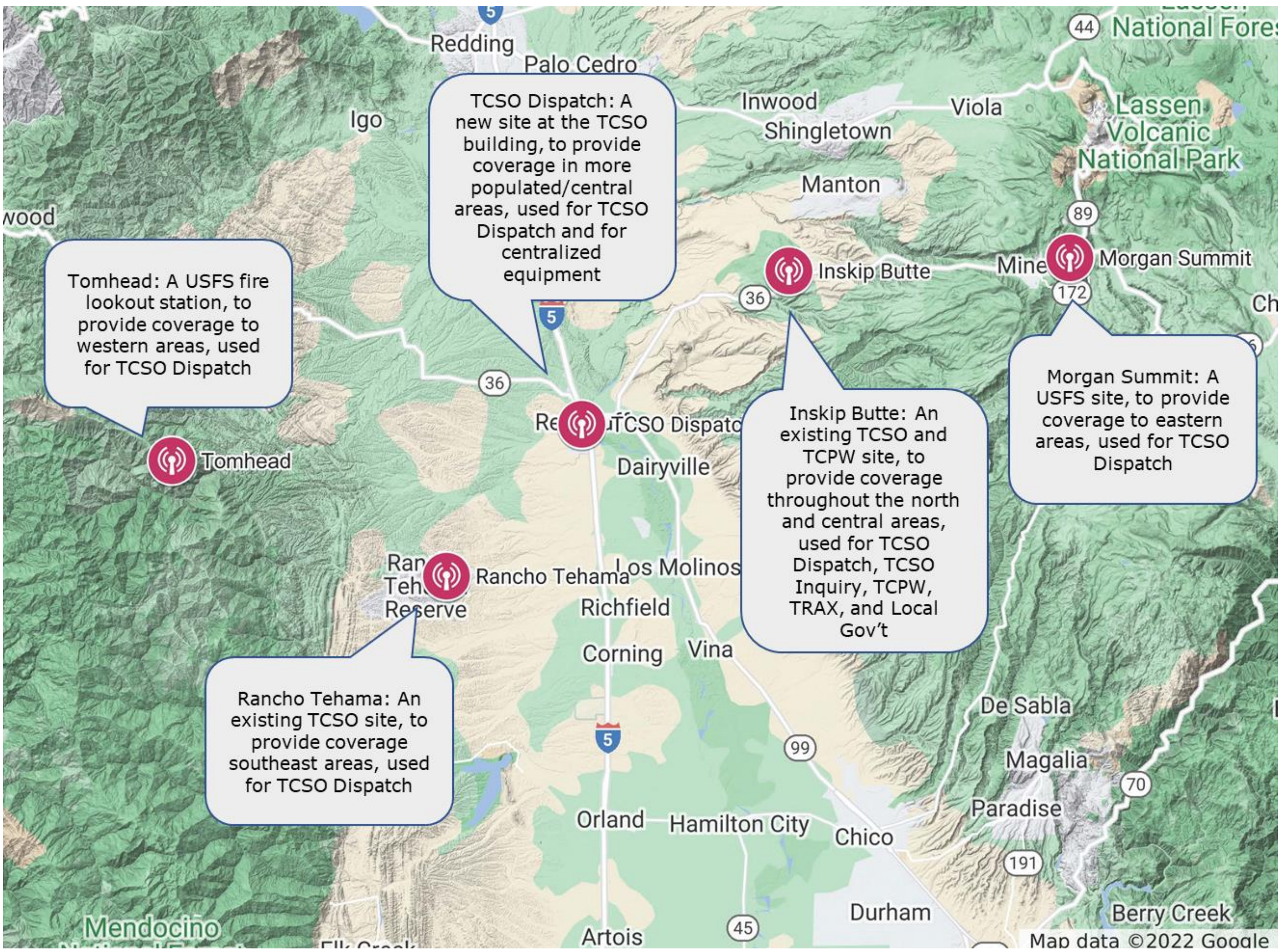
For the technology of	From the building-block choices of	We chose	For the purposes of	Because
Channel and Site Access	Conventional or Trunked Channel Access Single-Site, Manual or Vote-Scan Site Selection	Conventional Single Site	TCSO's Inquiry, TCPW's, TRAX's, and Local Government's operations	The agencies do not have large-enough fleets of radio users to require trunking and a single transmitter site provides sufficient coverage to their mobile radios
		Conventional Manual and/or Vote-Scan	TCSO's Dispatch operations	The agency does not have a large-enough fleet of radio users to require trunking – and – a determination on manual site selection or vote-scan requires further analysis (of radio capabilities and system performance)
Console Inter-connection	Control Stations or Direct/ Wireline	Direct/ Wireline	TCSO's Dispatch and Inquiry operations	The nature of dispatch operations for law enforcement will benefit from the clarity of audio and the features provided by direct/ wireline connections *Wireless control stations are also included for backup and interoperability purposes*
		Control Stations	TCPW's and TRAX's operations	Control stations meet the dispatch needs of public works and transit and they are easier and less costly to deploy
Site-to-Site Backhaul	Leased-Line, T-Carrier, or IP Microwave or Fiber No, Equipment, Ring, or MPLS Redundancy	IP-based, microwave links with a mix of no and equipment-based redundancy	All agencies' operations	IP systems are the most flexible and lowest-cost method to meet the bandwidth needs of the agencies Microwave is easier to deploy to remote sites than is fiber More centralized sites will use equipment-based redundancy while, to save costs, the most outlying sites will not use redundancy

The detailed listing of technology building blocks, their advantages and disadvantages, and their applicability to the operational needs of agencies is included in Section 4 of this report (pages 5-42).

Step 2: Selecting Sites

For the second step in our process, we collected information about potential radio sites and we used software tools that accept information about the sites' locations and elevations, as well as the technologies used in the equipment, and perform advanced calculations according to industry standards to create predicted models of coverage. This allowed us to pick sites the sites, or combinations of sites, that provide coverage where it is needed by each agency. We placed priority on using existing sites whenever possible and, when additional sites were needed, on locations owned by other governmental agencies and that need the least amount of improvement or construction. The result of this coverage-modeling process was the selection of five sites to be used in various ways to meet the needs of each agency. The following map shows the location of the selected sites as well as a summary of their use in the conceptual design.

Location and Purpose of Sites Included in Conceptual Design



A full description of our process for modeling predicted coverage from sites and the choices we made in selecting the sites depicted above is included in Section 5 of this report (pages 42-49). Maps of predicted coverage are included in Attachment A.

Step 3: Combining Technologies & Sites into a Conceptual Design

Our third step involves pairing technologies and sites so that, together, they create a conceptual design that meet user needs. For the agencies of TCSO, TCPW, and TRAX, as well as any users from local governmental agencies in Tehama County, this step resulted in a conceptual design of five individual subsystems as follows:

<table>
<tr><th colspan="3">Radio Subsystem 1: For TCSO's Dispatch Operations – A Two-Cell, Voted-Multi-Cast, Analog, Conventional Simulcast Subsystem</th></tr>
<tr><th>Radio Sites</th><th>Technologies</th><th>Site-Channel Configuration/Operational Use</th></tr>
<tr><td>An "East Side" Simulcast Cell with sites at TCSO Dispatch, Inskip Butte, and Morgan Summit</td><td rowspan="2">VHF analog conventional simulcast cells with 3 sites for the East Side cell and 2 for the West Side – the two cells will operate in a voting-multicast configuration.</td><td rowspan="2">The two cells will use the same receive frequency so that all 5 sites are capable of receiving all calls made by a user radio. The receivers of all five sites will be voted and the best signal will be sent to both the East Side and West Side cells for rebroadcast; however, those two simulcast cells will use different transmit frequencies due to the distances between sites (which would result in simulcast interference). Radio use selection of the East Side cell or the West Side cell will be accomplished either by vote-scan or manual selection – details are included below.</td></tr>
<tr><td>A "West Side" Simulcast Cell with sites at Rancho Tehama and Tomhead</td></tr>
</table>

<table>
<tr><th colspan="3">Radio Subsystem 2: For TCSO's Inquiry Operations – A VHF, P25, Conventional P25 Subsystem</th></tr>
<tr><th>Radio Sites</th><th>Technologies</th><th>Site-Channel Configuration/Operational Use</th></tr>
<tr><td>A single site at Inskip Butte</td><td>VHF P25 conventional</td><td>This single channel will be encrypted so that inquiries that carry Personally Identifiable Information (i.e., information that identifies an individual such as name and driver license number) can comply with California Department of Justice (CA DOJ) released Information Bulletin 20-09-CJIS without the operational imposition of transmitting such information in separate/distinct radio calls. The coverage on this channel will be viable for portable coverage throughout the north-central area of the county and for in-car use beyond that. This channel can also be used for tactical operations that benefit from: i) occurring on a channel other than dispatch and/or ii) being encrypted (e.g., SWAT operations).</td></tr>
</table>

Radio Subsystem 3: For TCPW – A VHF, Analog, Conventional P25 Subsystem		
Radio Sites	**Technologies**	**Site-Channel Configuration/Operational Use**
A single site at Inskip Butte	VHF analog conventional	This single channel will provide coverage to TCPW's mobile radios throughout most of the county.
Radio Subsystem 4: For TRAX – A UHF, DMR, Conventional P25 Subsystem		
Radio Sites	**Technologies**	**Site-Channel Configuration/Operational Use**
A single site at Inskip Butte	UHF DMR conventional	This single channel will be capable of carrying two sets of information due to its two digital time slots. One time slot will be used to provide voice communications to TRAX's mobile radios throughout most of the county. The second time slot will be available for data messaging including: i) possible future intelligent transit application data from TRAX's vehicles and/or ii) possible future GPS-based location services from TCSO and/or TCPW's vehicles.
Radio Subsystem 5: For Local Government – A VHF, Analog, Conventional P25 Subsystem with Voting Receivers		
Radio Sites	**Technologies**	**Site-Channel Configuration/Operational Use**
A single transmission site at Inskip Butte with 4 additional voted receiver sites	VHF analog conventional, single transmitter site and 4 additional voted sites	This single channel will provide coverage to mobile radios for local government agencies throughout most of the county. It uses voting receivers at the same sites as the TCSO Dispatch channel to improve coverage for portable radios. It could also serve as a backup and/or alternate channel should the dispatch channel experience failure or congestion.

The design of the TCSO Dispatch subsystem will collect user-transmitted audio from the five sites and transmit the voted/best version of that conversation from five sites; however, the site-to-site distances do not allow all five sites to be in one-simulcast "cell". Instead, they must be in two interconnected cells; one of three sites for the east side and one of two for the west side. (A simulcast cell is a collection of sites that transmit on the same frequencies – they must be within limited distances from each other or else their transmissions will produce interference in areas that require good coverage.)

Because the two TCSO Dispatch cells (the two sides) transmit on different frequencies, there will be two different TCSO Dispatch "modes" (or channel selections) in each radio that has access to the TCSO Dispatch channel – there will be a "Dispatch East" and a "Dispatch West" mode. Again, users on both simulcast cells (i.e., both "sides") will hear the same broadcast of all conversations (including audio from dispatchers and calls from other field users that are received by any of the five sites) but the different modes are required to accommodate the fact that those on the east side will receive that conversation on a different physical frequency from those on the west side. Also, the voter will deliver the best/voted audio (from both the east and west sides) to TCSO dispatchers. When dispatchers transmit, their audio will be routed through the voter to both the east and west sides for broadcast to users.

There are two options for how users of the TCSO Dispatch subsystem will access/select the west and east sides. They could use an automated method in which their radio selects the best side based on received signal strengths (this is known as radio vote-scan) or the user themselves could manually select a side based on their location. Although vote-scan is the easier and more automated method for selecting a side, we are unsure if it can be deployed because: i) we are unsure if it is supported in all radio models used by TCSO and ii) it requires very regular and very frequent transmissions from all sites. Therefore, we suggest that TCSO proceed with manual switching (with the suggestion that any user east of I-5 use the east side and vice versa for the west side) while we further investigate the capabilities of current and possible future TCSO radios and conduct a field trial of vote-scan with a small set of radios.

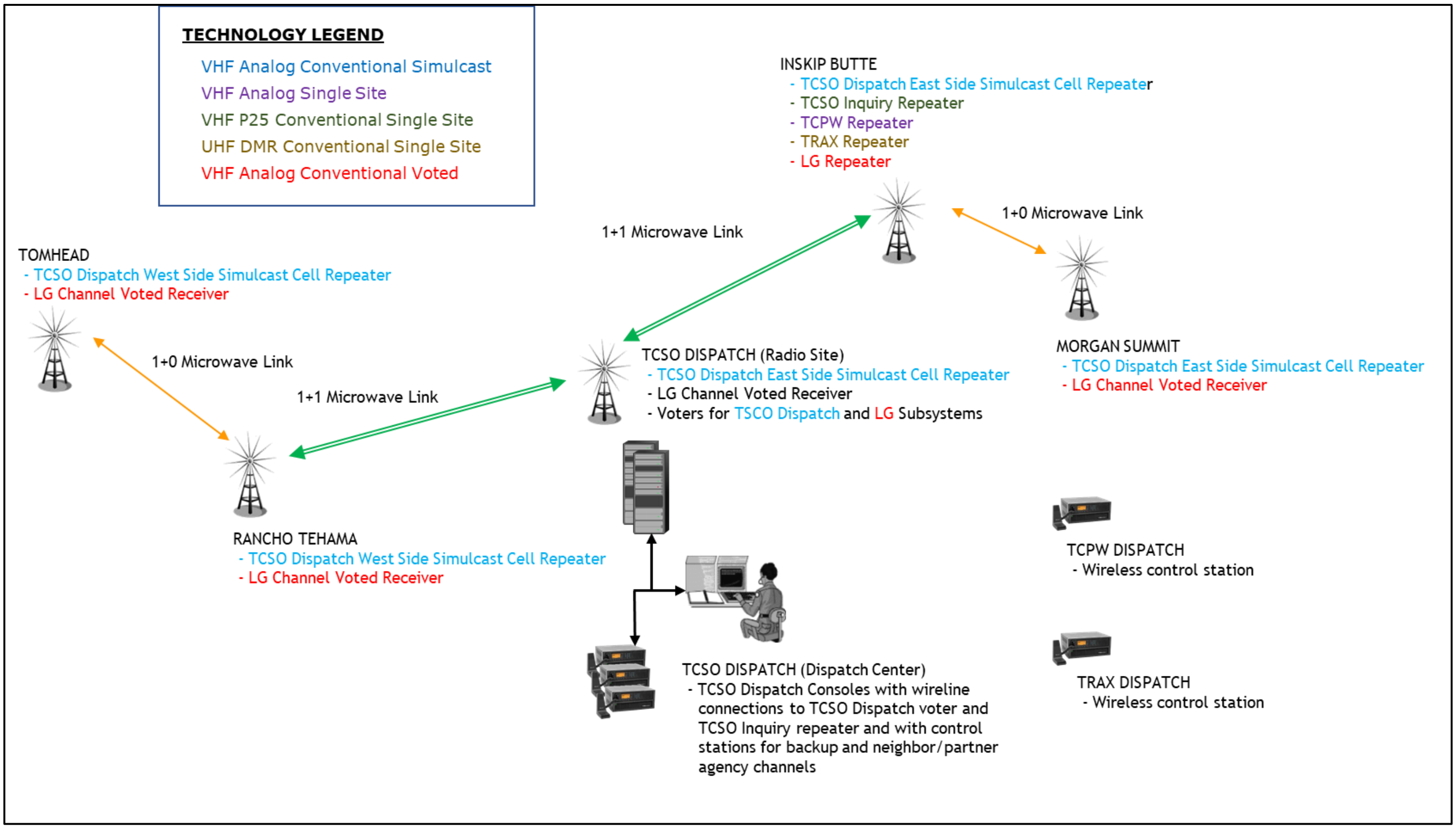
The operational implications of the other subsystems are generally uncomplicated as they use the same analog, VHF, conventional technologies currently in use by TCSO and TRAX with the following exceptions:

1) The TCSO Inquiry subsystem will use P25 digital technologies and it will support encryption so that personal information can be transmitted in compliance with CA DOJ requirements. This subsystem could also be used for sensitive tactical operations such as SWAT.

2) The TRAX subsystem will use UHF DMR technologies which can carry two simultaneous streams of audio or data signaling in one radio channel. We expect one stream will carry TRAX's voice conversations and the other will be available to carry data such as GPS-based location services (including from TCSO or TCPW) or intelligent transit applications.

Each of these systems will support basic but slightly different sets of user features including the transmission of user IDs and emergency messages. To support the feature of dispatcher priority (in which a dispatcher can pre-empt audio from user radios and, instead, broadcast their own audio), the TCSO Dispatch and TCSO Inquiry subsystems will rely on a direct wireline connection from TCSO dispatch consoles to the subsystem's infrastructure. IP-based microwave connections will be used for site-to-site links. The following schematic diagram summarizes our conceptual design.

Schematic Diagram of Conceptual Design



More information on our process of combining technologies and sites into a conceptual design of the five subsystems, along with greater details on the operations of the subsystems, is included in Section 6 of this report (pages 49-61).

As noted above, the selection of some technologies (such as DMR for TRAX) could allow reuse of existing equipment such as user radios; however, most of the infrastructure and user radios in use by TCSO, TCPW, and TRAX have aged to the point of no longer being supported by its manufacturer. Due to their lack of support and in order to ensure users have full access to all features available from their subsystems, we suggest replacing all equipment other than those TCSO user radios that have been purchased very recently. (Included in our recommendations for equipment replacements are the dispatch consoles at TCSO dispatch.) Still, some equipment, despite its lack of manufacturer support, could be reused in order to reduce the overall cost of the conceptual design.

A review of the reusability of existing equipment (and a guide for selecting replacement user equipment) is included in Section 7 of this report (pages 61-64).

We conclude this report with budgetary cost estimates for the one-time/capital deployment of the conceptual design (including its five subsystems and user radios) as well as for its annual support and maintenance.

Our budgetary estimate for the conceptual design's capital cost is $5,241,000 which does not include: i) the costs for subscriber radios for local government agencies (as the quantities of those radios are currently unknown) or ii) any intelligent transit application for TRAX or any mapping applications for TCSO or TCPW. Details on this amount, including a breakdown of the amounts for each subsystem and, where applicable, the agency (or agencies) associated with each subsystem's costs, begin on page 65 of this report.

These costs are typically distributed in milestone payments that occur over the deployment timeframe of the project to deploy the system. If procured as a direct/capital purchase from a vendor, Tehama County and TRAX can expect this amount to be distributed over a period of approximately 24 months. There are other options for distributing the costs including purchasing some equipment (such as user radios) separately and earlier from the rest of the project or financing/leasing the purchase through programs available from vendors or independent financing companies.

We have also **estimated that the annual costs for maintaining and operating the system will be $175,000** with the additional need for between 4 and 7 days of internal staff effort to complete tasks that cannot be outsourced to a vendor.

Our cost estimates are intended to provide Tehama County and TRAX with enough information to plan project resources and budgets for the next steps of developing procurement specifications and working with a selected vendor on a detailed design and implementation plan. All costs have been developed to be budgetary in nature meaning they are slightly higher than the highest costs we expect to be quoted by vendors.

A full breakdown of these costs, along with more details on our process to develop them, is included in Section 8 of this report (pages 54-70).

We envision the next steps for this project are a review of this report by the representatives of TCSO, TCPW, and TRAX in order to understand the technologies, the way they are applied to create our conceptual design, and the ability of that design to meet user needs. Additionally, we hope the budgetary estimates can be used to assist in identifying possible sources of funding and in allocating funds to a multi-year project.

In parallel to the review of this report, CDX Wireless will assist TRAX in developing a Request for Information (RFI) to gather the current landscape of vendor offerings for intelligent transit applications. This will involve releasing a set of questions to vendors of such applications (through the RFI), collecting their responses, and compiling the answers received from vendors into one report. Vendors will also be asked to provide budgetary pricing for their offerings so that TRAX can likewise develop plans and budget for funding for an intelligent transit application.

Contents

2. Purpose and Scope

This Alternatives & Recommended Solution Report describes alternative radio-system technologies that are available to improve the capabilities of the two-way radio communications systems in use by the Tehama County Sheriff's Office (TCSO), Tehama County Public Works (TCPW), and the Tehama Rural Area eXpress (TRAX). It provides recommendations for which of those alternatives best meet the needs and requirements of TCSO, TCPW, and TRAX as collected and presented our prior report, the Inventory and Needs Assessment Report. It assembles the recommended alternatives into a conceptual-level system design and provides a budgetary estimate for that design. It is expected that this report will allow stakeholders from of TCSO, TCPW, and TRAX to agree on a strategy for pursuing a design as the solution to refresh/replace the existing systems.

3. Foundations of This Report: Prior Work Completed

In preparation for this report, our project team of staff from CDX Wireless and TCSO/TCPW/TRAX completed and accepted an Inventory and Needs Assessment Report that documents the condition and performance of the public safety and public service two-way radio communications systems and computerized dispatch as well as user needs for improvements to those systems.

This report assumes familiarity with the terms used to describe the basic equipment used in two-way radio systems. For a reminder of those terms (such as repeater, channel, voting receiver, etc.), please see Section 3.1 of our Inventory and Needs Assessment report.

That report categorized the performance of the existing systems, and the needs of users for improvements, according to the following topics:

Radio System Topic	Details Collected:
Coverage	Where is wireless access provided and where is it required? What levels of coverage reliability are required?
Capacity	How many users does the system need to support and how many channels are required for the various agencies?
Channel Selection	Are the purposes of various channels known and it is easy to select (and use) the correct channel for various situations?
Channel Scanning	Are there easy processes for scanning (monitoring) other channels (other than one's primary-use channel) in order to have a necessary level of situational awareness?
Equipment Usability	Are the layouts and controls of the user radios, including accessories, easy to use so as to efficiently and effectively conduct operations?

Radio System Topic	Details Collected:
Features	Which functions (e.g., encryption, over-the-air rekeying, mixed conventional-and-trunking operations, scan, and emergency) are required for the voice radio system networks?
Interoperability	What level of communications between departments and outside agencies is required and how are those communications established and conducted?
Service	Are the levels of response for technical assistance appropriate to maintain radio operations and is service provided in a timely manner?

That prior report recapped its major findings with the following two designations:

Those findings that required immediate attention – these are referred to as "Immediate Action Required" and are identified by the following symbol:

Those findings that do not require immediate attention but should be addressed in a possible future system (i.e., those issues, concerns, or needs that will addressed in future reports) – these are referred to as "Carry Forwards" and are identified by the following symbol:

The following table lists the immediate recommendations and topics to be carried-forward for the voice radio and dispatch application systems used by TCSO, TCPW, and TRAX as identified in our prior report:

Area of Assessment	Action Type	Recommendations / Topics
Radio Sites	Immediate	• The tower at the TCSO Dispatch (TCSO Jail) facility should be structurally assessed and strengthened/remediated per the outcome of that assessment.
	Carry-Forward	• Non-critical improvements are recommended for site and tower grounding, antenna transmission line routing and grounding, site backup power, and equipment rack bracing.

Area of Assessment	Action Type	Recommendations / Topics
General Technology	Immediate	• n/a
	Carry-Forward	• Various technologies should be evaluated for future systems; including different radio frequency bands, analog and digital modulation methods, and conventional and trunked architectures; however, they should all be evaluated against their ability to meet user needs for performance (including coverage, features, interoperability) and cost.
Coverage	Immediate	• Improving awareness of how and when to select the TCSO Rancho Tehama Reserve site/channel could improve perceptions of coverage as well as TCSO operations in the area.
	Carry-Forward	• Improving coverage to TCSO, TCPW, and TRAX is an important goal for a new system. This includes ensuring a new system delivers radio coverage in areas not currently served as well as enable county-wide coverage (i.e., the ability for users at distant ends of the county to talk directly to each other without imposing cumbersome site/channel selection methods).
Interoper-ability	Immediate	• n/a
	Carry-Forward	• Continuing the currently high levels of interoperability among TCSO and its neighbor/partner law-enforcement agencies is important for a future system. Increasing the amount of interoperability between TCSO, TCPW, and TRAX should be evaluated.
Features	Immediate	• n/a
	Carry-Forward	• All user organizations felt new features, mainly GPS-location services, would help their operations. Other requested features for a new system included: – For TCSO: Radio ID, Emergency, and Encryption – For TCPW: the ability to talk to TCSO and to scan other channels – For TRAX: ‘canned’ messages

Area of Assessment	Action Type	Recommendations / Topics
Capacity	Immediate	• n/a
	Carry-Forward	• Both TCSO and TRAX noted that having a second channel (for tactical operations for TCSO and for a split between fixed-route and paratransit for TRAX) would be beneficial. • Representatives of Tehama County's Board of Supervisors requested a separate radio channel for other governmental functions (a "local government" channel for animal services, building services, parks, etc.)[1]
Equipment Usability	Immediate	• Providing a refresher course on radio features and operations to TRAX users could eliminate some confusions some operators have about radio controls.
	Carry-Forward	• Replacing the existing TCSO dispatch consoles with equipment that provides at least the same functionality but that is current/supported by its manufacturer should be a goal of a future system. • The specific enhancements noted by TCSO dispatchers, improved interface with EvidenceOnQ and DA access, will be investigated as possible enhancements to RIMS. • Deploying an Intelligent Transit System application for TRAX will be investigated for its capabilities, fit to TRAX's operations, and cost effectiveness.
Support	Immediate	• Representatives from TRAX should confirm the availability of the installation media for Rides Unlimited so that it could be reinstalled on a new should its current computer fail.
	Carry-Forward	• Ensuring that any future replacement or upgraded radio system has an appropriate and cost-effective set of support and maintenance services will be important to its long-term sustainability.

[1] This requirement for a "local government" channel was not in our Inventory and Needs Assessment Report but it was raised by attendees at a presentation of that report to the Tehama County Transit Agency Board on November 22, 2021.

4. Radio System Technology Options

To create the design alternatives described in his report, our project team evaluated various 'building blocks' that are available when designing a radio system. These options are presented below and they represent the core choices that can be combined in numerous ways to achieve a solution. They include:

- Ownership – the basic economic construct of the system which affects mainly cost, including capital vs. operational cost differences; there are three basic models: private (owned by the organization that uses it), shared (owned by many organizations), and subscription (owned by an organization other than the one that uses it, a fee-for-use model)
- Frequency Band – the portion of the radio spectrum in which a system will operate – this affects issues such as coverage (range and strength) and susceptibility to interference
- Modulation Method – the way in which signals (voice and data) are encoded for transport by the system – this affects issues such as coverage, capacity, and capabilities (features)
- Site Configuration – the way in which channels are deployed at and used among sites – this affects coverage and capacity
- Channel & Site Access Method – the manner of control that governs how multiple users can access the same channel and how they select sites – this affects coverage, site roaming (i.e., the way users select sites), and capacity
- Dispatch Interface – the method by which dispatch consoles connect to the system – this affects dispatcher features and audio reliability and quality
- Backhaul Technology – the technique used to create links between sites – this affects mainly system reliability.

As each category of building blocks is presented, the options it contains will be compared to the "Carry Forward" requirements listed above (and simplified into shorter sentences). A table will be used to show whether each option has: i) an inherent ability to meet that requirement, ii) the possibility of meeting that requirement, depending on method of implementation, iii) an inherent <u>in</u>ability to meet that requirement, or iv) no impact (neither positive nor negative) on that requirement.

In this way, we can use these various alternatives building blocks to create a system design that best meets the most carry-forward requirements.

4.1. Ownership Model

There are three basic models regarding ownership of a public safety radio communications system:

- <u>Private</u>: In which an organization owns the physical assets of the system and pays for the capital (one-time) and ongoing (operations and maintenance) costs of the system.

- <u>Shared</u>: In which a group of organizations (typically with a similar or common operational goal) owns the physical assets of the system. The sharing of either or both of the capital and/or ongoing costs of the system may also be a component of a shared system. A common model is one in which one organization contributes the capital costs of the system and recoups all or some of its capital and/or operational costs (typically without profit) by charging a fee to the organizations that use the system. (Note that the organizations that are allowed use on the system are limited to those that have the similar or common operational goal.)

- Subscription: In which one organization owns the physical assets of the system and pays for the capital and ongoing costs of the system and recoups all or some of its costs by charging other organizations for the use of that system. TRAX's use of the DMR repeater owned and operated by Day Wireless is an example of a subscription system. Traditionally, the owner/operator of the system had been a corporation (such as a cellular network provider who did not impose restrictions on the type of organizations that are allowed use on the system); however, recently two new types of subscription-based ownership have emerged. The first is that of a statewide (or multi-county region-wide) system that is owned by a state-level governmental agency (or a joint-powers authority with representation from the region served by the system). A relevant example of this type of subscription-based ownership is the State of California's California Radio Interoperable System (CRIS). The second is a corporate-backed cellular network that limits system access to agencies involved in public safety. The FirstNet™ cellular system from AT&T, Inc. is an example.

Among the main differentiators between private, shared, and subscription systems is that the costs of private and shared systems typically include large capital costs and (relatively) small ongoing costs. In contrast, the costs to use a subscription system are typically structured such that there is a low (or no) one-time fee but that ongoing costs are high. (Note that the ongoing costs of a large and/or complex public safety radio system can be large; however, they are typically between 5% and 15% per year of the one-time costs of the system.)

The distribution of costs is not the only differentiating factor between these models of ownership – issues of control are also factors. A private system operates under the direct control of the one organization that has funded, built, and operated it. That one organization decides on the performance parameters of the system and the system is designed specifically to meet the needs of that one organization. Likewise, the usage policies of a private system are left to the discretion of the one organization that owns it. For example, the owner of a private system can decide which individuals or groups have priority use of the system in cases of emergencies or other high-demand situations.

A typical model for a shared system is one that is similar to a private system in that it is funded, built, and operated by a particular set of organizations for a specific purpose; however, its design and usage are typically governed by representatives of the larger group of organizations. This structure usually involves a usage agreement to define the responsibilities of all parties and it may lead to cases in which technical or operational decisions are made to serve the largest number of constituent organizations, but possibly not serving all. Another model of a shared system in one in which one or more organizations jointly contribute capital costs and jointly pay ongoing operational costs. This structure can ensure that needs of many organizations are met but should be accompanied by stronger governance agreements to define how financial, technical, and operational decisions will be made by all parties. Strong advantages to shared systems are that their costs (including one-time and ongoing) can be shared among all constituent organizations and their design can allow cross communications between those same constituent organizations ("interoperability").

A subscription-based system's strongest advantages are its low capital cost and its relatively low operational cost. A one-time cost may exist to gain initial access to the system and the ongoing costs can be low in order to provide a competitive offering. The disadvantage to subscription systems is that they are designed (for both technical and operational use) to meet some mixture of customer/user needs and business goals of the owning organization. The coverage, capacity, etc., they provide will meet the needs of many, but not all, users.

Although their designs are targeted to public safety and public service users, we do not recommend TCSO/TCPW/TRAX consider the subscription-based systems of CRIS and FirstNet for use as their primary communications systems for the following reasons:

- As described in our Inventory and Needs Assessment Report, the CRIS system has only one site in Tehama County and as shown in the coverage maps available from the department that operates the system, CalOES, the coverage from that site does not meet the needs of TCSO, TCPW, and TRAX.

- Also, the CRIS system uses 700MHz P25 trunked technology. These technology 'building block' options are detailed below but it is sufficient to state that they are significantly different from the technologies used by TCSO, TCPW, and TRAX as well as the technologies used by the important operational neighbor/partners with who those three agencies communicate. Use of CRIS would make interoperating with neighbor/partners significantly more difficult.

- The FirstNet system uses fourth and fifth generation (4G and 5G) long term evolution (LTE) cellular radio technology to provide wireless mobile broadband service to public safety agencies, nationwide. In our experience, FirstNet; and other cellular, subscription/fee-based wireless systems; are currently viable to augment private or shared, traditional two-way radio systems but they are not yet sufficient as wholesale replacements of them for primary use by public safety agencies. Such systems have yet to provide the localized coverage to meet the needs of public safety agencies and they do not yet have user devices (user radios and accessories) in the form-factors or to the specifications of those that are used by public safety personnel. We encourage TRAX and the County of Tehama to be aware of and engaged in FirstNet's deployment and to consider FirstNet as options to: i) provide radio service for personnel that do not typically carry a two-way radio (such as support staff) and ii) provide service to areas outside that served by its traditional two-way radio system (i.e., roaming outside of the primary service area). We do; however, recommend that TRAX and Tehama County continue to plan for the implementation of the type of private or locally-shared voice radio communications systems discussed in this report to serve the needs for mission-critical public safety radio communications services.

The following table shows how each of these building-block options meets (or does not meet) the Carry-Forward requirements for an upgraded or replacement system for TCSO, TCPW, and TRAX:

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Private	Shared	Subscription
Sites	Sites improved or constructed to standards for grounding, line routing, power, and rack bracing.	⊙	⊙	⇔
Coverag	Existing coverage maintained and improvements made to "corners" of county.	⊙	⊙	⊙

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Private	Shared	Subscription
	Also, coverage be as countywide as possible (minimize channel-changing based on location).	⊙	⊙	⊙
Interop	Maintain existing high levels of interoperability among TCSO and its neighbor/partner law-enforcement agencies.	⊙	⊙	☒
	Increase interop between TCSO, TCPW, and TRAX, if possible.	⊙	✪	⊙
Features	Deploy/support GPS-based location services.	⬄	⬄	⬄
	Add Radio ID, Emergency, and Encryption for TCSO.	⬄	⬄	⬄
	Add Scan for TCPW.	⬄	⬄	⬄
	Add Short/Canned Messages for TRAX.	⬄	⬄	⬄
Capacity	Add a 2nd countywide/repeated channel for TCSO (for tactical operations) and for paratransit (separate from fixed-route).	⬄	⬄	⬄
	Add a "local government" channel.	⬄	⬄	⬄
User Eqpt	Replace the existing TCSO dispatch consoles with supported equipment that meets needs for features.	⬄	⬄	⬄
Support	Support any new system with an appropriate and cost-effective set of maintenance services.	⬄	⬄	⬄
Legend	✪ - Building block option inherently meets identified requirement ⊙ - Building block option could meet identified requirement depending on implementation ☒ - Building block option inherently cannot meet identified requirement ⬄ - Building block option has no impact on identified requirement			

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Private	Shared	Subscription
Summary	**We recommend private or shared systems as the use of radio systems is critical to the mission of the TCSO, TCPW, and TRAX and the technical and operational design of those systems should be as tailored as possible to user needs.** **We also recommend that subscription systems, particularly cellular-based systems that are focused on use by public safety agencies and that can provide them priority access (such as FirstNet), be considered as methods to augment the coverage and/or capabilities of a private or shared system for TCSO, TCPW and TRAX.**			

4.2. Frequency Band

No other factor has a more profound effect on the performance of a radio system than does its frequency band. Therefore, this section of this report includes a significant level of detail about the available options.

The radio wave is an electromagnetic wave that oscillates at a specific frequency. The rate at which it oscillates (travels from its peak to its trough and back) helps to define the way the radio wave propagates or travels wirelessly through the air. Radio frequencies are typically defined in Megahertz, abbreviated MHz. A single hertz represents one cycle (one oscillation) per second, while a Megahertz represents one million cycles (one million oscillations) per second. So, a radio frequency operating at 50 Megahertz will have its electromagnetic wave oscillating at 50 million cycles per second.

Frequencies within certain ranges tend to exhibit common characteristics. Because of this, frequencies are generally grouped within their ranges and those ranges are called bands. The Federal Communications Commission (FCC), acting as the body that regulates use of spectrum for all but federal agencies, has regulatory conventions that further subdivide these bands into smaller sub groupings. Bands typically used in the public safety radio system industry are:

- Very High Frequency (VHF) - 30 MHz to 300 MHz
- Ultra High Frequency (UHF) – 300 MHz to 3000 MHz with specific sub-bands in
  - 450 MHz – 512 MHz
  - 700MHz
  - 800MHz

These bands and their properties and applicability to the needs of TCSO, TCPW, and TRAX are presented in the following sections of the report.

4.2.1. *Very High Frequency (VHF) Band*

The Very High Frequency (VHF) band, as identified by the International Telecommunication Union (ITU), is the radio frequency range from 30 MHz to 300 MHz. For public safety communications, it is further sub-divided into VHF Low-band in the 30-50 MHz range and VHF High-band in the 150-174 MHz range. VHF High-band frequencies are currently in use in by TCSO and TCPW as well as many of the municipal law enforcement and public works departments in Tehama County.

VHF channels are generally considered shared channels and are not exclusive to the licensee. Channel assignment is based on "best effort" to minimize interference; however, interference protection is not guaranteed. A limited form of exclusivity is only granted to licensees who deploy centralized trunked radio systems in the 150-174 MHz band and who can show that all existing licensees (incumbents) will not be affected by the signal's use. This is extremely difficult to attain (and often impossible) on VHF channels in or near metropolitan areas.

VHF is an unstructured band, with no designated separation between base station/repeater transmit and receive frequencies. (Other bands, described below, have inherent structures in which frequencies are assigned only in pairs and those pairs are laid out with specific ranges for transmitters and receivers, thus reducing the possibility of interference.) Although it is possible to license a VHF frequency pair for use in repeater operations, it is typically difficult to do so in practice due to the limited amount of VHF spectrum. If repeater pairs are found and licensed, they are subject to interference as receiver and transmitter frequencies may be very close to each other. Due to this potential for interference, VHF systems typically need a higher degree of filtering which can increase their costs.

VHF's propagation characteristics can be very good for public safety radio systems, with a range generally somewhat farther than line-of-sight from the transmitter. VHF also works very well in areas of dense foliage and trees when compared to higher bands such as 700 and 800MHz. VHF; however, does not penetrate buildings or urban areas as well as those higher-frequency bands.

Within VHF, the Low-band (30 MHz to 50 MHz) is greatly affected by sunspot activity, atmospheric noise, and interference from electrical equipment. For these reasons, and because of other forms of interference, many of the major manufacturers have limited offerings for systems and equipment in the Low-band portion of the VHF band. VHF High-band (150 MHz to 174) MHz; however, remains a viable choice, with equipment options available from many manufactures, provided that the necessary quantities of frequencies can be obtained and in a grouping that minimizes interference.

4.2.2. *Ultra High Frequency (UHF) Band*

UHF (Ultra High Frequency) is formally defined by the International Telecommunication Union (ITU) as the radio frequency range from 300 MHz to 3000 MHz. It is further sub divided for use in public safety radio systems into sub-bands that include:

- The UHF "main" band in the 450-470 MHz range
- The 700MHz band
- The 800MHz band

While all of these sub-bands are referred to as the UHF band, the latter two (700MHz and 800MHz) have characteristics that are unique enough to differentiate them from both the "main" (450MHz) sub-band and from each other. While it may be technically correct to call all sub-bands listed above as "UHF", in practice (and for the sake of this report) only those between 450 and 512 MHZ are typically called "UHF" and the other sub-bands are referred to by their numeric designator (i.e., the "800MHz band"). UHF main band frequencies are currently in use in the radio system used by TRAX.

Channels in the UHF band are generally shared channels. Shared channels often require that users on monitor before transmitting to minimize interference to co-channel systems. Limited exclusivity can be obtained in the 450-470 MHz portion of the band as described for VHF above.[2]

4.2.1. *The "Main" UHF Band (450-470MHz)*

UHF is a structured band, with designated base station/repeater transmit and receive frequencies spaced 5 MHz apart. While this structure exists, the relatively small amount of separation between the transmit and receive frequencies does still often require complex filtering and frequency planning to eliminate interference.

UHF propagation characteristics are very good for public safety radio systems, with a range generally slightly farther than line-of-sight from the transmitter. UHF also works well in areas of dense foliage and trees when compared to higher bands such as 700 and 800MHz. UHF frequencies do not penetrate buildings or urban areas as well as those same higher bands; however, they do provide better penetration than VHF frequencies.

UHF and higher bands are generally not affected by sunspot activity, atmospheric noise, and interference from electrical equipment.

UHF, like VHF High-band, remains popular with just about every major manufacturer of radio equipment with nearly all system types and equipment available for this band.

4.2.2. *700MHz Band*

700MHz is a sub-range of the UHF band but its characteristics warrant that it be described separately from the other sub-bands. The 700MHz band is divided into two segments: the Narrowband Segment (which consists of channels in the 769-775 MHz and 799-805 MHz ranges) and the Wideband Segment (which consists of a total of 20MHz of spectrum in the 758-768 MHz and 788-798 MHz ranges).

The Wideband Segment, a portion of which is also known as the "D block", was set aside for use in the National Public Safety Broadband Network when the U.S Congress enacted the Middle Class Tax Relief and Job Recovery Act of 2012 (Spectrum Act). That Act also formed the First Responder Network Authority (FirstNet) as an independent authority within the U.S. Department of Commerce with responsibilities for deploying and operating the nationwide public safety broadband network and for holding the license for the Wideband Segment. Therefore, the Wideband Segment is not directly licensable to local government for use in public safety radio communications systems.

The Narrowband Segment is even further sub divided for use in public safety radio systems: the lower (769-775 MHz) band is used for transmissions from base stations to user radios and the upper (799-805 MHz) band is used for transmissions from user radios to base stations. In this way, 700MHz is a structured band, with designated base station/repeater transmit and receive frequencies spaced 30MHz apart so that they have much lower probability of interfering with each other than do unstructured channels in the VHF and UHF bands.

The Narrowband Segment of the 700MHz band is adjacent to the 800MHz band and most of the user radio equipment manufactured today that is capable of operating in the 700MHz band is also capable of

[2] Limited exclusivity is easier to attain on this band due to increased channel separation and less congestion.

operating in the 800MHz band. 700MHz channels are 12.5kHz wide and are not subject to any planned narrowbanding initiative.

For the 700MHz Narrowband Segment, the FCC determined that it would allow individual regions (states or sections of states) to determine how they would allocate the channels among public safety users. Each region was to develop a regional plan detailing the criteria for allocating and licensing of the channels within 700MHz. Tehama County is part of the Region 6 FCC Regional Planning Area, and the current Region 6 700MHz plan allots the Tehama Operational Area (OA), which includes County-level and municipal-level agencies alike, a total of twelve (12) 700MHz narrowband channels.

700MHz band channels can be used with exclusive-use providing that the licensee meets criteria of the Region 6 700MHz regional plan. Exclusive use means that the region defines rules that protect the use of the same channel (the co-channel) and those channels immediately above and below the channel (the adjacent channels) from being reused/relicensed in ways that could cause interference.

700MHz propagation characteristics are good for public safety radio systems, with a range generally coinciding with line-of-sight from the transmitter. 700MHz suffers greater losses in areas of dense foliage and trees when compared to lower bands such as VHF and UHF; however, it provides better penetration into buildings than the lower bands of VHF and UHF (450 – 470 MHz).

4.2.3. *800MHz Band*

800MHz is a sub-range of the UHF band and, like 700MHz, its characteristics warrant that it be described separately from the other sub-bands. It is subdivided for use in public safety radio systems into a lower 806-815 MHz band which is used for user radio transmissions (to the base stations) and an upper 851-860 MHz band which is used for base station transmissions (to the user radios). Additionally, the lower 3 MHz of each sub-band is specifically reserved for public safety use (and is referred to as the National Public Safety Planning Advisory Committee, or NPSPAC, set of frequencies) while the upper 6 MHz of each sub-band is available for public safety, business-and-industrial, and specialized mobile relay (SMR) use. In this way, like 700MHz, 800MHz is a structured band, with designated base station/repeater transmit and receive frequencies spaced 45MHz apart so that they have much lower probability of interfering with each other than do unstructured channels in the VHF and UHF bands. Also, the lower portion of the 800MHz band is adjacent to the upper portion of the 700MHz and most of the user radio equipment manufactured today that is capable of operating in the 800MHz band is also capable of operating in the 700MHz band.

800MHz band channels can be protected by exclusive use providing that the licensee meets loading criteria of 70 units for channels in the general pool (see FCC rules CFR Sec. 90.631(b)). For 800MHz, exclusive use means that a frequency cannot be reassigned for a 70-mile radius of the licensee’s station. 800MHz channels are 20 or 25 kHz wide (depending on the channel) and are not subject to any planned narrowbanding initiative.

800MHz propagation characteristics are good for public safety radio systems, with a range generally coinciding with line-of-sight from the transmitter. 800MHz suffers greater losses in areas of dense foliage and trees when compared to lower bands such as VHF and UHF; however, like 700MHz, it provides better penetration into buildings than the lower bands of VHF and UHF (450 – 470 MHz).

800MHz remains popular with just about every major manufacturer of radio equipment with most system types and equipment available for this band.

4.2.4. *Comparison of Band Options*

The following table shows how each of these building-block options meets (or does not meet) the Carry-Forward requirements for an upgraded or replacement system for TCSO, TCPW, and TRAX:

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact			
		VHF	UHF	700MHz	800MHz
Sites	Sites improved or constructed to standards for grounding, line routing, power, and rack bracing.	⇔	⇔	⇔	⇔
Coverage	Existing coverage maintained and improvements made to "corners" of county.	⊙	⊙	⊙	⊙
	Also, coverage be as countywide as possible (minimize channel-changing based on location).	⊙	⊙	⊙	⊙
Interop	Maintain existing high levels of interoperability among TCSO and its neighbor/partner law-enforcement agencies.	✪	☒	☒	☒
	Increase interop between TCSO, TCPW, and TRAX, if possible.	⊙	⊙	⊙	⊙
Features	Deploy/support GPS-based location services.	⇔	⇔	⇔	⇔
	Add Radio ID, Emergency, and Encryption for TCSO.	⇔	⇔	⇔	⇔
	Add Scan for TCPW.	⇔	⇔	⇔	⇔
	Add Short/Canned Messages for TRAX.	⇔	⇔	⇔	⇔
Capacity	Add a 2nd countywide/repeated channel for TCSO (for tactical operations) and for paratransit (separate from fixed-route).	⊙	⊙	⊙	⊙
	Add a "local government" channel.	⊙	⊙	⊙	⊙
User Eqpt	Replace the existing TCSO dispatch consoles with supported equipment that meets needs for features.	⇔	⇔	⇔	⇔

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact			
		VHF	UHF	700MHz	800MHz
Support	Support any new system with an appropriate and cost-effective set of maintenance services.	⇔	⇔	⇔	⇔
Legend	✪ - Building block option inherently meets identified requirement ⊙ - Building block option could meet identified requirement depending on implementation ☒ - Building block option inherently cannot meet identified requirement ⇔ - Building block option has no impact on identified requirement				
Summary	**We recommend the VHF frequency band for TCSO and TCPW because:** **a) Has better propagation characteristics in the open and rural terrain that is the majority of the service area of TCSO and TCPW. The overall effect of a VHF-based is one that will need fewer base station sites (and will therefore cost less) than will a system that uses another band.** **b) It has the same band as used by TCSO's and TCPW's neighbors/partners and will therefore allow easier methods of interoperability with them, and** **Because VHF is an unstructured band, its use carries with it the challenges of finding and licensing pairs of frequencies that have adequate spacing between transmit and receive. This may limit the total number of channels that can be deployed in a replacement or upgraded system.** **We also recommended the continued use of UHF for TRAX because it has many of the same propagation characteristics as VHF but frequencies can be easier to acquire and it could allow reuse of existing TRAX equipment.**				

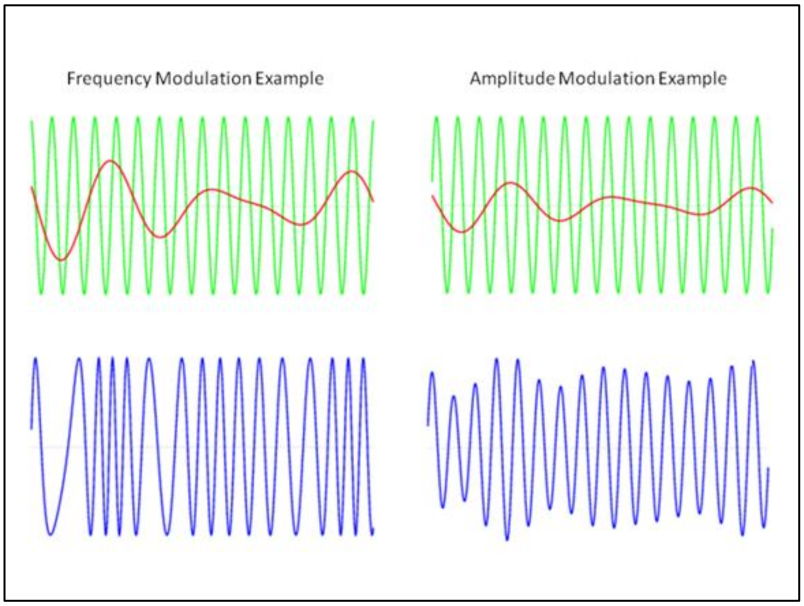
4.3. Modulation Method

Radio waves can be made to carry information by varying a combination of the amplitude, frequency or phase of the wave through a process called modulation. Put another way, modulation refers to the method used to encode voice and/or data information onto a frequency or channel so that information can transmitted. There are many variations in the way this is accomplished but they generally fall into either an analog or digital method.

4.3.1. *Analog Modulation*

Analog modulation takes an audio waveform, like the human voice or discrete tones, and directly imposes it on a carrier signal (i.e., onto the transmission frequency). There are two main types of analog modulation in use today on public safety radio systems: Amplitude Modulation (AM) and Frequency Modulation (FM). AM is a modulation type in which the amplitude of the carrier signal is modified, and FM is a modulation type in which the frequency of the carrier signal is modified as shown in the figure below. FM is predominantly used today over AM in radio telecommunications, due to its greater ability overcome noise due to interference and signal loss.

Frequency and Amplitude Modulation



To a large degree, analog modulation is capable of carrying only voice signals but it can also carry low-speed data if that data is translated into tones that are in the audible range. This technology works by transferring low-speed data (1,200 baud) in short bursts that occur either at the beginning or end of transmissions. Examples of tone-based data transmissions on analog modulation include short or "bursty" data such as a radio's identification number, an emergency signal, and the alert tones used by pagers or siren systems. For these burst-data signaling features (which are typically referred to be a trade name of MDC1200) to be functional, radios and dispatch consoles must be capable of and programmed for their use. (As expressed in prior reports, we understand that while most TCSO radios are capable of operating with MDC1200 functionality, very few radios are programmed to do so. Also, per input from users, as described below, users generally do not view MDC1200 features as critical to their operations.)

4.3.2. *Digital Modulation*

Digital modulation takes a waveform (audio voice or data signals) and encodes it into a digital bit stream of 1's and 0's. The way that it is encoded is a function of the voice coder, commonly known as the vocoder. The vocoder of today typically has a digital signal processor (DSP) coupled with an algorithm to detect human voice and parse it into specific phonemes each with its specific code. The voice information is condensed into a series of codes that are encapsulated in packets and transmitted. A vocoder at the distant station has the same code dictionary and is able to reconstruct the voice for reception by the receiving party. These codes are much more compact than a complete digital representation of the voice so the bandwidth required to send vocoded voice can be greatly reduced.

Once the voice information is encoded into a digital format, the information can then be modulated onto the carrier frequency. This is typically accomplished by using some form of shift keying in which some attribute of the transmission frequency is quickly shifted between different values so as to represent different combinations of digital 1's and 0's. (The attributes that can be shifted in digital modulation include Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), or methods that combine multiple types of shift keying like Quadrature Amplitude Modulation (QAM) which combines phase and amplitude shift keying. The method chosen for modulation is typically dependent on the data rate desired and relative distance desired for propagation.) In a similar way, data can be transmitted and received by directly using digital shift keying modulation, without the need to translate that data into tones.

4.3.3. *Analog & Digital: Pro's and Con's*

The basic technique of analog frequency modulation has played such a dominant role in public safety radio communications since the inception of the industry that it has become the legacy standard for technology. Analog frequency modulation is typically the 'default' technology built into radio equipment and it is generally supported as the 'common denominator' among vendors of all user radios.

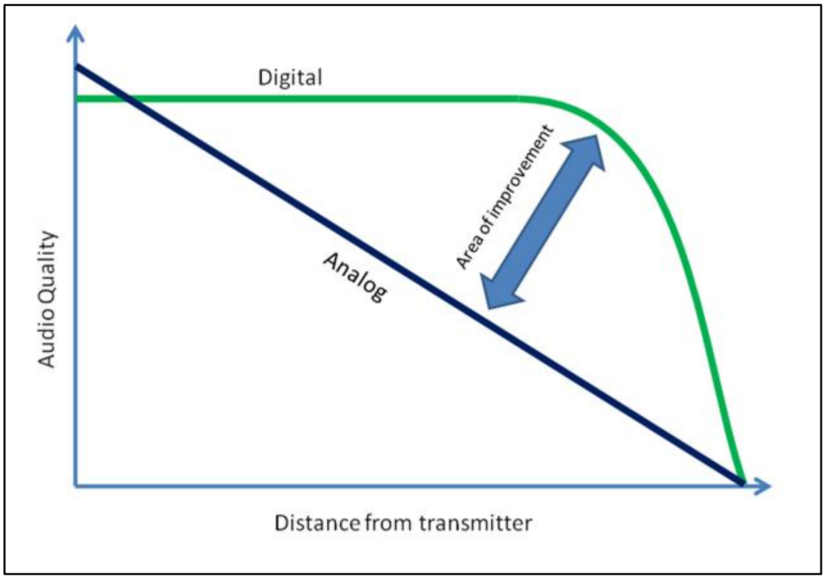
The primary advantage of analog modulation over digital modulation is its simplicity in implementation in electronic circuitry. Common electronic components can be used to make circuits to encode or decode voice or tones whereas modern forms of digital modulation require some level of digital signal processing and vocoding to implement. This means that analog radio can be less costly than digital radios.

Another advantage of analog modulation is the fidelity of the signal. Signals can be reproduced with a high degree of fidelity given the proper amount of bandwidth. Modern digital modulation techniques are optimized for voice processing and have difficulty processing tones and noises other than speech.

However, this same requirement for bandwidth to faithfully reproduce signals is also a disadvantage of analog modulation techniques. Nearly all modulation methods that are capable of faithfully recreating human voice in a 6.25 kHz channel are digital (although no such mandates have been established, future FCC actions may force channels in the bands used by public safety to further "narrowband" to such bandwidths).

Another disadvantage for analog modulation is the accumulation of noise as the signal is modulated, transmitted, received, and demodulated. Each one of these stages introduces noise into the signal. Once noise is introduced into an analog modulated signal it cannot be removed. Therefore, analog signals degrade linearly with the distance they travel. On the contrary, while digital signals may accumulate noise as they travel from their transmitter, they will continue to represent their pattern of 1's and 0's until the point that they become totally overcome with noise, usually past the point at which an analog signal becomes indistinguishable from the noise itself. In other words, the quality/intelligibility of an analog signal degrades slowly as the signal gets weaker (i.e., as the distance between transmitter and receiver increases) while the quality/intelligibility of a digital signal remains high until a point that the signal becomes too weak and then it very quickly degrades. This is shown in the following figure.

Digital vs. Analog Audio Quality



Digital modulation techniques also typically use some form of forward error correction. Error correction allows digitally modulated signals to correct the received bit stream. Error correction provides a more consistent audio quality up until the point where the number of errors is too great such that the received signal can no longer be corrected and the received signal rapidly becomes unintelligible. This can further enhance digital's ability to faithfully reconstitute its original signals from its 0's and 1's, even with great distance from the transmitter.

The ability of digital modulation to be less susceptible to noise, and its use of error correction methods to reconstruct an original signal even when noise is present, typically result in digital modulation producing radio coverage over a greater area than analog modulation (for a given and common level of audio quality).

A further advantage of digital modulation is its inherent abilities to carry data information. Whereas analog modulation must convert the 1's and 0's of a data stream to an analog audio signal ("tones") for transmission and then reconvert the received signal from audio to data, the entire stream can be maintained as data in a system that employs digital modulation.

4.3.4. *Project 25 – The North American Standard for Digital Radio for Public Safety and Public Service*

The public safety radio industry includes numerous technology standards that define common interfaces and signaling formats between and within various parts of voice and/or data radio systems. Some standards are old and some are emerging; however, in general, selecting a radio solution that adheres to a set of protocols that are open and shared among many vendors can produce a system that is more cost effective and more interoperable than a solution that is closed or supported by only one (or few) vendors.

Project 25 (P25) is a suite of standards for digital two-way radio systems. It was developed primarily for use by federal, state/province, and local public safety agencies in North America. It is an open digital radio standard specified by the American National Standards Institute (ANSI) as TIA-102. Products built to the

P25 standard also comply with the U.S. Federal Communications Commission (FCC) mandates for the use in 12.5 kHz narrowband systems covered by Part 90 regulations.

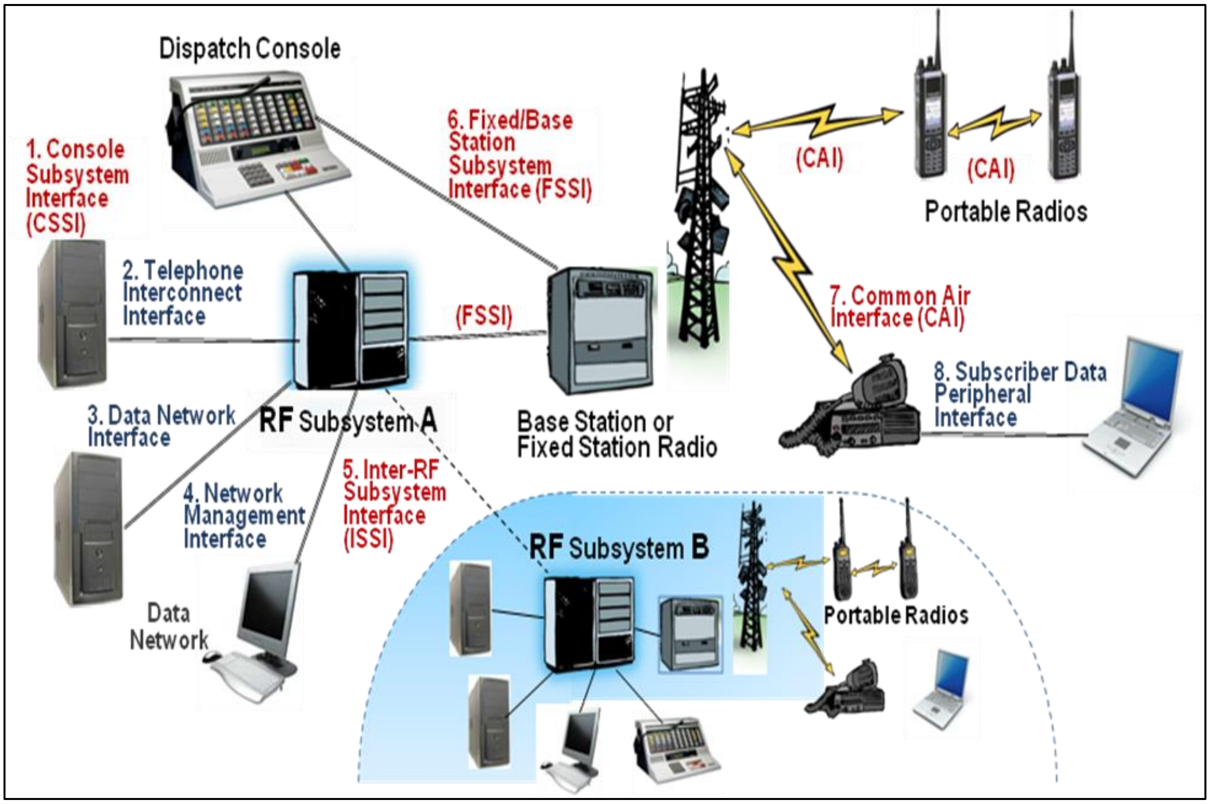
The Association of Public Safety Communications Officials (APCO) recognized the need for a user driven digital radio standard to meet impending narrowbanding standards while still meeting public safety needs for feature sets, competitive procurement, interoperability, and audio quality. To develop this standard, APCO started Project 25 which built upon lessons learned from a previous standard development effort, Project 16 (analog trunking), which was based on functional requirements. Project 25 incorporates technical as well as functional requirements for narrowband digital operation.

The P25 standard encompasses eight interfaces that cover the basic system components for public safety communications, they are:

1. Console SubSystem Interface (CSSI) – the connection between dispatch consoles and the radio system
2. Telephone Interconnect Interface – the connection between a phone network and the radio system
3. Data Network Interface – the connection between a data network and the radio system
4. Network Management Interface – the connection between network management applications and the radio system
5. Inter RF-SubSystem Interface (ISSI) – the connection between different radio systems
6. Fixed Station Subsystem Interface (FSSI) (also known as the Digital Fixed Station Interface (DFSI)) – the connection of base stations to other parts of the radio system
7. Common Air Interface (CAI) – the connection between user radios and the system
8. Subscriber Data Peripheral Interface – the connection between data terminals and user radios

These interfaces are shown the figure below and the standards that define them allow manufacturers to develop individual products and systems whose components can be interchanged while still providing overall system functionality.

Project 25 Suite of Standard Interfaces



All Project 25 over-the-air transmissions are digital but the development of standards has been split into two phases. Phase I was developed and released first and it addressed the Common Air Interface (CAI) and conventional and trunked FDMA[3] systems operating at 12.5 kHz bandwidth. Phase II came later and it addressed a CAI of 6.25 kHz TDMA[4] for trunked systems as well as the Inter Sub-system Interface (ISSI) and Console SubSystem Interface (CSSI), the Digital Fixed Station Interface (DFSI), and the Inter-RF SubSystem Interface (ISSI). The other interfaces (#'s 2-4 and 8) listed above and shown in Figure 5 remain incomplete.

It is important to note that a requirement of CAI Phase II is backwards compatibility to Phase I. This means that a Phase II system can operate in a mixed-mode configuration of Phase I FDMA and Phase II TDMA.

[3] FDMA, or Frequency Division Multiple Access, is method to allow more users to access a given amount of spectrum by dividing the bandwidth of one channel into multiple channels (i.e., one 25kHz channel is made into two 12.5kHz channels). This method of allowing more users to access the same amount of spectrum is relatively easy to implement; however, it can lower the signal-to-noise ratio of transmitted signals thereby increasing the probability of interference from other channels as well as reducing the distance over which a transmission can carry a usable signal (i.e., it can result in smaller areas of reliable coverage).

[4] TDMA, or Time Division Multiple Access, is another method to allow more users to access a given amount of spectrum; however, it divides a channel into different time slots and radios transmit only in the time slot allocated to them by the system. This method accommodates additional users by reducing the amount of time allocated to each individual user. TDMA requires a highly synchronized network such that field units know when to transmit and when to receive, thereby requiring user radios to always be able to hear the base station infrastructure to maintain synchronization. TDMA systems do not work in a simplex or direct unit-to-unit mode.

Also, most radios that support P25 digital transmissions (of either Phase I or Phase II modes) also support analog signaling. This allows a P25-capable radio to use analog channels when needed.

The P25 standard for CAI defines feature requirements; however, it requires some to be offered as mandatory while allowing others to be offered as options. If a feature is mandatory, it must be included in all equipment that is marketed as compliant to P25 standards. If a feature is optional, it may or may not be included (and, if included, it may be at additional cost) but when offered it must comply with P25 standards. Below is a partial listing of features that are mandatory and optional in P25 systems:

- Mandatory
  - Broadcast Voice Call
  - Group Voice Call
  - Individual Voice Call
  - Registration
  - Roaming
  - Analog Mutual Aid (Subscriber Feature)
- Optional
  - Individual Voice Call
  - Call Interrupt
  - Discreet Listening
  - Emergency Message/Call
  - Radio Unit Monitoring Remote Monitor
  - Talking Party Identification
  - Call Alerting
  - Short Messaging
  - Radio Unit Disable/re-enable
  - AES encryption of voice

There are also additional mandatory and optional features related to the over-the-air rekeying (OTAR, or the sending of key-management commands to a radio over the radio channel) for those radios that use AES encryption of voice.

P25 is available in many of the public safety radio bands used in the U.S. including VHF, UHF, 700MHz, and 800MHz and there are many manufacturers of P25-compatible equipment. A P25 Compliance Assessment Program (CAP) has been established to verify conformance with the P25 standard and interoperability with the various manufacturers' radios. The P25 CAP program is a voluntary program that allows P25 equipment suppliers to formally demonstrate their products' compliance with a select group of requirements within the suite of P25 standards. The purpose of the Program is to provide emergency response agencies with evidence that the communications equipment they are purchasing meets P25 standards for performance, conformance, and interoperability. Equipment that has successful completed it receives an accompanying publication of a Supplier's Declaration of Compliance (SDOC)[5].

P25 also has specific relevance to law enforcement operations in California. In late 2020, the California Department of Justice released Information Bulletin 20-09-CJIS which addressed the subject of "Confidentiality of Information from the California Law Enforcement Telecommunications System (CLETS)". This required agencies to submit to the CA DOJ, CLETS Administration Section by no later than December 31, 2020, a plan for implementation of for either: i) encrypting radio calls that carry Personally Identifiable Information (i.e., information that identifies an individual such as name and driver license number) or ii) policies to restrict access to combinations of Personally Identifiable Information (e.g., transmit such information in multiple, separate radio calls). As P25 includes an optional capability for AES-encrypted calls, use of P25 is a common method of achieving compliance with the first option. We understand that the

[5] SDOC's are generally available from vendors but are formally published at https://www.dhs.gov/science-and-technology/approved-grant-eligible-equipment

TCSO has already implemented the second option and while it requires no new technology or changes to equipment, it does impose operational inconveniences. Therefore, P25 should be considered by TSCO for inquiry operations (on a channel other than the primary/dispatch channel).

4.3.5. *Other Digital Radio Standards*

There are other standards for digital radio systems but none of them have been specifically created for the North American public safety market.

Digital Mobile Radio (DMR) is an open digital radio standard that was specified by the European Telecommunication Standards Institute (ETSI). Products built to the DMR standard also comply with the U.S. Federal Communications Commission (FCC) mandates for the use in 12.5 kHz narrowband systems covered by Part 90 regulations. ETSI's primary goal for DMR was to specify a digital system with low complexity, low cost, and interoperability across vendors to provide a solution for business and industrial radio users. While DMR has significant deployments in the US, it does not support the features most often required by public safety (as does P25). The system currently used by TRAX utilizes DMR technology and DMR's capabilities for data could be used by TRAX (and others in Tehama County) for transmission of information such as GPS-based location services.

Also available is Terrestrial Trunked Radio (TETRA), formerly Trans-European Trunked Radio. It is a suite of standards developed primarily for use by country, state/province and local public safety agencies in Europe. It is also an open digital radio standard specified by ETSI. TETRA is a TDMA standard which provides four user slots within a 25 kHz channel. Although its current emission mask does not permit its use in the United States it would meet bandwidth requirements for 6.25 kHz efficiency. TETRA has had very limited deployment in the US and, where it has been used, it is most often by organizations in the transportation, utilities, manufacturing, and energy industries.

NXDN (Next Generation Digital Narrowband) is a technical protocol for mobile communications. Although technically not an open standard (i.e., it is not a standard governed by a standards body like ETSI or TIA), NXDN is a set of proprietary, but open protocols that have been jointly developed by Icom Incorporated and Kenwood Corporation. Like DMR systems, the goal for NXDN was for systems with low complexity, low cost, and interoperability across brands. The NXDN protocol is intended for business and industrial users and smaller public safety communications systems in the United States; however, its deployment is not as widespread as is that of Project 25.

4.3.6. *Comparison of Modulation Options*

The following table shows how each of these building-block options meets (or does not meet) the Carry-Forward requirements for an upgraded or replacement system for TCSO, TCPW, and TRAX:

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Analog (w/ Bursty Data)	P25 Digital	Other Digital
Sites	Sites improved or constructed to standards for grounding, line routing, power, and rack bracing.	⇔	⇔	⇔

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Analog (w/ Bursty Data)	P25 Digital	Other Digital
Coverage	Existing coverage maintained and improvements made to "corners" of county.	◉	◉	◉
	Also, coverage be as countywide as possible (minimize channel-changing based on location).	◉	◉	◉
Interop	Maintain existing high levels of interoperability among TCSO and its neighbor/partner law-enforcement agencies.	✪	☒	☒
	Increase interop between TCSO, TCPW, and TRAX, if possible.	◉	◉	◉
Features	Deploy/support GPS-based location services.	☒	◉	✪
	Add Radio ID, Emergency, and Encryption for TCSO.	◉	✪	✪
	Add Scan for TCPW.	◉	◉	◉
	Add Short/Canned Messages for TRAX.	☒	◉	◉
Capacity	Add a 2nd countywide/repeated channel for TCSO (for tactical operations) and for paratransit (separate from fixed-route).	◉	◉	◉
	Add a "local government" channel.	◉	◉	◉
User Eqpt	Replace the existing TCSO dispatch consoles with supported equipment that meets needs for features.	⇔	⇔	⇔
Support	Support any new system with an appropriate and cost-effective set of maintenance services.	⇔	⇔	⇔

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Analog (w/ Bursty Data)	P25 Digital	Other Digital
Legend	✪ - Building block option inherently meets identified requirement ⦿ - Building block option could meet identified requirement depending on implementation ☒ - Building block option inherently cannot meet identified requirement ⬄ - Building block option has no impact on identified requirement			
Summary	**We recommend the continued use of analog modulation for TCSO dispatch and TCPW in order to ensure continued interoperability with each other and with neighboring/partnering local-level law enforcement, fire, and public works agencies.** **TCSO's use of P25, with its capabilities for encryption, will meet the need for protecting personal information for radio inquiry calls.** **We recommend the continued use of DMR for TRAX as it will allow reuse of existing in-vehicle radios. Also, DMR's ability to support data messaging will TRAX to use that capability for a future intelligent bus transit system application (to relay information such as bus location, etc.). DMR could also be used by TCSO and TCPW to exchange GPS-based location services.**			

4.4. Site Configuration

Site Configuration refers to how a system uses varying numbers of sites to provide coverage over a wide area.

4.4.1. *Single Site*

A single-site system is, as its name implies, a system that utilizes only one transmitter (or repeater) site. The coverage of that system is defined by (and limited to) the coverage of that single site. Should that coverage not be sufficient, configurations of multiple sites, such as multicast or simulcast as described below, may be employed to serve a larger operational area. Currently, TCPW and TRAX each use a single-site system (TCPW has one site at Inskip Butte and TRAX uses the subscription-based system with a site at Cohasset Ridge.)

4.4.2. *Voting and Multicast*

Voting systems add sites that have only receivers (called "receive-only" sites) to a single site configuration. Those receive-only sites send the signals they receive from user radios to equipment called "voters" that analyze all of the received signals, select the one of best signal quality, and provide that to the transmitter site for broadcast to the user radios.

Multicast is a process in which multiple repeaters, in different locations, are linked together to form a wide-area seamless network. Each repeater in the system has a different transmit frequency but the same receive frequency. When a user radio transmits, repeaters within range of that user receive that signal and send the received audio to a voter which, as described above, selects/votes the one with the best quality. That "voted" signal is sent to all repeater sites for retransmission. Since each repeater in the system has a different transmit frequency, radio users have to know which repeater site to turn to based on their location. (Alternatively, the user radio itself can perform that function based on the strength of the received signal, depending on the model of the user radio. This feature, known as vote-scan, is described in more detail below.)

Multicast is relatively easy to implement at a system level; however, finding enough frequencies to make a cohesive system can be difficult, particularly in metropolitan areas.

4.4.3. *Simulcast*

Simulcast is similar to multicast in that it uses distributed repeaters and voters to receive and select user messages from across a wide area and to select one as the "best" but it adds the additional functionality of retransmitting the selected audio signal from all repeaters on the same frequency. In order for this to work without the multiple transmissions on the same frequency causing interference to each other, simulcast systems require tight design and control of the transmitted signal such that it appears to the receiving user radio as if it came from one transmitter. Three aspects of the transmitted signal require control and they are amplitude, phase, and frequency stability – achieving interference-free performance of all of them imposes specialized hardware at each site which increases the overall cost of a simulcast system.

Control over these aspects also involves optimizing the locations at which signals arrive (from multiple sites) without interfering with each other. This means that designing a simulcast system can often be an iterative process – an initial attempt to impose control methods can cause interference in one area while tweaks to the design can results in that interference being moved to another location. The result; however, is that when simulcast is designed and implemented appropriately, it can provide excellent coverage (including in-building coverage) over a large area because a user radio can receive the same broadcast signal from multiple sources.

The area served by a single simulcast system; however, can be limited due to the possibility of the multiple signals generated from many sites that are geographically separated by very large distances arriving at a user radio and producing destructive interference (i.e., out of phase). For simulcast to operate properly (i.e., in order to deliver intelligible audio to users), sites must be located within specific distances from each other. This maximum site-to-site distance depends on the modulation method used but is typically between 8 miles (for digital modulation methods) and 15 miles (for analog modulation). Greater site-to-site distances can be achieved through advanced design and implementation methods that direct signals in such a way as to 'move' the destructive interference to acceptable location. Such methods can allow site separation of up to 20 miles and they include use of highly directional antennas and by delaying (for durations as short as microseconds) the transmission of signals from specific sites.

Simulcast does have the advantage of conserving frequencies while serving a very large service area. Also, it does not require intelligence in the user's radio to select a site since the composite received signal from all simulcast sites arrives to the radio on a single frequency. Simulcast is effective in situations where frequencies are scarce and an organization must either serve a large service area or must provide a high level of signal strength to deliver sufficient radio coverage to handheld (portable) radios that operate inside of buildings. Simulcast systems can be trunked or conventional and analog or digital.

4.4.4. *Comparison of Site Configuration Options*

The following table shows how each of these building-block options meets (or does not meet) the Carry-Forward requirements for an upgraded or replacement system for TCSO, TCPW, and TRAX:

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Single Site	Voting/Multicast	Simulcast
Sites	Sites improved or constructed to standards for grounding, line routing, power, and rack bracing.	⇔	⇔	⇔
Coverage	Existing coverage maintained and improvements made to "corners" of county.	⊙	✪	✪
	Also, coverage be as countywide as possible (minimize channel-changing based on location).	☒	✪	✪
Interop	Maintain existing high levels of interoperability among TCSO and its neighbor/partner law-enforcement agencies.	⇔	⇔	⇔
	Increase interop between TCSO, TCPW, and TRAX, if possible.	⇔	⇔	⇔
Features	Deploy/support GPS-based location services.	⇔	⇔	⇔
	Add Radio ID, Emergency, and Encryption for TCSO.	⇔	⇔	⇔
	Add Scan for TCPW.	⇔	⇔	⇔
	Add Short/Canned Messages for TRAX.	⇔	⇔	⇔
Capacity	Add a 2nd countywide/repeated channel for TCSO (for tactical operations) and for paratransit (separate from fixed-route).	⇔	⇔	⇔
	Add a "local government" channel.	⇔	⇔	⇔
User Eqpt	Replace the existing TCSO dispatch consoles with supported equipment that meets needs for features.	⇔	⇔	⇔

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Single Site	Voting/Multicast	Simulcast
Support	Support any new system with an appropriate and cost-effective set of maintenance services.	⬄	⬄	⬄
Legend	✪ - Building block option inherently meets identified requirement ⦿ - Building block option could meet identified requirement depending on implementation ☒ - Building block option inherently cannot meet identified requirement ⬄ - Building block option has no impact on identified requirement			
Summary	**We recommend the continued use of voting/multicast and/or simulcast for TCSO as that agency uses portable (handheld) radios and regularly operates inside of buildings. The coverage benefit from multiple sites will address TCSO's requirements for coverage improvements.** **We recommend the continued use of single sites for TCPW and TRAX as those agencies primarily use mobile (in-vehicle) radios which, generally, can be served by one well-placed site.**			

4.5. Channel and Site Access Methods

Channel and Site Access refers to the method by which users or radios select the frequency (channel) and site on which they operate to talk to others.

4.5.1. *Conventional Systems*

Conventional systems could be considered the most basic of radio operations in which two or more users have a dedicated frequency (or channel) to which they are tuned and on which they operate. When a user needs to communicate with the other user, the first user simply selects the channel they wish to talk on and then presses the "push-to-talk", or PTT, button on their radio and begins speaking. By pressing his PTT, the user activates the radio's transmitter and the radio converts the user's voice through the modulation process into a radio wave that transmits through the air. Radios at the distant end that are tuned to the same channel will receive this signal, demodulate it, and emit the spoken voice from a speaker in the radio.

Conventional systems users can communicate directly radio to radio, which is also known as simplex operation. In simplex operation both units transmit and receive on a single frequency and do not require intermediate infrastructure to operate.

Repeated operation is also used in conventional systems. In a repeated system, two frequencies are required, one is the repeater station's receive frequency and one is the repeater station's transmit frequency. An initiating user transmits on the repeater station's receive frequency, the repeater station receives it, the repeater station immediately (instantaneously) rebroadcasts the initiating user's message on the repeater station's transmit frequency, and the receiving units receive that message if they are tuned to the repeater station's transmit frequency.

A conventional system may be deployed with more than one site – it may use voting/multicast or simulcast site configurations to provide coverage over a wide area. If the system uses multicast, then there must be some method to ensure the user selects the best site to provide coverage based on their location. The first such method is manual user selection – the user of the radio selects both the channel and the site based on who they wish to speak with and their location. While this method does impose decision-making operations on the part of the radio user, it can be simplified in cases where there is a natural boundary between the areas of the system's sites (such as a major highway or a geographic landmark).

[NOTE: A conventional system that uses manual site selection can also deploy a secondary technology so that the various sites can use the same pair of frequencies. This method is called Continuous Tone-Coded Squelch System (CTCSS, often also referred to "Private Line" or "PL" which is a marketing term used by one equipment manufacturer) and it uses subaudible tones to differentiate transmissions among several sites that operate on the same set of frequencies. If a repeater at a site is programmed to operate with a CTCSS tone, when it receives a transmission from a subscriber, it will determine if that transmission carries a matching CTCSS tone. If the transmission from the user carries a tone that matches the repeater's, then the repeater will repeat the transmission (and if it does not, the repeater will not repeat it). In this way, a user can select the combination of one CTCSS and one frequency pair to transmit to/from one site and another CTCSS tone to transmit to/from on another site on the same frequency pair. The drawback to this method is it leaves open the possibility for interference between any sites transmitting on the same frequencies. If one site begins to repeat a transmission that has it's CTCSS tone at the same time that another site begins to repeat a transmission, on the same frequency, that has it's CTCSS tone, any subscriber radio that, based on its location, can receive signals from both sites will receive a mix of unintelligible audio. The use of CTCSS is currently in use on the TCSO main channel – the sites at Inskip Butte and Rancho Tehama use the same frequencies but different CTCSS tones. Because of the separation between those two sites and because few TCSO officers actually use the Rancho Tehama site, there have not been significant complaints of interference.]

For the most part, in conventional systems, the user must know and must select the channel they wish to use to talk to others. An alternative to forcing the site-selection process in a voting/multicast system onto users is called "vote-scan" and it places the responsibility for selecting the best site on an algorithm in the user radios. Not all radio models support vote-scan but those that do are configured to know which frequencies in the system are cooperatively deployed to carry the same conversations. Such radios then continuously (and quickly) scan for transmissions on those channel and switch to the one that provides the best signal. This can be a very effective way for a radio to be in control of which site/channel it has selected if there are regular and frequent transmissions from all of the available sites/channels. If; however, a site/channel is silent for prolonged periods, then a radio that is near it will not have the opportunity to sample its transmissions and it may miss out on an opportunity to switch to it.

There is a third method of site selection called "geo fencing" that is only available in a few models of radios from a select set of vendors. In "geo fencing", a radio is equipped with a GPS receiver and it uses GPS coordinates to know its location. That radio is also programmed with information that directs it to use specific sites based on its location (i.e., if it's GPS coordinates are inside a "fence" for Site 1, it should use Site 1).

For example, if Site 1 uses Frequency Pair A to carry the "Police Dispatch" channel in the north portion of a city and if Site 2 uses Frequency Pair B to carry that same channel in the south part of a city, then:

- If manual user selection is deployed, users will need to know if they are in the north or south part of the city and select Frequency A or Frequency B to get the best coverage for the "Police Dispatch" channel. Again, this can be made easier if there is a clear and easily recognized boundary between the south and north parts of the city.
- If vote-scan is deployed, user radios will sample transmissions on both Frequency A and Frequency B when/as they occur and select the corresponding site based on the strength of the signals received from Site 1 and Site 2.
- If geo-fencing is used, user radios that are equipped with GPS receivers and configured for geo-fencing operations will select Site 1 if they are within the pre-defined fence of the north side of the city and they will select Site 2 if they are within the south-side's pre-defined fence.

Because geo-fencing is so limited in its availability among models of radios, it will not be considered further in this report.

Systems that use simulcast technology do not need any method for site selection. In such systems, all sites are broadcasting the same transmissions on the same frequencies. As described above, this is done by using additional system control equipment and in order to extend coverage over a large area and to do so without imposing operational or technical complexities onto the users or their radios. Recall; however, that for simulcast to operate properly, sites must be approximately 8 to 15 miles from each other (or at greater distances, with advanced system design methods).

4.5.2. *Trunked Systems*

Trunked systems utilize computerized control to manage a group of repeater channels. Users select among various radio "talkgroups" which act as virtual channels and which segment users into groups that require participation in common conversations.

When a user in a trunked system wishes to relay a message to the group, he selects a talkgroup on their radio and then presses his user radio's PTT. His radio will then send in a request over a dedicated "control" channel to the trunked system's computerized controller. The controller reviews which channels are active and inactive and, if a channel inactive/available, the controller assigns that channel to the talkgroup. The controller notifies every other user radio that has selected the same talkgroup to tune to the assigned channel and notifies the original requester that the channel is ready and available. All of this call-setup activity occurs via the "control" channel (typically within 250 milliseconds) and it does not require any other action by the user other than to choose a talkgroup and press the radio's PTT button.

The users then have use of that channel until the conversation ends. The conversation is considered complete when no other users in that talkgroup continue the conversation. Once that happens, the controller notifies all radios to tune to the control channel to await further calls. Meanwhile, the channel they were previously using reverts back to the pool of inactive/available channels.

The primary purpose of the trunked system is to promote efficiency; many people can carry many conversations over only a few distinct frequencies. In large conventional systems, there may be repeaters that are lightly used which stand idle for a large majority of the time where other repeaters are nearly always transmitting because the user groups that use them have high traffic volumes. Trunking systems eliminate this disparity by rotating all user conversations through all available repeaters.

Because trunked systems are always broadcasting signaling on their control channels, the process of site selection is significantly simplified in multi-site systems. Radios that operate on trunked systems are programmed with the control channels of all sites in the system and they constantly perform a trunked-system version of vote-scan function on that list of control channels. This happens quickly as each site is continuously transmitting signals (on their control channels) so user radios have a constant supply of signals to sample and vote. Manual site selection is not needed in trunked systems.

Trunked systems can also be deployed in simulcast configurations; however, that technology is more often deployed when frequency availability is scarce and not in order to simplify the site selection process.

4.5.3. *Comparison of Channel and Site Access Options*

The decision to develop a conventional or trunked system typically comes down to the number of groups and users the system will have to support. Since trunked systems typically cost more to initially deploy than conventional systems (due to the addition of the control computers), resulting in a higher cost-per-unit served, some smaller organizations may not be able to justify such a system. To the corollary, at some point, the cost of developing standalone conventional systems for each user group that requires can cost more than a consolidated trunked system.

The decision to use multicast or simulcast for the system topology is typically dependent on the number of frequencies available and the size of the service area to be covered. As with trunking, a simulcast system includes higher costs for all of the equipment required to control the amplitude, phase, and frequency stability of the transmitted signals. The distance between sites is also a factor as simulcast imposes limited on the separation between sites.

The options for site selection can be applied to a system design in combinations of the choices available. For example, one group of sites may meet site-distance requirements to operate in together in a simulcast configuration (also referred to as a "simulcast cell") in the same system as another site (or set of sites), whose distance is too far from the initial set to be included in the "cell". In such cases, the technologies of vote-scan and/or manual select are also deployed so users access the best site or simulcast "cell".

For a large service area in which many users will operate but in an area where frequencies are scarce, a trunked simulcast solution may be the best choice. For a limited service area over which a moderate number of users will operate and over which frequencies are limited but somewhat available scarce, a trunked or conventional single-site or multicast system may be sufficient. For a large service area with a small set of users, a conventional system with simulcast and/or multi-cast sites may be the optimal choice.

The following table shows how each of these building-block options meets (or does not meet) the Carry-Forward requirements for an upgraded or replacement system for TCSO, TCPW, and TRAX:

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact					
		Conventional				Trunked	
		Single Site	Multi-Cast Manual	Multi-Cast VoteScan	Simulcast	Single-Site	Simulcast
Sites	Sites improved or constructed to standards for grounding, line routing, power, and rack bracing.	⇔	⇔	⇔	⇔	⇔	⇔

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact					
		Conventional				Trunked	
		Single Site	Multi-Cast Manual	Multi-Cast VoteScan	Simulcast	Single-Site	Simulcast
Coverage	Existing coverage maintained and improvements made to "corners" of county.	⊙	✪	✪	✪	⊙	✪
Coverage	Also, coverage be as countywide as possible (minimize channel-changing based on location).	☒	☒	✪	✪	⊙	✪
Interop	Maintain existing high levels of interoperability among TCSO and its neighbor/partner law-enforcement agencies.	⊙	⊙	⊙	⊙	☒	☒
Interop	Increase interop between TCSO, TCPW, and TRAX, if possible.	⊙	⊙	⊙	⊙	⊙	⊙
Features	Deploy/support GPS-based location services.	☒	☒	☒	☒	⊙	⊙
Features	Add Radio ID, Emergency, and Encryption for TCSO.	⊙	⊙	⊙	⊙	✪	✪
Features	Add Scan for TCPW.	⊙	⊙	⊙	⊙	⊙	⊙
Features	Add Short/Canned Messages for TRAX.	☒	☒	☒	☒	⊙	⊙
Capacity	Add a 2nd countywide/repeated channel for TCSO (for tactical operations) and for paratransit (separate from fixed-route).	⊙	⊙	⊙	⊙	✪	✪
Capacity	Add a "local government" channel.	⊙	⊙	⊙	⊙	✪	✪
User Eqpt	Replace the existing TCSO dispatch consoles with supported equipment that meets needs for features.	⬄	⬄	⬄	⬄	⬄	⬄
Support	Support any new system with an appropriate and cost-effective set of maintenance services.	⬄	⬄	⬄	⬄	⬄	⬄

<table>
<tr><th rowspan="3">Topic</th><th rowspan="3">Radio System Carry-Forward Requirement</th><th colspan="6">Building Block Option & Impact</th></tr>
<tr><th colspan="4">Conventional</th><th colspan="2">Trunked</th></tr>
<tr><th>Single Site</th><th>Multi-Cast Manual</th><th>Multi-Cast VoteScan</th><th>Simulcast</th><th>Single-Site</th><th>Simulcast</th></tr>
<tr><td>Legend</td><td colspan="7">✪ - Building block option inherently meets identified requirement
⊙ - Building block option could meet identified requirement depending on implementation
☒ - Building block option inherently cannot meet identified requirement
⬄ - Building block option has no impact on identified requirement</td></tr>
<tr><td>Summary</td><td colspan="7">While the technologies of trunking and simulcast appear to have distinct advantages to addressing the needs of TCSO, TCPW, and TRAX, there are two concerns with them:
Trunking is very efficient if there are a large number of radio users (many hundreds to many thousands or more). In situations with fewer radio users, the cost of the additional equipment required by trunking can be prohibitive.
Simulcast can be used to provide simplified operations over a wide area but it requires sites to be within specified distances of each other (approx. 8 to 15 miles) to avoid interference (or at greater distances, with advanced system design methods). This limited site distance can require more sites (and more cost) than would otherwise be needed to provide reliable coverage to an area.
We recommend conventional systems for the sole reason that the agencies of TCSO, TCPW, and TRAX do not have large enough fleets of radio users to necessitate trunking technologies.
We recommend investigating the technologies of simulcast and/or vote-scan for their abilities to cover wide areas with simplified user operations. Manual site selection will also be investigated if the other options are not viable; however, geo-fencing will not due to its limited deployment among various vendors’ radios.</td></tr>
</table>

4.6. Console Interconnection Options

The method of connection between dispatch consoles and the radio sites has a significant impact on system operations and features available to dispatchers.

The two primary technical options that exist for connections between dispatch consoles and the radio sites are Control Station and Direct Wireline.

4.6.1. *Control Stations*

Control stations are car-based user radios that are equipped to operate in the environment of a desktop or an equipment room. Dispatch consoles can have connections to the control stations so that a dispatcher can control basic functions such as select a channel and transmit on the selected channel. In other words, a dispatcher can control the same functions of the radio as can the operator of a mobile radio. (Essentially, a control station enables a dispatcher to operate as a field user on an agency’s radio channel.) The control stations must be both: i) located in a reliable coverage area of the radio channel for which they are programmed and ii) connected by some method to equipment of the dispatch center that wishes to communicate on that radio channel. One dispatch console can be connected to many control stations so that the operator has access to many channels, likewise, one control station can be connected to many dispatch consoles so that all dispatchers share it as a common resource.

Control stations and consoles can work together to deliver the bursty-data features described above – the dispatch center creates and decodes the bursty-data tones used for features such as radio unit ID and emergency message and relays them to/from user radios through the control stations.

The main advantage of using control stations is cost-effectiveness. As radio sites are often at distant locations (mountain tops, roofs of tall buildings, etc.) and dispatch centers are often in population centers, a control station provides a link between them without need for additional interconnecting infrastructure. The detriment of control stations is that the dispatcher participates as a peer with all other radio users and does not have any ability for supervisory intervention.

4.6.2. *Direct Wireline*

The alternative to a control-station connection between radio sites and dispatch centers is a direct wireline connection. In this technology, some method of telecommunications connection is used to directly interface a dispatch console (or a center of dispatch consoles) to the radio sites (or set of system control equipment). The method of connection may be a wireline or wireless telecommunications circuit (leased phone line, fiber, microwave are all examples) but in all cases the electronics of the dispatch consoles have a direct interconnection to the equipment of the radio sites. In a single-site conventional system, the connection to the system is made directly to the repeater; in a conventional voted system, to the voter; in a trunked system, to the trunking system controllers.

Whatever method of connection is used, a direct connection enables the critical feature of dispatch priority. This feature allows dispatchers to interrupt any transmission from a user radio and override it with their audio. This feature can be valuable as dispatchers may have more information than field users. For example, a field user may start a transmission about the presumed location of a fleeing suspect but a dispatcher, informed by a 9-1-1 call, may interrupt that user’s transmission with a more up-to-date location.

The other immediate benefits of a direct connection can include clearer and more reliable audio between dispatchers and field users. Also, a direct connection may also enable other features, depending on the type of technology (analog, analog with bursty data, trunked, etc.) used in the system.

The signaling and technology of a direct connection can vary with the type of technology used in the radio system. Options include:

- Four wire connection: This is the most traditional method in which a four-wire, analog connection is made from a dispatch console (or network of co-located dispatch consoles) to a repeater station. The four wires, typically a four-wire phone circuit, carry the basic information of transmitted and received audio (and, if used, bursty data). This method is used in analog, conventional systems.
- Digital Fixed Station Interface (DFSI): This method is used in Project 25 digital conventional systems and it provides a digital-signaling based interconnection between the console(s) and the repeater stations. One direct connection is required between each dispatch console (or network of co-located dispatch consoles) and repeater station. Note that not all dispatch console or repeater products support DFSI.

- Console SubSystem Interface: This method is also part of the Project 25 standards and it can be used with both conventional and trunked technologies. Unlike DFSI connections, CSSI connections require one connection between the system infrastructure and the console network. This technology thereby simplifies the interconnection requirements between consoles and systems but it comes at the expense of additional system components to facilitate that connection.
- Proprietary Digital: Some vendors have implemented their own signaling interfaces between dispatch consoles and radio sites. These interfaces generally achieve the same outcomes as DFSI or CSSI but require that the console and radio site equipment be provided by the same vendor.

Dispatch consoles that use a direct connection to the radio system's site are often deployed with backup control station links that serve as a fallback method of communications between dispatchers and field users in cases where the direct connection should fail.

4.6.3. *Comparison*

The following table shows how each of these building-block options meets (or does not meet) the Carry-Forward requirements for an upgraded or replacement system for TCSO, TCPW, and TRAX:

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Control Station	Standards-Based Direct/Wireline	Proprietary Wireline
Sites	Sites improved or constructed to standards for grounding, line routing, power, and rack bracing.	⇔	⇔	⇔
Coverage	Existing coverage maintained and improvements made to "corners" of county.	⇔	⇔	⇔
	Also, coverage be as countywide as possible (minimize channel-changing based on location).	⇔	⇔	⇔
Interop	Maintain existing high levels of interoperability among TCSO and its neighbor/partner law-enforcement agencies.	⊙	⊙	⊙
	Increase interop between TCSO, TCPW, and TRAX, if possible.	⊙	⊙	⊙
Features	Deploy/support GPS-based location services.	⇔	⇔	⇔
	Add Radio ID, Emergency, and Encryption for TCSO.	⊙	⊙	⊙

Topic	Radio System Carry-Forward Requirement	Building Block Option & Impact		
		Control Station	**Standards-Based Direct/Wireline**	**Proprietary Wireline**
	Add Scan for TCPW.	⇔	⇔	⇔
	Add Short/Canned Messages for TRAX.	⇔	⇔	⇔
Capacity	Add a 2nd countywide/repeated channel for TCSO (for tactical operations) and for paratransit (separate from fixed-route).	⇔	⇔	⇔
	Add a "local government" channel.	⇔	⇔	⇔
User Eqpt	Replace the existing TCSO dispatch consoles with supported equipment that meets needs for features.	⦿	✪	⦿
Support	Support any new system with an appropriate and cost-effective set of maintenance services.	⇔	⇔	⇔

Legend

✪ - Building block option inherently meets identified requirement

⦿ - Building block option could meet identified requirement depending on implementation

☒ - Building block option inherently cannot meet identified requirement

⇔ - Building block option has no impact on identified requirement

Summary

We recommend the use of a standards-based direct/wireless interface between the dispatch consoles of TCSO and the radio system infrastructure as it will provide clear, reliable audio with the feature of dispatch priority. The exact signaling interface (4-wire, DFSI, CSSI) will depend on the selection of the technology of the radio system as will the other features supported. We also recommend the use of backup control stations for TCSO dispatch positions.

We recommend control stations for the less intensive operations involved with TCPW's and TRAX's dispatch centers. TRAX may; however, deploy a direct connection between their dispatch center and their radio system site(s) for the sake of a future intelligent bus transit system application and should that be available we recommend it also be used for voice radio operations.

4.7. Backhaul Options

Three general technology options exist for interconnecting radio sites to each other or for connecting radio sites to dispatch. They are leased line, T-Carrier, and Internet-Protocol.

4.7.1. *Leased Line*

A leased line is a telephone-grade circuit, usually procured from a telephone service provider, that is dedicated to the connection between two points. It is typically capable of carrying one analog voice conversation such as one 4-wire link between a dispatch console and a repeater. Leased lines can be generally reliable but they are also susceptible to noise and interference that can affect the quality of the audio signals they carry. Leased lines can also often incur high reoccurring costs.

4.7.2. *Microwave or Fiber T-Carrier*

When an interconnection between two points requires more capacity than one voice conversation or when it also involves data signaling (e.g., for communications between system controllers), a circuit-based link (also known as "carrier" or "T-carrier" technology) can be used. In this technology, audio is converted to a digital signal and then aggregated into a higher-speed data link for transport between two endpoints. At the distant end, the high-speed data is broken down into its composite signals and then converted back to an analog audio signal.

T-carrier connections establish and reserve each connection for each audio signal regardless of whether or not there is an active conversation; one audio-level circuit is required for each possible conversation and bandwidth is not shared among those conversation on an as-needed basis. T-carrier connections also require fixed routes to connect their endpoints. These characteristics of reserved bandwidth and fixed routes make T-carrier connections very stable; however, they can also be expensive and complex to deploy.

The two primary physical methods for transporting a T-carrier signal are microwave and optical fiber ("fiber"). Microwave uses a fixed-path wireless connection between two fixed locations that must have a clear line-of-sight between them. Obstructions between the endpoints, such as buildings or mountains, can preclude the use of a microwave link. Microwave links use frequencies in the ranges of 6 to 23 GHz and bandwidths in the ranges of single Mb/s to many Gb/s. Fiber requires the deployment of strands of optical fiber between the two endpoints and it can provide nearly unlimited bandwidth. In practice, two-way radio systems generally use microwave to reach remote (mountain top) sites and they can use either fiber or microwave (and sometimes a mix of both) to connect to sites in more populated areas.

4.7.3. *Microwave or Fiber Internet Protocol*

To improve the efficiency and to lower the cost of site links, radio system can use packet-based connections that use technology known as "Ethernet" or "Internet Protocol" (IP). Just like T-carrier connections, IP-based connections convert audio signals to digital streams but they then further convert the digital signal to a series of packets. Each packet is appended with an address of the destination endpoint and sent into a network that uses various routing methods to ensure that the packets arrive at their destination and are reassembled in the correct/original order. Packets are sent through the network only when there are audio conversations and the bandwidth of the network is shared among audio conversations as they occur. This ability to route information without the need to establish/reserve a distinct connection for each audio conversation make IP-based connections easier and less-costly to deploy.

When used in two-way radio systems, IP-based connections; however, must be designed to limit the degree of variability of different routes so that there is sufficient stability in the connection – this guarantees that parts of audio conversations are not delayed which could produce missed parts of words or could hold-up the start of a radio call.

Like T-carrier connections, IP-based connections can be carried via microwave or fiber.

4.7.4. *Backhaul Reliability Methods*

The physical transport methods of microwave and fiber connections are both generally highly-reliable; however, each is susceptible to outages. A microwave link can be disrupted by temporary obstructions (including, in some cases, heavy rain) or the failure the microwave wireless equipment (including the dish antennas or the transmission lines that connect the microwave radio to the antennas). A fiber link can be disrupted by the failure of the networking equipment at each end of the connection or damage to the fiber that actually interconnects the endpoints (e.g., disruption of the ground in which the fiber is buried).

There are three primary methods used to protect the integrity, and thereby increase the overall reliability, of microwave and fiber links. They are:

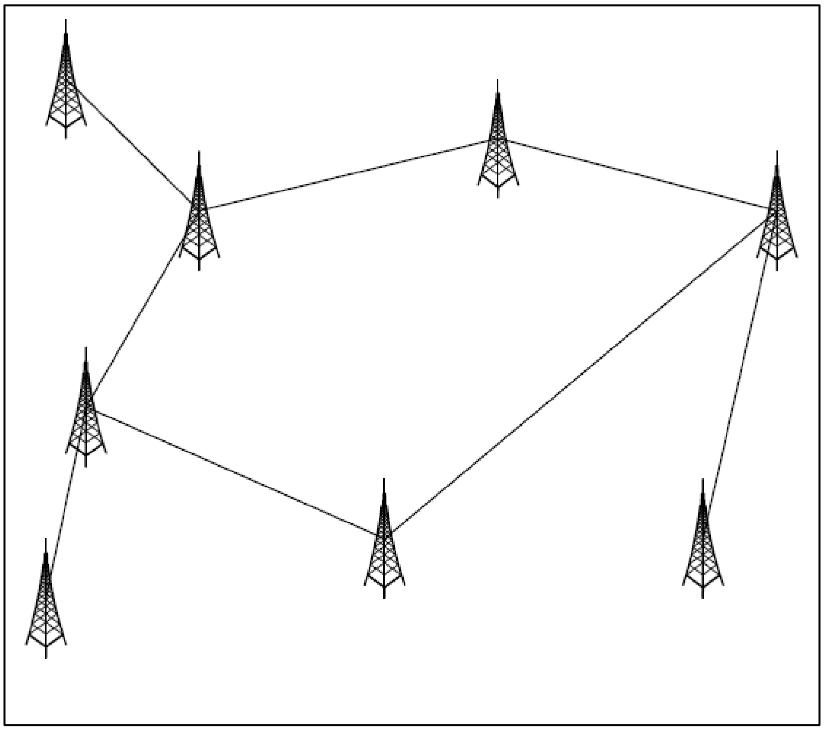
- Redundant equipment: In this method, each endpoint has two sets of microwave or fiber transmitters and receivers – only one set is used at any time but the backup set can be placed into service should there be a failure of the active set. The backup set may be configured to be always up-and-operational and automatically placed into use upon failure of the active set – this is called a hot-standby configuration (sometimes noted as "2+0"). Alternately, the backup set may be in a disabled state and manually activated for use only upon failure of the active set – this is called a cold-standby configuration (sometimes noted as "1+1"). In most cold-standby ("1+1") configurations using microwave, there is redundant microwave radio equipment but not redundant microwave transmission lines or antennas. The benefit of hot-standby is that a recovery from the failure of active equipment is automatic but it comes at the expense of additional equipment to monitor for and react to such a failure.

- Alternate fixed paths (ring topology): When multiple sites are connected by fiber and/or microwave, the connect-the-dots paths between them may be established in a line so that one site connects to another site which connects to another site and so on in a line. This topology is referred to as a series of "spurs". Alternately, the connect-the-dot pattern used to link sites may be drawn so that there is a circle (or similar closed shape) that includes all of the sites and so that every site connects to two others and there are no spurs. This topology is referred to as a ring and because each site has connections to two other sites and together the sites can use those alternate paths to maintain links to all sites should one site-to-site connection fail. For example, assume Sites A, B, C, and D are interconnected in a ring as follows: A connects to B which connects to C which connects to D which connects back to A. In this example, should a failure occur in the link between A and B, then B will remain linked due to its connection to C and A will remain linked due to its connection to D. Note that even in a ring network, cold- or hot-standby equipment redundancy may still be deployed in site-to-site connections that involve very important sites such as a link that connects to dispatch centers.

- Alternate dynamic paths (multiprotocol label switching): When a network grows very large and there is no simple way to interconnect the involved sites in a line or even a single closed-loop shape, the result may be a connect-the-dots pattern that resembles a mesh with multiple interconnected closed shapes (and, potentially, some spurs). In such cases, a technology known as multiprotocol label switching (or MPLS) can be used to enhance the reliability of the flow of signals among all the sites. MPLS is a complex technology that is used only in IP-based network and which, in short, applies additional delivery information ("labels") to each packet to ensure its delivery even through site-to-site networks that are large, complex, or of different underlying physical characteristics. When one endpoint in the mesh of interconnected sites transmits an MPLS-labeled packet, it simply broadcasts it out to the mesh-connected network of sites and the MPLS equipment at each site dynamically routes that packet to its destination. Two packets might travel different paths in their travels across the mesh-configured network. The MPLS labels also speed up the delivery of packets and they can enable levels of priority so that the most important packets incur the least delay in each link. MPLS is a very powerful technology but it is generally only needed in systems that have large quantities of sites and/or that have complex paths of interconnection ("mesh-shaped" connections).

The following diagram shows a set of sites that have a central ring and that have three spurs that interconnect to the ring. Such a network could make use of MPLS but it more likely that it will simply achieve reliability thought its topology as a ring as well as equipment redundancy. The connections in this diagram could be microwave, fiber, or a mix of the two.

Backhaul With 5 Site Ring and 3 Spurs



4.7.5. *Comparison of Backhaul Technologies*

The options for backhaul type as presented above (leased line, T-carrier, or IP-based) along with the options for backhaul reliability-enhancing methods (equipment redundancy, ring, or MPLS) are all system-architecture-level concerns that do not directly address the requirements as identified by the users of TCSO, TCPW, or TRAX. We generally choose which of these technology building-blocks to include in a system's design based on the size and complexity of that radio system – those systems with small numbers of sites and channels can often be well served with spurs that use equipment redundancy for the most critical sites. As the number of sites grow, topologies with rings become more common. Systems that span multiple counties or even entire states tend to use MPLS for site-to-site interconnections. Also, microwave is commonly used to reach more remote sites whereas fiber can be used in more populated areas. Finally, IP-based connections are, for the reasons of cost-effectiveness and overall scalability noted above, the most prevalent connection method used in deployments of new systems.

4.8. Conceptual Design Selection – Technology

To create a conceptual design option, we look at two factors. First, we evaluate the technology building blocks that were presented in the previous sections and select those that meet user needs. The following table shows those selected building blocks to be part of a conceptual design for a new system as designated by a "✓) and those deemed non-viable as designated by a "🚫". Note that in some instances one technology may be viable for one agency whereas a different technology may be viable for another – this is due to the different operational requirements of law enforcement TCSO, TCPW, and TRAX.

Topic	Technology Building Block Option	Building Block Viability			
		TCSO	TCPW	TRAX	Notes/Rationale
Ownership	Private	✓	✓	✓	Private systems promote a tailored design and single-agency control over system operations. Shared systems promote interoperability. Subscription-based systems are unlikely (at this time) to meet needs for interoperability, coverage, and user-devices.
	Shared	✓	✓	✓	
	Subscription	🛇	🛇	🛇	
Frequency Band	VHF	✓	✓	🛇	VHF for TCSO and TCPW will promote interoperability with each other and with critical neighbors and partners. VHF also has good propagation characteristics in rural and forested areas. UHF for TRAX, which does not have similar requirements for interoperability, will allow reuse of exiting in-bus radios. 7/800MHz is not a common band among other agencies in/around Tehama County so it's use would be incompatible with interoperability.
	UHF	🛇	🛇	✓	
	7/800MHz	🛇	🛇	🛇	
Modulation	Analog	✓	✓	✓	Analog for TCSO and TCPW will promote interoperability with each other and with critical neighbors and partners. P25 is viable for non-dispatch operations for TCSO in order to comply with the CA DOJ's requirements for security of personal information (for radio inquires). DMR for TRAX will allow reuse of exiting in-bus radios. DMR is also an option to support GPS-based location services for TCSO and TCPW (through secondary in-car radios).
	Digital P25	✓	🛇	✓	
	Digital Other (DMR)	🛇	🛇	✓	

Topic	Technology Building Block Option	Building Block Viability			
		TCSO	TCPW	TRAX	Notes/Rationale
Site Configuration	Single Site w/ Voting	✓	✓	✓	TCSO's county-wide service area and use of use of portable radios imposes a substantial coverage requirement that will be difficult to meet with a single site. A single site may suffice for TCSO's inquiry channel which could be accessed from in-car mobile radios. TCPW's and TRAX's use of mobile radios imposes a less-stringent coverage requirement that may be met via a single site. Additional information about coverage and sites is in the following section of this report.
	Multi-Cast Voting	✓	✓	✓	
	Simulcast	✓	✓	✓	
Site & Channel Access Method	Conventional Single Site	✓	✓	✓	TCSO, TCPW, and TRAX do not have sufficient quantities of radios to require the additional costs and complexities of trunking systems. Simulcast and vote-scan will be investigated to ease site selection when more than one site is required to meet coverage requirements. Additional information about coverage and sites is in the following section of this report.
	Conventional Multi-Cast Manual	✓	✓	✓	
	Conventional Multi-Cast VoteScan	✓	✓	✓	
	Conventional Simulcast	✓	✓	✓	
	Trunked Single Site	🛇	🛇	🛇	
	Trunked Simulcast	🛇	🛇	🛇	
Console	Wireless Control Stations	🛇	✓	✓	The nature of dispatch operations for law enforcement generally benefits from the features of direct wireline console connections, most notably dispatch

Topic	Technology Building Block Option	Building Block Viability			
		TCSO	TCPW	TRAX	Notes/Rationale
	Direct Wireline	✓	🛇	🛇	priority. The lower volume of calls and the nature of dispatch for TCPW and TRAX do not require the additional cost/complexity of wireline dispatch connections.
Backhaul Technology	Leased Line	🛇	🛇	🛇	The susceptibility to noise and the high ongoing cost associated with leased lines make them non-viable for TCSO, TCPW, and TRAX. The on-demand flexibility of IP-based connections are much more suitable.
	T-Carrier	🛇	🛇	🛇	
	IP-Based	✓	✓	✓	
Backhaul Reliability	Redundant Equipment	✓	✓	✓	Backhaul reliability through redundant equipment and/or redundant links is likely to be viable for the size and scope of systems in Tehama County. MPLS is likely to be not needed.
	Redundant Links (Ring)	✓	✓	✓	
	Mesh/MPLS	🛇	🛇	🛇	

The Takeaway

Based on the analysis of the available options, we recommend the following technologies:

1) **A VHF, analog, conventional system for TCSO's dispatch operations**
2) **A VHF, P25, conventional system (with encryption) for TCSO's inquiries**
3) **A VHF, analog, conventional system for TCPW**
4) **A UHF, DMR, conventional system for TRAX (but one owned/operated by TRAX) – this would also be available for TCSO and TCPW for GPS-based location services**
5) **A VHF, analog, conventional system for local government**
6) **Wireline dispatch connections for TCSO but control stations for TCPW and TRAX**
7) **IP-based backhaul with either equipment- or link-based reliability**

Following the selection of technologies, turn to the second factor - we identify available radio sites and model coverage from them to determine which sites produce a fully viable conceptual design.

The topics of sites and coverage are covered in Section 5. Section 6 brings together the technologies covered in above and the site selections as described in Section 5 into a conceptual design.

Note: These two factors of selected technologies and the selected sites have dependencies on each other – for example, simulcast may be viable if the distance between sites is within its criteria of 8-15 miles of separation between sites (or at greater distances, with advanced system design methods). Additionally, when multiple sites are needed and simulcast is not viable, we then analyze the other methods for site access.

5. Radio System Site Options

In addition to technology, a foundational attribute of a two-way public safety / public service radio system's design is its coverage. Defining a system's coverage involves iteratively selecting and evaluating different repeater sites and modeling the coverage they are expected to produce based on their locations and elevations as well as the technical parameters of the electronics housed at the sites as well as of the user radios. The outputs allow us to determine the combination that provides sufficient radio signal levels in the areas where users operate.

This section of this report describes the practices we use as we develop the coverage portion of our conceptual designs as well as outcomes of those practices that result in the selection of a set of sites.

5.1. Coverage Design Best Practices

When designing the coverage of a system, we follow two important best practices. These same best practices should be followed by Tehama County when evaluating a prospective system's coverage design and when discussing coverage needs with potential vendors and other parties.

1) **Be Specific About the Scenario Details**: Coverage designs are typically shown as coverage prediction maps in which a color pattern depicts the areas that are expected to have signal of sufficient strength (or quality) to provide usable audio communications. For a given radio site (or collection of sites) the size and area of that color pattern will vary with the details of the scenario included in the prediction. These include:

    a. Radio Technology: Different modulation methods and site/channel access methods will produce different patterns of coverage, even when deployed at the same power levels at the same site.

    b. Talk-In vs Talk-out: The former is the coverage of subscriber radios as they transmit into the system; the latter is the coverage of the system's broadcasts out to subscriber radios. A properly-designed system will have balance between talk-in and talk-out coverage (i.e., there will not be a larger area of talk-in or talk-out coverage but they will be as closely aligned in size and shape as possible).

    c. Reliability Percentage: Coverage is expressed with a reliability factor; the area shown by the color pattern is an area in which the users will have an expressed probability/percentage of having sufficient radio signal for communications to occur. For example, 95% coverage area reliability means that if a user is in the area of the color pattern, they will be able to communicate 95% or more of the times they need to. Users in areas not included in the color pattern may still be able to successfully use their radios; however, those areas have simply been predicted to have less than the stated coverage reliability (i.e., users will experience 94% or less probability of accessing the system).

d. Operational Mode: A coverage prediction for mobile (in-car) radios will typically have a larger color pattern than a coverage prediction for portable (hand-held) radios because mobile radios have higher power and use more efficient car-mounted antennas. Likewise, a coverage prediction for portable radios that are operating outside (on streets) will have a larger color pattern than a coverage prediction for portables that are used inside of buildings because the buildings produce loss that degrades the strength of the radio signal.

e. Delivered Audio Quality: The usability (or clarity) of a radio signal is referred to by the term Delivered Audio Quality or DAQ. There is a scale for DAQ that ranges from 1 to 5, with 1 being unusable audio output and 5 being perfect intelligibility. A DAQ rating of 3.4 is the threshold rating considered acceptable for a public safety system ("speech understandable without repetition, some noise or distortion present"), and coverage predictions are typically based on that rating. A coverage map developed for a DAQ rating of 3.0, which is often used as the threshold for public service radio systems (and which is defined as "speech understandable with slight effort and occasional repetition") will have a larger color pattern than one developed for a DAQ rating of 3.4.

In summary, when looking at any coverage prediction map, it can be easy to focus only on the size and shape of the color pattern that indicates areas of coverage; however, we advise that the details of the scenario also be clearly stated by the preparer and clearly understood by the viewer.

2) **Design for the "Most Likely Case" Scenario**: Because the details of different scenarios can have significant effects on the size and shape of the color pattern on a coverage prediction map, it is best practice to select the set of details that comprise the "most likely case" and use them when designing a system. The coverage-indicating color pattern on one map of a site (or collection of sites) produced with the details for one scenario will be different from that produced for another scenario and its different details. For example, a prediction for 90% reliability for mobile radios at a DAQ rating of 3.0 will have a much larger color pattern than a map for 95% reliability for portable radios in buildings at a DAQ rating of 3.4. We realize that an agency like TCSO is likely to use portable radios to communicate while most communications by TCPW and TRAX will be via in-vehicle/mobile radios. These two scenarios are different and meeting their coverage requirements will include selecting different sets of radio sites, system equipment, and system configurations. Not following this best practice and designing for a scenario other than the "most likely case" will result in a system that does not deliver radio signals of sufficient strength in the areas in which users actually operate their radios.

In developing our conceptual design for TCSO, TCPW, and TRAX, we produced coverage prediction maps that specify the details of the scenario. Our site selections were based on the following sets of most likely cases:

Agency / Operation	Coverage Scenario – Most Likely Case
TCSO – Dispatch	Balanced talk-in and talk-out, portable radio on hip (officer on street), DAQ 3.4, and 95% coverage reliability
TCSO – Inquiry	Balanced talk-in and talk-out, mobile radio, DAQ 3.4, and 95% coverage reliability
TCPW	
TRAX	
Local Government	

5.2. Radio Site Selection Process

The primary outcome of a radio system's coverage design is the identification of the sites to be used in the system. Other outcomes include the selection of antenna system components and the determination of configurations for repeaters and subscriber radios; however, the selection of which sites to use comes first.

In some areas of the nation and the state of California, there are a sufficiently large number of available radio sites (including existing sites or land available for the development of a new site) so that the process of selecting sites begins with identifying the locations in which coverage is needed and then picking nearby locations for the sites to provide that coverage. This is not the case in the far eastern and western portion Tehama County. The limited availability of sites in those areas of Tehama County is due to the large percentage of land that is federally owned (which is difficult to develop) as well as the large percentage that is remote and very sparsely populated.

Because of these constraints, we followed a process of evaluating sites and determining which of them provide the most coverage to areas that are:

1) Currently covered by the existing system and
2) Not currently covered but identified in our earlier report as in need of improvement.

The set of existing sites includes those currently in use by Tehama County and TRAX as well as those in and around Tehama County in other systems. These include:

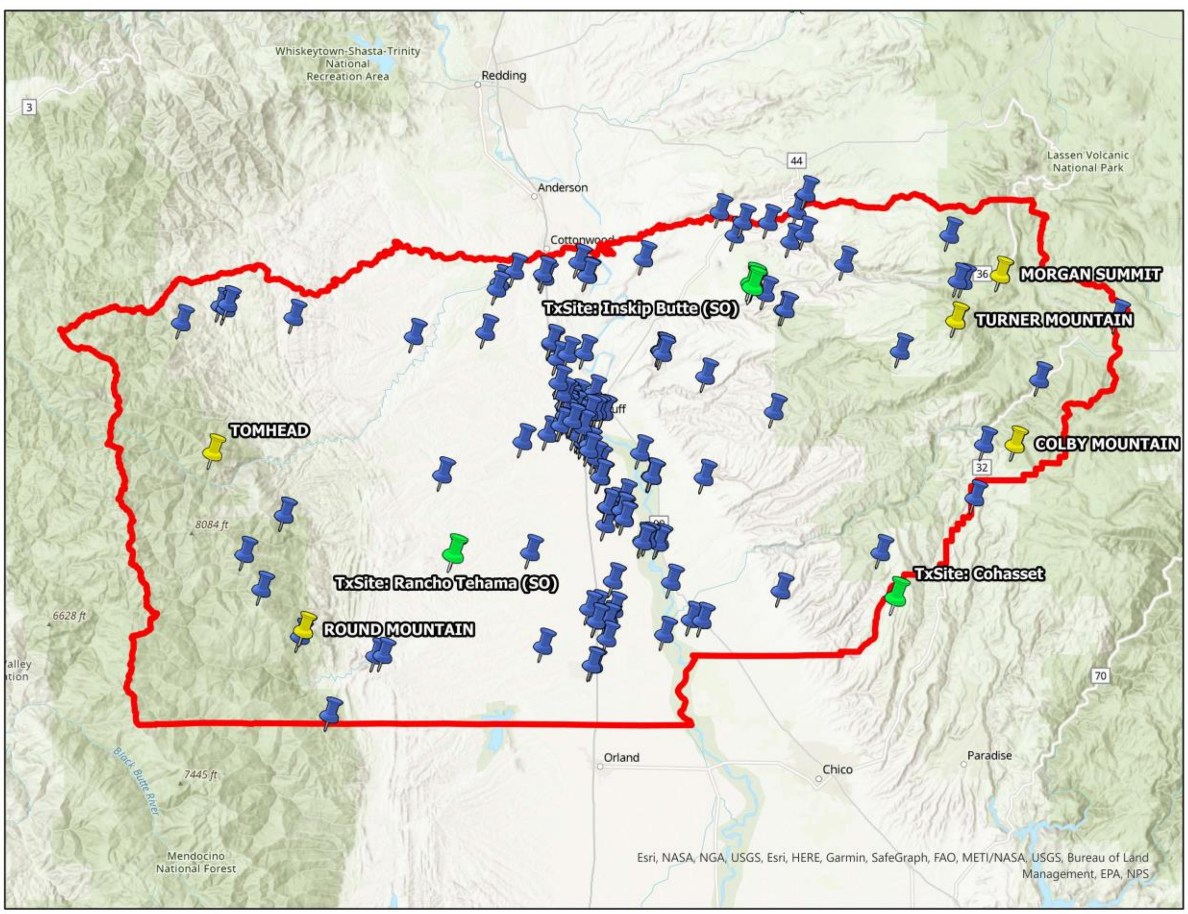
- Existing Sites Currently Used By Tehama County and TRAX
    - Inskip Butte
    - Rancho Tehama
    - Cohasset Ridge
- Existing Sites Currently Potentially Available to Tehama County including:
    - The Tehama County Sheriff's Office Dispatch Center

- Sites in use by other governmental agencies such as US Forest Service and the National Parks Service
- Sites developed by commercial entities and available for lease to governmental agencies and private companies alike
- Sites in use by private organizations that may be available upon agreement with that owner.

In all steps of our evaluation, preference was placed on existing sites (including those used by Tehama County and other, neighboring systems) over new sites and on sites owned by governmental agencies over sites owned by commercial entities.

In total, the sites we evaluated for coverage included those in the following figure. Sites with a green-pin icon are existing sites used by TCSO, TCPW, or TRAX; yellow pins are sites owned by the US Forest Service or National Parks Service; and blue are commercial/private sites.

Sites Evaluated for Coverage



5.3. Coverage Modeling Process & Site Selections

Once a set of candidate/prospective sites was established, we began the process of predicting coverage from each of them in order to create a conceptual design.

To complete this coverage modeling, we used EDX SignalPro® propagation prediction-and-verification software. This industry-leading software implements the recommendations contained in TIA TSB-88[6] for coverage and interference analysis. SignalPro® is especially useful in simulcast coverage modeling as it uses statistically-determined simulations to integrate signal strength and simulcast interference into a composite coverage reliability display.

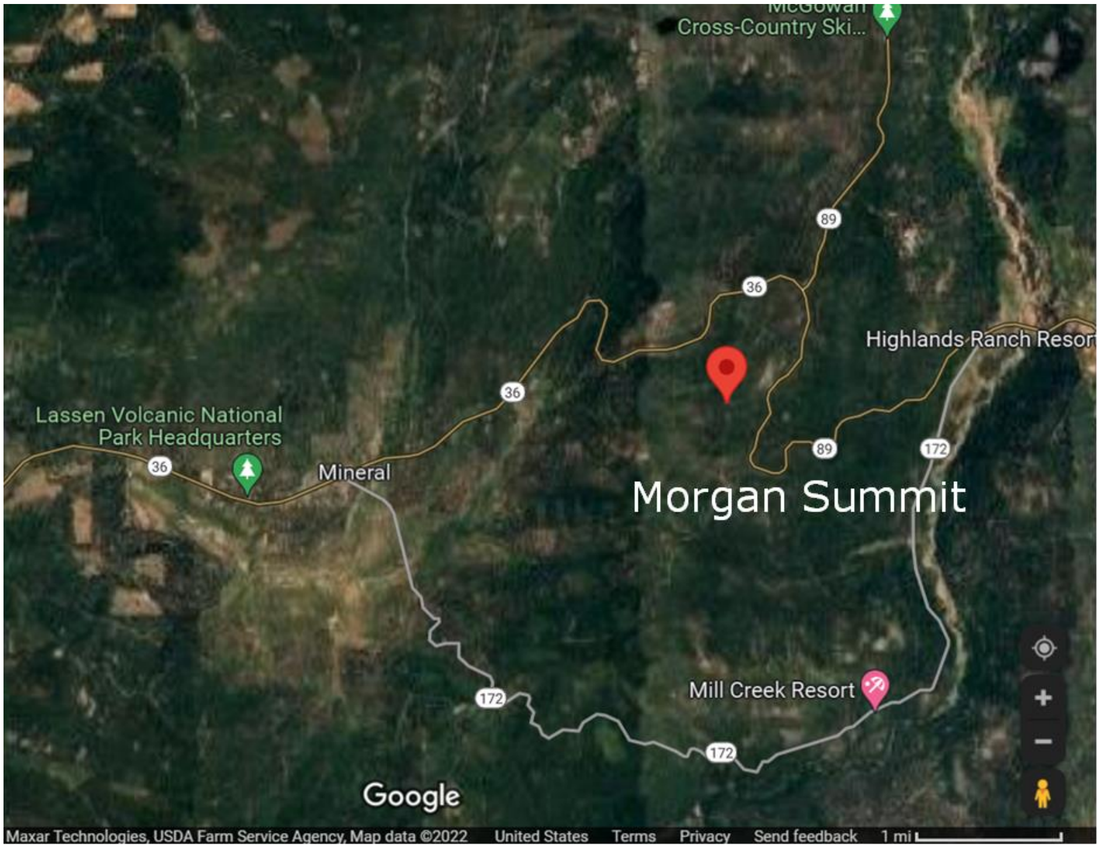
We began by creating coverage prediction maps for available sites and we then looked at how they, individually, provided coverage to areas of Tehama County and we found the following results:

Radio Site	Area Primarily Covered
Inskip Butte	North and Central County
TCSO Dispatch	South and Central County
Morgan Summit *	Northeast County
Rancho Tehama	West and Southwest County
Tomhead (also known as Tomhead Mtn)*	West and Northwest County

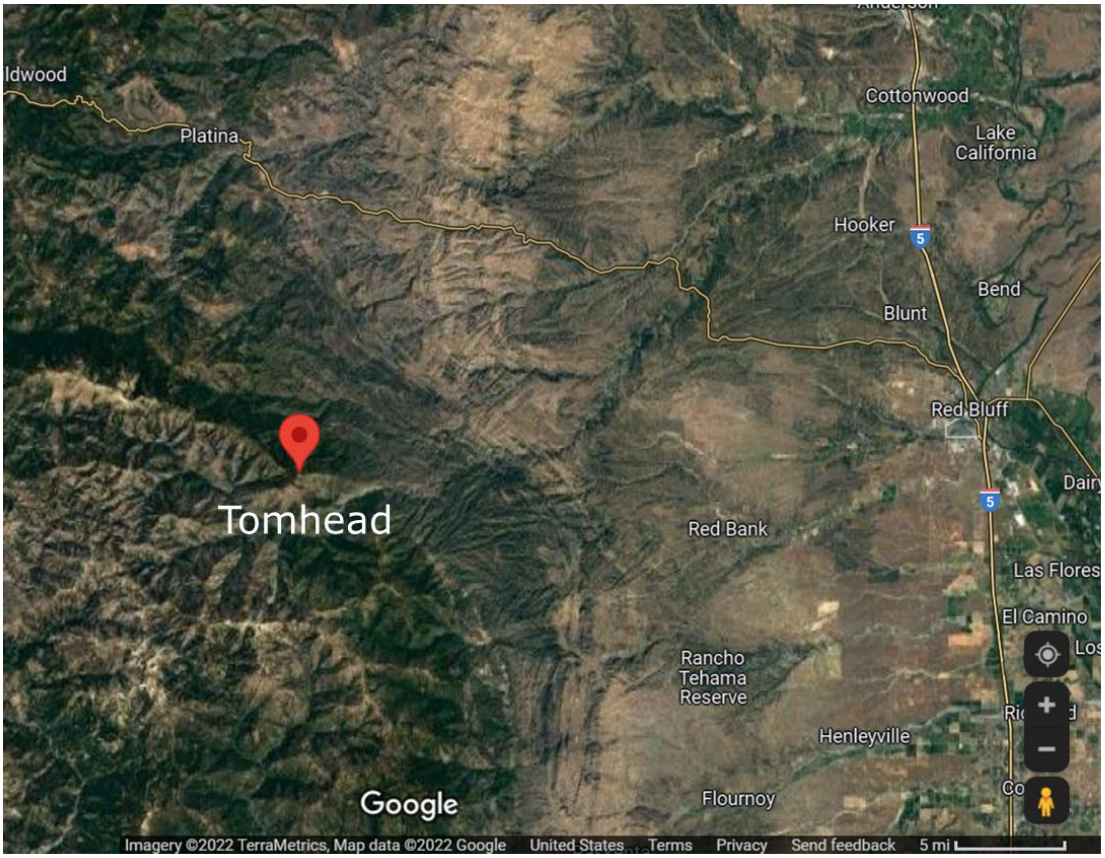
* Morgan Summit is an existing USFS radio tower site that is approximately 3.4 miles due east of the Lassen Volcanic National Park Headquarters. Tomhead is an existing USFS lookout tower that is approximately 20 miles due west of Red Bank. The figures below show their locations and more information about the presumed status of these sites is also included below.

6 The Telecommunications Industry Association (TIA) published a Technical Service Bulletin known as TSB-88 which includes guidelines and data on calculating/predicting coverage from a radio system.

Location of Morgan Summit



Location of Tomhead



The site at Morgan Summit is an existing US Forest Service location. Based on available information, we believe there to be an existing tower at Morgan Summit but the site will need a new shelter and new electrical service (which we assume will be best served by solar power equipment). The site at Tomhead is, likewise, a US Forest Service location; however, we understand it currently has a fire lookout tower but no power, tower, or shelter – these capabilities must be added to make the site viable for use as a two-way radio site.

Coverage prediction maps for the five subsystems that make use of these sites are contained in Attachment A of this report; however, we encourage readers to review the following section, Section 6, which further describes how the sites are combined with various technologies into subsystems as well as the operational implications of those combinations, before viewing the maps.

6. Technologies and Sites: A Conceptual Design

6.1. Conceptual Design Process

Following the identification of viable technologies (as described in Section 4) and the section of viable induvial sites (as provided in Section 5), we then attempted to group these two defining attributes into combinations that, together, best meet user needs.

To a large extent, this effort involves creating combinations of site/channel access methods, including any possible ways to use simulcast and/or multi-cast/voting, that maximize the following:

- Meeting the countywide coverage objectives of continuing existing coverage and improving coverage in specific areas
- Incorporating user requirements for the "most likely case" as described above (including different levels of portable or mobile coverage for different agencies and operational requirements)
- Addressing the requirement of simplifying site selection

As noted above, simulcast is dependent on limited distance between sites – sites that are more than a set distance (8 to 15 miles) will not properly operate in a simulcast system without advanced system design methods and even those can only support site distances of approximately 20 miles.

The result of this process is a set of sites that we've grouped together into five subsystems that correspond to the different agencies and their operational usage cases. These are described in the following table:

Radio Subsystem 1: For TCSO's Dispatch Operations – A Two-Cell, Voted-Multi-Cast, Analog, Conventional Simulcast Subsystem		
Radio Sites	**Technologies**	**Site-Channel Configuration/Operational Use**
An "East Side" Simulcast Cell with sites at TCSO Dispatch, Inskip Butte, and Morgan Summit	VHF analog conventional simulcast cells with 3 sites for the East Side cell and 2 for the West Side – the two cells will operate in a voting-multicast configuration.	The two cells will use the same receive frequency so that all 5 sites are capable of receiving all calls made by a user radio. The receivers of all five sites will be voted and the best signal will be sent to both the East Side and West Side cells for rebroadcast; however, those two simulcast cells will use different transmit frequencies due to the distances between sites (which would result in simulcast interference). Radio use selection of the East Side cell or the West Side cell will be accomplished either by vote-scan or manual selection – details are included below.
A "West Side" Simulcast Cell with sites at Rancho Tehama and Tomhead		

Radio Subsystem 2: For TCSO's Inquiry Operations – A VHF, P25, Conventional P25 Subsystem		
Radio Sites	**Technologies**	**Site-Channel Configuration/Operational Use**
A single site at Inskip Butte	VHF P25 conventional	This single channel will be encrypted so that inquiries that carry Personally Identifiable Information (i.e., information that identifies an individual such as name and driver license number) can comply with California Department of Justice (CA DOJ) released Information Bulletin 20-09-CJIS without the operational imposition of transmitting such information in separate/distinct radio calls. The coverage on this channel will be viable for portable coverage throughout the north-central area of the county and for in-car use beyond that. This channel can also be used for tactical operations that benefit from: i) occurring on a channel other than dispatch and/or ii) being encrypted (e.g., SWAT operations).

Radio Subsystem 3: For TCPW – A VHF, Analog, Conventional P25 Subsystem		
Radio Sites	**Technologies**	**Site-Channel Configuration/Operational Use**
A single site at Inskip Butte	VHF analog conventional	This single channel will provide coverage to TCPW's mobile radios throughout most of the county.

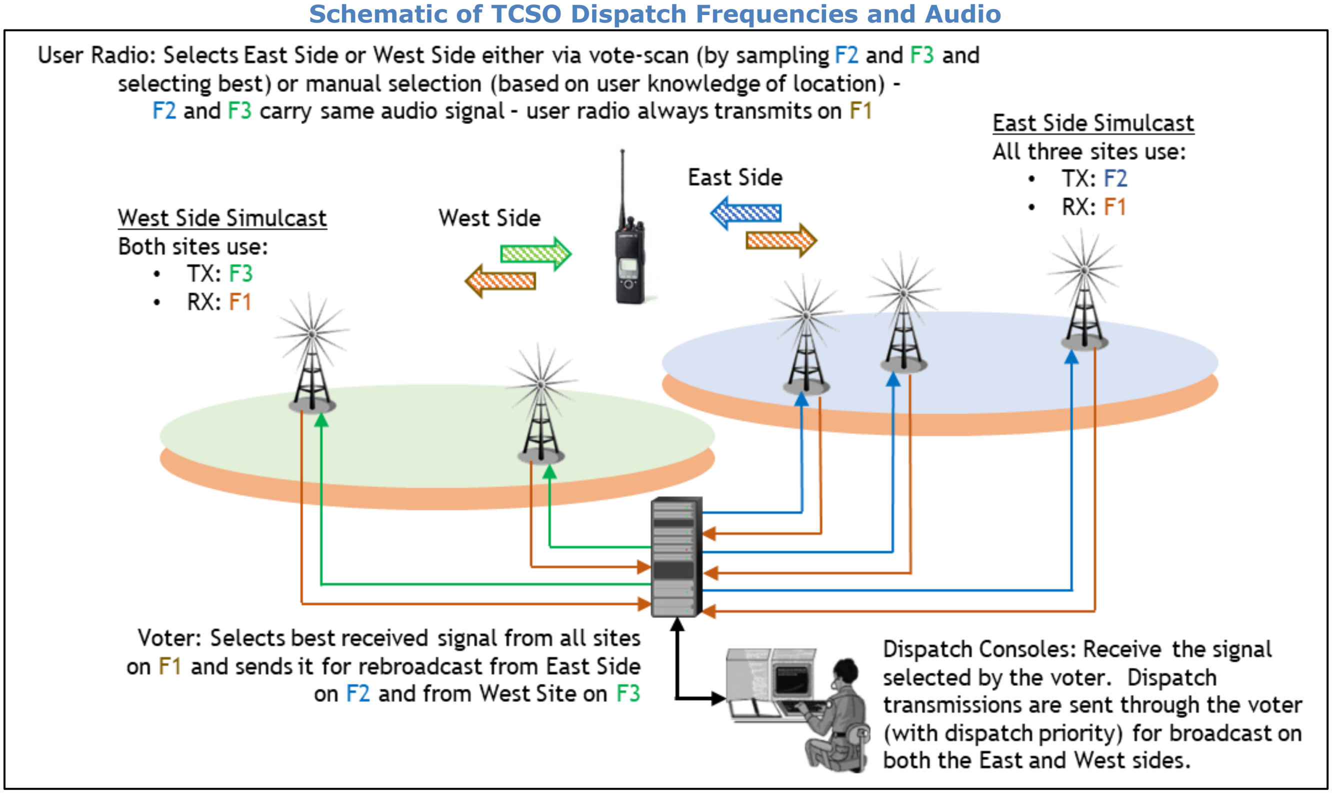
Radio Subsystem 4: For TRAX – A UHF, DMR, Conventional P25 Subsystem		
Radio Sites	**Technologies**	**Site-Channel Configuration/Operational Use**
A single site at Inskip Butte	UHF DMR conventional	This single channel will be capable of carrying two sets of information due to its two digital time slots. One time slot will be used to provide voice communications to TRAX's mobile radios throughout most of the county. The second time slot will be available for data messaging including: i) possible future intelligent bus transit application data from TRAX's vehicles and/or ii) possible future GPS-based location services from TCSO and/or TCPW's vehicles.

Radio Subsystem 5: For Local Government – A VHF, Analog, Conventional P25 Subsystem with Voting Receivers		
Radio Sites	**Technologies**	**Site-Channel Configuration/Operational Use**
A single transmission site at Inskip Butte with 4 additional voted receiver sites	VHF analog conventional, single transmitter site and 4 additional voted sites	This single channel will provide coverage to mobile radios for local government agencies throughout most of the county. It uses voting receivers at the same sites as the TCSO Dispatch channel to improve coverage for portable radios. It could also serve as a backup and/or alternate channel should the dispatch channel experience failure or congestion.

The design of the TCSO Dispatch subsystem collects user-transmitted audio from the five sites and repeats the voted/best version of that conversation from five sites; however, the site-to-site distances do not allow all five sites to be in one-simulcast cell – they must be in two interconnected cells; one for the east side and one for the west side.

The following figure shows a schematic of use of frequencies and the flow of audio signals for the TCSO Dispatch channel.

Schematic of TCSO Dispatch Frequencies and Audio



Because the two TCSO Dispatch cells (the two sides) transmit on different frequencies, there will be two different TCSO Dispatch "modes" (or channel selections) in each radio that has access to the TCSO Dispatch channel – there will be a "Dispatch East" and a "Dispatch West" mode. Again, users on both simulcast cells (i.e., both "sides") will hear the same rebroadcast of all conversations (including audio from dispatchers and calls from other field users that are received by any of the five sites) but the different modes are required to accommodate the fact that those on the east side will receive that conversation on a different physical frequency from those on the west side. Also, the voter will deliver the best/voted audio (from both the east and west sides) to TCSO dispatchers. When dispatchers transmit, their audio will be routed through the voter to both the east and west sides for broadcast to users.

As noted in the figure above, there are two possible ways that a TCSO user radio will select either the east or west side – TCSO radios could be configured for vote-scan so that the radio itself selects the best cell (the best side) based on signals it receives or it could require users to manual select either the west or east side mode based on their location. Vote-scan is an automatic method in which the radio samples transmissions from multiple sites (on multiple frequencies) and selects the one with the best quality. This feature relieves users from the task of selecting a channel but there are two considerations:

1) Vote-scan is a feature that is available in many, but not all, makes and models of user radios. From the inventory of user radios that we collected in prior tasks, <u>we identified many TCSO radios that we believe are not capable of supporting vote-scan</u> either because the vendor did not ever support that feature in that model or because the model is discontinued and therefore vendor-provided software upgrades (including an upgrade to support vote-scan) are no longer available.
2) Vote-scan performs well when the channels/sites involved have transmissions that occur both regularly and frequently. Such transmissions allow radios that use vote-scan to have enough signals to sample in order to select the best site. If transmissions are not regular or frequent, a radio could not have enough information to select the best site. This is especially true for radios that regularly travel between the coverage areas of the different site. For example, a radio in the west side may select the west side's sites based on a recent transmission; however, if there are no transmissions while the radio travels well into the east side, then it will remain on the west side's sites, potentially missing audio from the east side's sites. Based on our experience listening to the current TCSO Dispatch channel, we <u>are unsure if it carries transmissions on a sufficiently regular and frequent basis to support efficient use of the vote-scan feature.</u>

The alternative to using vote-scan to automate the selection of a cell/channel is to require users to select either the west or east side based on their knowledge of their location. To a degree, TCSO radio users are already performing this operation on the TCSO Dispatch channel – they change from the Inskip Butte site to the Ranch Tehama site as they travel from the east side to the west side of the county. (We understand that some TCSO radio users have a better comprehension of how, where, and when to switch than do others and that those users with that understanding and practice experience better performance from the radio system than those that do not.)

It is important to note that the proposed voted east-side/west-side conceptual design is different from the current configuration of the TSCO Dispatch channel as deployed at Inskip Butte and Rancho Tehama. In today's configuration, each of these two sites only repeats the signal it receives – audio received by Rancho Tehama is not repeated from the Inskip Butte site (and vice versa). Our proposed use of a voter will collect received audio from all sites and rebroadcast it from all sites.

We propose to simplify the switching criteria between the east and west sides as follows: users east of the I-5 highway should use the east side sites (they should manually select the TCSO Dispatch East Side mode on their radios) and users west of the I-5 highway should use the west side sites (they should manually select the TCSO Dispatch West Side mode on their radios). There is enough coverage overlap between the two cells that a user that is traveling across I-5 does not need change exactly as they make that transition – if they are engaged in an incident as the travel from east to west (or vice versa) they can continue using whatever mode they used to start the conversation until they travel well past the I-5 dividing line.

Because of the uncertainties regarding vote-scan as described above (availability in radios and efficiency of use due to infrequent transmissions), we propose that TCSO proceed with manual switching and that, simultaneously, we:

1) Further investigate the capabilities of current and possible future TCSO radios
2) Conduct a field trial of vote-scan with a small set of radios (those that are capable of the feature) to determine if there are sufficiently regular and frequent radio calls to allow it to operate efficiently.

6.1.1. *TCSO Inquiry Channel Operational Overview*

The conceptual design for the TCSO Inquiry subsystem provides P25/digital service to mobile and portable radios with a coverage area that is very similar to the existing site at Inskip Butte (i.e., coverage to mobile radios in most of the county should be good and coverage to portable radios at street-level should be usable throughout the north-central part of the county).

Operating as a P25/digital channel will allow traffic on this channel to be encrypted. We see three operational implications to this:

1) This encryption-capable channel could be used to comply with the requirements of the California Department of Justice's Information Bulletin 20-09-CJIS which addressed the subject of "Confidentiality of Information from the California Law Enforcement Telecommunications System (CLETS)". TCSO users could conduct inquires on this encrypted channel, thereby meeting the requirements to encrypt "radio calls that carry Personally Identifiable Information (i.e., information that identifies an individual such as name and driver license number)." This would eliminate the operational burden of the current practice of transmitting different sets of Personally Identifiable Information in separate/distinct radio calls.
2) With its encryption capabilities, this channel could also be used for sensitive tactical operations such as SWAT, evictions, warrants, etc. It may actually be more appropriate to refer to this channel as an encrypted tactical channel ("TSCO eTAC"), rather than an inquiry channel, so that its use is considered more generally for protected communications.
3) This digital channel can carry digital signaling and GPS-based location services is among the features supported by P25 conventional channels. This is one option for supporting location services from TCSO radios; the other is the DMR subsystem included for TRAX. Although the specifications for P25 conventional radio channels do include signaling protocols for GPS-based location services, we have not had experience with its operations in any systems and, furthermore, we have not heard from any vendors of successful deployments of location services on a P25 conventional channel. (We have seen success in deploying location services on P25 trunked systems.) Therefore, at this time, we simply note the possibility of that this channel is capable of supporting

location services; however, we suggest the use of the DMR subsystem, included for TRAX, as the primary method for this feature for TCSO and TCPW.

We recommend that any channel that is used to carry encryption be used in an "always encrypted" mode and that it never be operated as a sometimes-encrypted/sometimes-clear channel.

6.1.2. *TRAX DMR Subsystem Operational Overview*

The conceptual design for the TRAX subsystem provides DMR/digital service to mobile and portable radio with a coverage area that is expected to be an improvement to that provided by the existing site at Cohasset Ridge. Coverage is expected to TRAX's mobile radios in most of the county.

This subsystem will use UHF frequencies and DMR technologies. We see three operational implications to this:

1) This set of technologies will allow reuse of the existing in-vehicle radios.
2) DMR provides two time slots in one physical radio channel and each time slot could be used for voice conversations or data signaling. We envision that one time slot will be used for audio conversations from TRAX's fixed-route and paratransit vehicles (as well as any portable-radio users such as administration or maintenance). We envision that the second time slot could be used for data signaling to support either or both of the following: a) intelligent bus transit applications (which include GPS-based location services) for TRAX's vehicles and/or b) GPS-based location services for TCSO's and TCPW's vehicles. The latter would require a second radio, one capable of UHF DMR technologies and equipped with GPS-enabling receivers and processors, in TCSO and TCPW vehicles.
3) This set of technologies is different from those of the TCSO and TCPW subsystems and, although it provides the benefits described above, they will not support direct (radio-to-radio) interoperability between TRAX and TCSO or TCPW. Communications between TRAX drivers and TCSO or TCPW field users will still need to involve non-radio communications between their respective dispatchers.

6.1.3. *TCPW and Local Government Subsystem Operational Overviews*

The subsystem for TCPW will use an analog, VHF, single site repeater at Inskip Butte. This will provide service to mobile and portable radio with a coverage area that is very similar to the existing TCPW site at Inskip Butte (i.e., coverage to mobile radios in most of the county should be good and coverage to portable radios at street-level should be usable throughout the north-central part of the county).

The Local Government subsystem is similar to the TCPW subsystem but it also includes voting receivers at four additional sites (Tomhead, Rancho Tehama, TCSO Dispatch, and Morgan Summit) to improve coverage for portable radios.

Because of their frequency band and modulation methods, both of these channels will support interoperability with each other, with the TCSO Dispatch channel, and with other VHF conventional analog channels of neighbor and partner agencies.

6.2. Coverage Prediction Maps

Coverage prediction maps for these subsystems are contained in Attachment A of this report.

The table below lists the maps that are included - they represent the most likely case for each agency as well as, in some cases, alternative use cases. The following color convention is used on the maps: orange shading depicts talk-in coverage (radios to system), blue/purple shading depicts talk-out coverage (system to radios), and pink shading depicts areas that have both talk-in and talk-out coverage.

<table>
<tr><th colspan="3">Radio Subsystem 1: For TCSO's Dispatch Operations – A Two-Cell, Voted-Multi-Cast, Analog, Conventional Simulcast Subsystem</th></tr>
<tr><th>Map Number & Description</th><th>Sites Included</th><th>Operational Scenario</th></tr>
<tr><td>Map #1a, TCSO Dispatch East Side Simulcast (Portable Radio on Street)</td><td>Repeaters at Morgan Summit, Inskip Butte, and TCSO Dispatch – additional voting receivers at Rancho Tehama and Tomhead</td><td rowspan="2">95% coverage reliability and DAQ 3.4 to/from a portable at hip level operating outdoors (at street level)</td></tr>
<tr><td>Map #1b, TCSO Dispatch West Side Simulcast (Portable Radio on Street)</td><td>Repeaters at Rancho Tehama and Tomhead – additional voting receivers at Morgan Summit, Inskip Butte, and TCSO Dispatch</td></tr>
<tr><td>Map #1c, TCSO Dispatch East Side Simulcast (Mobile Radio)</td><td>Repeaters at Morgan Summit, Inskip Butte, and TCSO Dispatch – additional voting receivers at Rancho Tehama and Tomhead</td><td rowspan="2">95% coverage reliability and DAQ 3.4 to/from a mobile radio</td></tr>
<tr><td>Map #1d, TCSO Dispatch West Side Simulcast (Mobile Radio)</td><td>Repeaters at Rancho Tehama and Tomhead – additional voting receivers at Morgan Summit, Inskip Butte, and TCSO Dispatch</td></tr>
<tr><td>Important Point</td><td colspan="2">The inclusion of separate maps for the East Side and West Side simulcast cells of the TCSO Dispatch subsystem should not be viewed as if those two cells are independent and carrying different conversations. They will be interconnected and they will operate together to carry one conversation as described in Section 6.2.1, above.</td></tr>
<tr><th colspan="3">Radio Subsystem 2: For TCSO's Inquiry Operations – A VHF, P25, Conventional P25 Subsystem</th></tr>
<tr><th>Map Number & Description</th><th>Sites Included</th><th>Operational Scenario</th></tr>
<tr><td>Map #2a, TCSO Inquiry (Mobile Radio on Street)</td><td>Single Site P25 repeater at Inskip Butte (with no additional voting receivers)</td><td>95% coverage reliability and DAQ 3.4 to/from a mobile radio</td></tr>
</table>

Map #2b, TCSO Inquiry (Portable Radio on Street)		95% coverage reliability and DAQ 3.4 to/from a portable at hip level operating outdoors (at street level)
Radio Subsystem 3: For TCPW – A VHF, Analog, Conventional P25 Subsystem		
Map Number & Description	**Sites Included**	**Operational Scenario**
Map #3, TCPW (Mobile Radio on Street)	Single-site repeater at Inskip Butte (with no additional voting receivers)	95% coverage reliability and DAQ 3.4 to/from a mobile radio
Radio Subsystem 4: For TRAX – A UHF, DMR, Conventional P25 Subsystem		
Map Number & Description	**Sites Included**	**Operational Scenario**
Map #4, TRAX DMR (Mobile Radio on Street)	Single-site DMR repeater at Inskip Butte (with no additional voting receivers)	95% coverage reliability and DAQ 3.4 to/from a mobile radio
Radio Subsystem 5: For Local Government – A VHF, Analog, Conventional P25 Subsystem with Voting Receivers		
Map #5a, Local Government (Mobile Radio on Street)	Single Site repeater at Inskip Butte with additional voting receivers at Morgan Summit, TCSO Dispatch, Rancho Tehama and Tomhead	95% coverage reliability and DAQ 3.4 to/from a mobile radio
Map #5b, Local Government (Portable Radio on Street)		95% coverage reliability and DAQ 3.4 to/from a portable at hip level operating outdoors (at street level)

6.3. Other Technologies for Radio User Features

The choices of analog, P25, and DMR all support user features that can supplement voice/audio calls to enhance operator safety and efficiency. In analog systems, such features are provided by the use of bursty-data (MDC1200) while the P25 and DMR digital technologies use digital signaling. The following table shows a list of the most common features of each technology used by public safety and public service agencies (other features are available with each technology – this list is partial and focused on features commonly used by organizations such as TCSO, TCPW, and TRAX):

Feature Name	Feature Description	Supported by:		
		MDC1200 (Analog)	P25 Conventional	DMR Conventional (Tier II)[7]
Radio ID	A numeric ID, unique to the radio, is carried with each transmission, identifying the radio that is transmitting	Yes, supported	Yes, supported	Yes, supported
Emergency Message / Call	Upon the push of a specific radio button, a high-priority message, often followed by a high-priority voice call, is sent by the radio, usually producing audible and visual alerts at dispatch consoles and other radios	Yes, supported	Yes, supported	Yes, supported
Digital Encryption	Voice conversation is scrambled/encrypted and can only be heard by radios or consoles that are programmed with the same 256-bit encryption key	Not supported	Yes, supported	Yes, supported
Radio Inhibit/ Uninhibit	A command from a system administrator disables all functionality of the radio; typically used for lost or stolen radios; can be undone with a subsequent command	Yes, supported	Yes, supported	Yes, supported
GPS-based Location Services	Radios can transmit their GPS-based location with each conversation, this information can be routed to a mapping application	Not supported	Yes, supported	Yes, supported
Radio Check	A query from a console or system administrator is sent to a specific radio to determine if it is on or off and what channel/ talkgroup it is on	Yes, supported	Yes, supported	Yes, supported
Radio Alias Table	Consoles or radios can be programmed to translate a radio's numeric ID to an alphanumeric string that can identify the radio user's name, badge number, rig-and-seat, etc.	Yes, supported	Yes, supported	Yes, supported
Radio Messaging / Status	Radios can be programmed to transmit a short, user-selectable alpha-numeric message (or status indicator)	Yes, supported	Yes, supported	Yes, supported

[7] DMR Tier II is a standard for licensed conventional DMR radio systems. It provides more features than Tier I (which is refers to unlicensed DMR systems). DMR also supports trunked technologies in what is referred to as Tier III.

The table above lists the features that are supported by the technologies; however, as is noted in the description of the P25 standard, not all are required to be implemented by vendors in all models of their user radios.

We recognize that features such as those listed in the table above were not identified as high-priority requirements by TCSO, TCPW, and TRAX. We have; however, seen their deployment and use enhance user safety and efficiency. With the knowledge that the technologies of the subsystems support these features (according to the table above), we recommend that TCSO, TCPW, and TRAX evaluate their potential benefits and consider their use in future systems.

6.4. Dispatch Connection & Backhaul

In addition to the radio technologies described above, we developed recommendations for the use of technology options for dispatch connectivity and site-to-site backhaul.

Our conceptual design includes the recommendation that the dispatch consoles at the TCSO Dispatch center will be replaced with new models because:

- The existing MIP5000 consoles are obsolete and are no longer supported by the manufacturer.
- Newer/replacement dispatch consoles can support the radio user features associated with analog bursty data and Project 25 as described above.

With this change in the dispatch console equipment, we also recommend changing the way they connect to the system. A direct/wireline connection, as described above in Section 4.6, provides more features (including the important feature of dispatch priority), better audio quality, and greater reliability of connection than does wireless/control-station connectivity. Details about how this is to be accomplished are immediately below. We also recommend that the TCSO dispatch consoles be equipped with wireless/control-station connectivity for both of the following purposes:

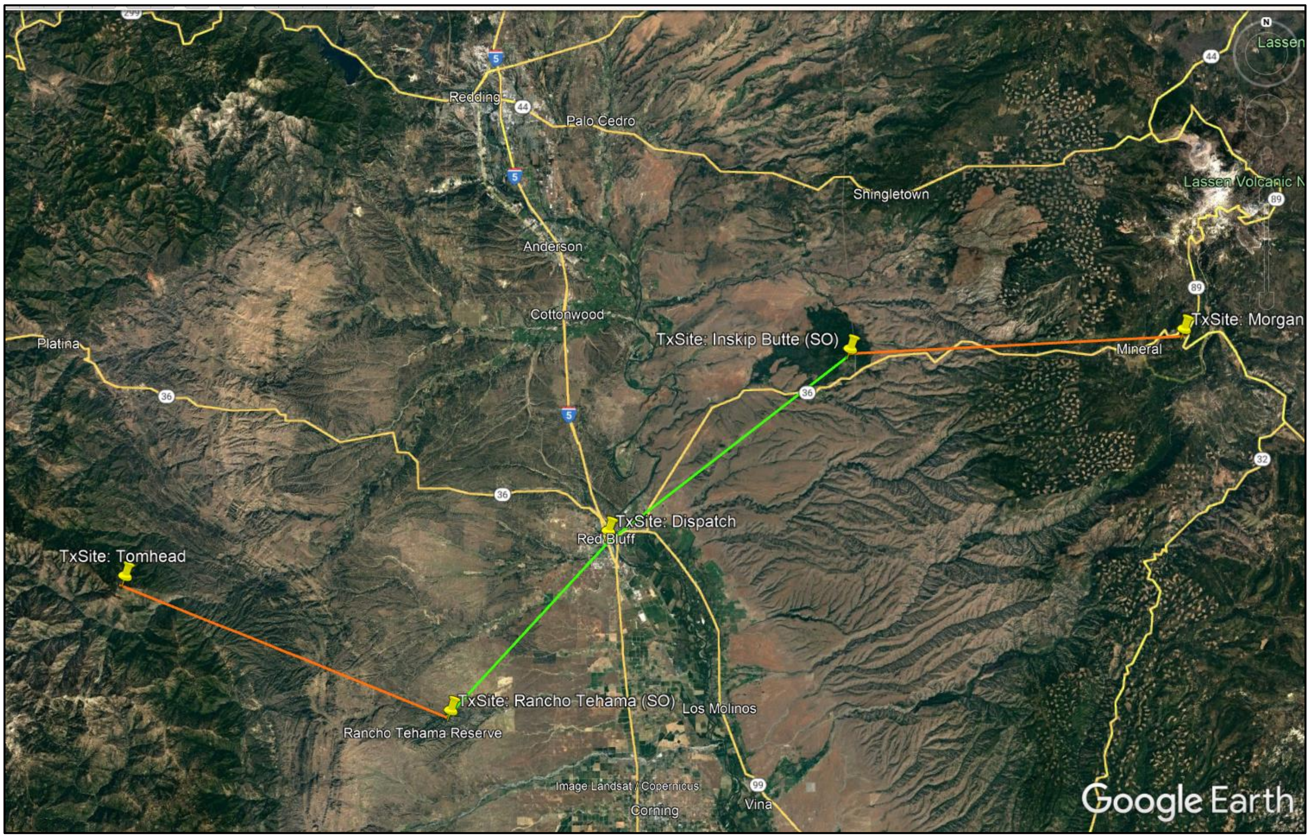
- Continued connectivity to the channels of neighbor/partner agencies for interoperability purposes
- Back-up purposes so that dispatchers can remain in-touch with field users should there be any failures of the wireline connection.

TCPW and TRAX both currently use wireless control stations for dispatch and our conceptual design does not change that choice of technology – control stations fit the operational needs of both organizations. The only possible adjustment to this recommendation could come if TRAX were to deploy a more advanced intelligent bus transit system application. Such applications can provide advanced functionality for transit dispatchers when paired with full dispatch consoles and direct/wireline connections.

Our conceptual design option also changes the methods of backhaul. The TCSO Dispatch and Inquiry subsystems will use wireline connectivity to the TCSO Dispatch center. For the TCSO Dispatch subsystem, this involves a wireline connection from the network of TSCO dispatch consoles to the voter that both collects the received audio from all TCSO Dispatch receivers and distributes the selected/best signal to all TCSO Dispatch transmitters. We recommend the voter be located at the TCSO Dispatch center. For the TCSO Inquiry subsystem, this involves a backhaul link between the network of TSCO dispatch consoles and the repeater to be located at Inskip Butte.

The method of backhaul between TCSO Dispatch (which will house the TCSO dispatch consoles along with a repeater and the voter for the TSCO Dispatch subsystem) and the sites of Inskip Butte (which will house repeater sites for many subsystems), Morgan Summit, Rancho Tehama, and Tomhead (the three all housing TCSO Dispatch repeaters) will be IP-based microwave. We recommend the configuration for the links that is shown in the following figure.

Configuration of Backhaul Links



In this figure, the locations of sites to be interconnected are shown as "yellow pin" icons and the links between them use the following convention: green lines show links that will use "1+1" equipment redundancy and orange lines show links that have no equipment redundancy. This configuration is included in our conceptual design for the following reasons:

1) Because of the geometry of these sites (they are generally in an east-and-west line) and the long distances between them, there was no opportunity to create a ring among them.

2) The endpoint sites of Morgan Summit and Tomhead are remote and both the coverage area they provide and the quantity of users they are likely to support are relatively limited when compared to the three more central sites of Rancho Tehama, TCSO Dispatch, and Inskip Butte. Protecting the links to those three central sites met our threshold to justify the expense of "1+1" equipment redundancy but, for the reasons noted, the same does not hold for the spurs to/from Tomhead and Morgan Summit. Should either of the links between TCSO Dispatch and Rancho Tehama or TCSO Dispatch and Inskip Butte, it could be restored by manually switching to the backup equipment and

during the interim, the affected sites would be inoperable (they would not provide received signals to the voter nor would the rebroadcast the voted signal). Should either of the links between Rancho Tehama and Tomhead or Inskip Butte and Morgan Summit fail, they would require on-site repair services to restore the connection. Again, in the interim, the affected site would be inoperable.

6.5. Interoperability Considerations

The technologies selected for this conceptual design were included to maintain interoperability in generally the same manner as it currently is for TCSO, TCPW, and TRAX. Specifically, the use of analog, conventional, VHF channels for the TCSO Dispatch and TCPW subsystems will also users from those organizations to continue to have access to each other's channels and to the various neighbor/partner agencies that also use those technologies. These neighbor/partners include the Red Bluff Police Department, the Red Bluff Fire Department, the Red Bluff Department of Public Works, the Corning Police Department, the Corning Fire Department, the Corning Department of Public Works, CalFire, and the USFS Districts of Lassen and Mendocino. This access includes:

1) The ability to cross-program each other's radios with each other's channels so that users of different agencies can directly talk to each other.
2) Also through radio cross-programming, users can use their radios to directly contact other agencies' dispatch centers and, likewise, be contacted by them.
3) The ability to scan each other's channels for situational awareness of incidents in the jurisdictions of neighboring/partnering agencies.

We realize that this high level of interoperability currently occurs mainly between TCSO and its neighboring/partnering public safety agencies and there is not the same degree between TCPW and its associated public works agencies. The selection of VHF, analog, and conventional technologies for this conceptual design allows TCPW to develop cross-programming and scanning capabilities with its neighbor/partners as well as with TCSO.

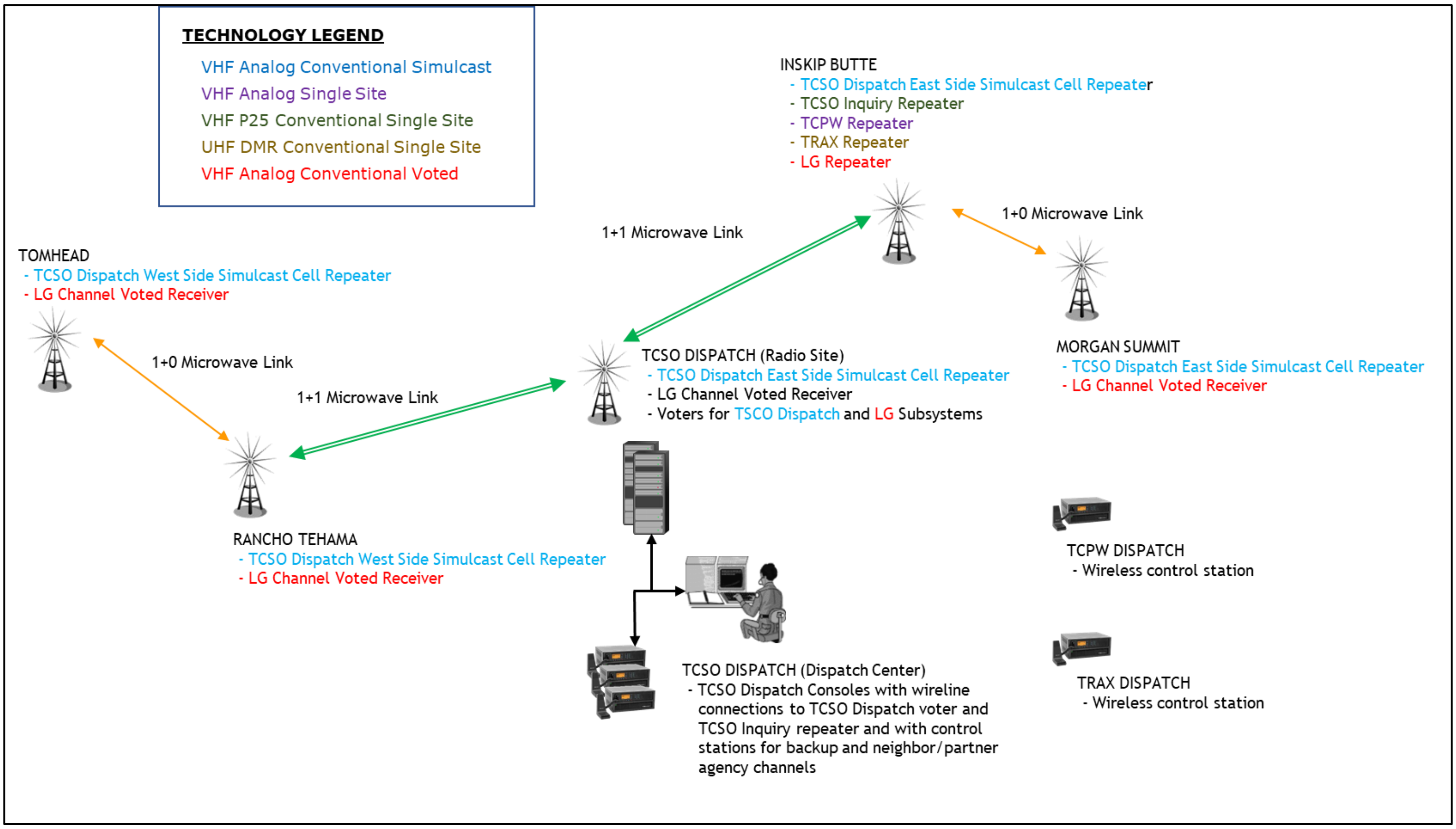
As described above, our conceptual design also includes recommendation for replacement dispatch consoles for TCSO and for them to use direct/wireline connections to the TCSO Dispatch and TCSO Inquiry subsystems along with control-station connections for continued connection to the channels of neighbor/partner agencies. With this configuration, TCSO dispatchers could patch various channels together. A patch connects two or more channels so that audio that occurs on one channel is heard on all other channels that are part of the patch. This feature can be an effective method to provide interoperability as users that need to talk to each other can do so even if they do not have each other's channels programmed into their radios. Patches are made by dispatchers and are typically in effect for only as long as required by the incident (i.e., once the need for communications between the users of the various channels is over, the patch is removed).

Our recommended conceptual design option does not change interoperability capabilities between TRAX and TCSO or TCPW. The different technologies of their subsystems do not allow TRAX operators to directly contact radio users from TCSO or TCPW. It is possible; however, for the TCSO dispatch consoles to be equipped with a control station that operates on the TRAX DMR channel; this configuration would allow TCSO dispatchers to create patches between TRAX and TCSO or TCPW when needed to allow direct user-to-user communications.

6.6. Schematic of Conceptual Design

The following figure provides a schematic diagram of the conceptual design option that is described in the preceding sections of this report.

Schematic Diagram of Conceptual Design



7. Existing Equipment Re-Useability & Usability

Some of the radio equipment that is currently in-use by TCSO, TCPW, and TRAX can be reused in the conceptual design described above. This section describes what can, and what cannot, be reused.

7.1. Subscriber Radio Re-Usability

The following table presents the inventory of subscriber radios for TCSO, TCPW, and TRAX. This table was included in our Inventory and Needs Assessment Report but we have added a color code to identify the reusability of the subscriber radios.

Those sets of radios shown in green highlight are both currently supported by their manufacturer and can be software-upgraded to be capable of operating on all relevant subsystems and/or supporting the additional features described above. Such software-upgradeable features include vote-scan, P25 (with encryption), and/or MDC-1200. For our budgetary pricing estimate for our conceptual design, included in the following section, we have assumed these radios will be software upgraded and re-used.

Those sets of radios shown in blue highlight are not supported by their manufacturer but they are capable of operating their associated subsystems with reprogramming. This classification mainly applies to TCPW and TRAX radios that are now operating on VHF analog conventional and UHF DMR systems, respectively, and whose proposed new subsystems, as included in our conceptual design, use the same general technologies. Because these radios are no longer supported by the manufacturers, we have assumed in our budgetary pricing estimate for our conceptual design that these radios will be replaced; however, their reuse is possible and could result in a cost-savings to their agency.

Those sets of radios shown in yellow highlight are not supported by their manufacturer and they are capable of operating on some of their associated subsystems but without the additional features described above. For example, most of the yellow-highlighted radios in TCSO's inventory are capable of operating on the VHF, analog, conventional TCSO Dispatch subsystem but without vote-scan (i.e., with manual cell selection) and without MDC-1200. Also, they will not be capable of operating on the P25 TCSO Inquiry channel. Because these radios are no longer supported by the manufacturers and because they do not support all features of their associated subsystems, we have assumed in our budgetary pricing estimate for our conceptual design that these radios will be replaced; however, their reuse is possible and could result in a cost-savings to their agency.

Those sets of radios shown in purple highlight are not supported by their manufacturer and we understand they are being discontinued from use by their agency. We have assumed in our budgetary pricing estimate for our conceptual design that these radios will be replaced.

Agency	Radio Information					
	Type	Manufacturer	Model	Quantity	Use	Radio Model Status
Tehama County Sheriff's Office						
	Mobile	Kenwood	TK-5720	34	Patrol & Admin Vehicles	Active
	Mobile	Motorola	XTL2500	16	Patrol & Admin Vehicles	Discontinued
	Mobile	Various Motorola & Kenwood - Older Models		11	In Process of Being Phased Out	Discontinued
	Portable	Motorola	XTS2500	65	Patrol & Admin Use	Discontinued
	Portable	Motorola	APX6000	11	Patrol & Admin Use	Active
	Mobile & Portable	ICOM	2720	27	Search & Rescue	Discontinued
	Portable	Motorola	XPR3500e	31	Correctional Staff	Active
TRAX						
	Mobile	Motorola	XPR4550	1	Dispatch	Discontinued
	Mobile	Motorola	XPR4550	16	Transit & Paratransit Use	Discontinued
Tehama County Department of Public Works						
	Mobile	Motorola	CP300	61	DPW Vehicles	Discontinued
	Portable	Motorola	CP200	15	Extra-Vehicle Work	Discontinued
	Control Station	Motorola	VXR7000	1	Gerber Base/ Dispatch Radio	Active

In addition to including upgrades or replacements to existing mobile voice mobile radios for TCSO and TCPW, we have included new UHF, DMR mobile radios for those agencies so they can interconnect GPS receivers and transit GPS-based location information to their respective dispatch centers. Our budgetary cost estimates do not; however, include costs for new mapping applications for either agency.

7.2. Dispatch Equipment Re-Usability

As noted above, we recommend that the existing TCSO dispatch consoles be replaced due to their age, their lack of support from their manufacturer, and the ability of new/replacement consoles to support the advanced features described above. For our budgetary pricing estimate for our conceptual design, included in the following section, we have assumed the TCSO dispatch consoles will be replaced.

The control stations used by TCPW and TRAX for dispatch are addressed in the previous section. We assume that TCPW's dispatch control station will be reused but that TRAX's will be replaced.

7.3. Infrastructure Equipment Re-Usability

As identified in our Inventory and Needs Assessment Report, the existing repeater stations in use for TCSO's and TCPW's radio sites are Motorola Quantar and Radius models that do not have support from their manufacturer. The TCSO repeaters at Inskip Butte and Rancho Tehama are incapable of operating in our proposed conceptual design and we have therefore assumed they will be replaced. Because the TCPW repeater is no longer supported by its manufacturer, we have also assumed it will be replaced; however, its reuse is possible and could result in a cost-savings to TCPW.

As TRAX is currently using a subscription-based service provided by Day Wireless, it currently does not have any reusable infrastructure equipment.

7.4. New Equipment Usability

For those sets of user equipment that cannot be reused in new systems, we have examined ways to promote easy usability of their replacements. This involves evaluating how the conceptual design can support the radio or console-usage requirements as identified through our needs assessment and, whenever possible, supported products that could be provided by multiple vendors (to allow TCSO, TCPW, and TRAX users to select products from more than one vendor in order to meet their individual needs). Those requirements, as gathered from users, are:

    - A future system should include radios that are easy to operate and are durable.
    - An array of accessories (including radio holders and remote microphones) is also needed.

- By using the standards of MDC1200 and P25, we are confident that multiple models of subscriber radios from multiple vendors could be used with the conceptual design. This could even include a mix of different radios, including from different vendors, to be selected/purchased for operation by different user groups, thereby allowing each agency/group to select radios based on factors such as ergonomics and available accessories. To accomplish this, we recommend each agency:
- Confirm which user features from those available by the technologies of MDC1200 and P25 are required by their users.

- Specify to vendors the need for radios that provide those features in compliance with the technology standards and, in the case of P25, require vendors to propose only radios that have successfully undergone P25 CAP testing in a multi-vendor environment for those features.
- Specify to vendors the general requirements for usability (ergonomics, accessories) for radios.
- View and demonstrate the products that meet both technical and usability requirements.
    - If possible, demonstrations should occur by a large and diverse set of representatives from the agency and should be conducted in conditions that represent the environment of their real usage (i.e., in the presence of sources of loud noise or in conjunction with heavy protective gear).
- Select those user radios that, in addition to criteria for cost, meet the requirements for technical compliance and that are demonstrated to meet user requirements for useability.

The drawbacks to an environment of multiple vendors of radios are: i) it requires the development and upkeep of multiple versions of radio programming files (one for each type of radio), ii) it adds complexity to developing and maintaining training materials as different radios have different usage methods for features, iii) it may involve complexity in purchasing and deploying accessories as not all accessories (such as speaker mics and portable radio holsters) work with all radios, even when the radios are from the same vendor, and iv) features that are not included in the standard will likely not work between radios from different vendors (e.g., the feature of over-the-air-reprogramming is not part of the P25 standard and, therefore, different vendors will have different/proprietary solutions for delivering it).

The same general situation and guidance exists for dispatch consoles. The selection of MDC1200 and P25 will allow for the selection or an array of dispatch console products from multiple vendors. We therefore recommend the same general guidance for selecting new dispatch consoles as was provided above for user radios, namely, specify requirements in terms of both the technical standard for the feature set (again, requiring P25 CAP completion) and the ergonomic preferences of users (screen layout, feature-functionality workflow, accessory operations) and then conduct demonstrations with a large/diverse sample of operators in environments that, as close as possible, represent real-life.

8. Cost Estimates

This section of this report provides cost estimates for our conceptual design option. Costs are broken into two sections:

- The capital costs to deploy the conceptual design and
- The ongoing costs to support/maintain the conceptual design.

Important Point	The costs included in this section are **budgetary estimates** that are intended to provide enough information to allow Tehama County and TRAX to plan the funding amounts and sources necessary to proceed with the next steps of developing procurement specifications and working with a selected vendor on a detailed design and implementation plan.

	All costs have been developed to be budgetary in nature meaning they are slightly higher than the highest costs we expect to be quoted by vendors. Our pricing information was drawn from multiple vendors and from multiple projects/clients based on vendors' list costs and to that pricing we added and additional contingency factor to cover unforeseen issues.

8.1. Capital Costs for the Conceptual Design

The following table shows the budgetary estimates for the one-time/capital costs to procure and deploy the conceptual design described in this report.

Also included are costs for the above-mentioned project contingency issues and professional services. The contingency costs were calculated as a straight percentage (10%) of all infrastructure costs and they are meant to be available to mitigate the types of risks associated with acquiring sites and frequencies. The costs for professional services are based on our response to the RFP for consulting services and they are intended to provide guidance for the oversight, management, and quality assurance of a vendor's deployment of a system.

Where possible, the costs of different subsystems of the conceptual design are associated with those agencies (TCSO, TCPW, Local Government, and TRAX) that would be their sole users. For example, TCSO would be the sole user of the TCSO Dispatch Subsystem so its costs are shown as associated with TCSO. Some subsystems are shared and in such cases their costs are shown as being associated with the multiple agencies that would use or otherwise benefit from that subsystem. Examples of subsystems with shared costs are:

- Radio site civil work and spare equipment (shared among all subsystems for all agencies)
- VHF antenna systems and site-to-site backhaul (shared among all the VHF subsystems for TCSO, TCPW, and Local Government)

The costs associated with project contingency, vendor implementation services, and professional services are also shown as being shared among all subsystems for all agencies.

Important Point

The table below depicts the distribution of costs if the system's equipment and services are included in one project contract that is paid with typical milestone payments to a single vendor. (The amounts and timing of the milestone payments are addressed below the following table.) There are options for distributing the costs more equitably among the timeframe of the project and they include:

- Removing some equipment and/or services from a single contract with a vendor and purchasing them directly in the earlier years of the project. Examples of items that can be purchased "outside" of a vendor contract in order to distribute their costs into earlier years of the project are subscriber (user) radios, site improvement services, and the backhaul (microwave) links that are used to interconnect sites.
- Financing the purchase of the system through a lease agreement or other, similar mechanism. Financing options can be arranged for directly between Tehama County and a financing agent of their choice or most major vendors of two-way radio systems offer financing packages for projects of this nature. The costs of financing will vary based on the amount of the capital purchase, the lessee's credit rating, the term of the lease, and other factors.

Also, not included in these estimates are the costs for: i) any intelligent bus transit application for TRAX or any mapping applications for TCSO or TCPW, ii) any radios for local government agencies as quantities of radios for those agencies were unknown.

Subsystem	Category Components	Budgetary Estimate (Separated, Where Possible, By Agency) TCSO	TCPW	Local Government	TRAX
Radio Site Civil Work	New and/or upgraded shelters, towers, and main/standby power sources including the improvements noted in the Inventory/Needs Assessment Report as well as improvements to the new sites of Morgan Summit and Tomhead	$565,000 (Shared among all agencies)			
TCSO Dispatch Subsystem	A five site, two-simulcast-cell, VHF, analog, conventional radio subsystem	$330,000			
TCSO Inquiry Subsystem	A single site, VHF, conventional, P25 radio subsystem	$30,000			
TCPW Subsystem	A single site, VHF, analog radio subsystem		$18,000		
Local Government Subsystem	A single site (with four satellite receivers), VHF, analog radio subsystem			$122,000	
VHF Antenna Systems	Antennas, combiners, multicouplers, filters, and transmission lines for all VHF subsystems at all sites	$108,000 (Shared among TCSO, TCPW, and Local Government)			
TRAX Subsystem	A single site, UHF, DMR subsystem (incl. antennas)				$28,000

Subsystem	Category Components		Budgetary Estimate (Separated, Where Possible, By Agency) TCSO	TCPW	Local Government	TRAX
Radio Dispatch Consoles and Interoperability Interfaces	Four new dispatch consoles for TCSO with encryption capabilities and with backup control stations and gateways to connect to external channels of partners/neighbors		$328,000			
Radio Logging Recorder	A software upgrade to the existing logging recorder to accommodate P25/encryption		$55,000			
Site-to-Site Backhaul	New, licensed microwave connections with 1+1 links between Rancho Tehama, TCSO Dispatch, and Inskip Butte and 1+0 links to Tomhead and Morgan Summit – also includes site routers to connect site equipment to backhaul		$807,000 (Shared among TCSO, TCPW, and Local Government)			
Infrastructure Spare Equipment	Typical set of spares for infrastructure		$52,000 (Shared among all agencies)			
Project Contingency	Contingency & Professional Services (10% of all infrastructure above)		$230,000 (Shared among all agencies)			
Subscriber Radios – New Radios * (User devices including hand-held (portable),	TCSO VHF	120 VHF encrypted portables / 30 VHF encrypted mobiles	$513,000 / $130,000			
	TCSO UHF	30 DMR mobile radios (for GPS location-based services)	$81,000			

Subsystem	Category Components		Budgetary Estimate (Separated, Where Possible, By Agency)			
			TCSO	TCPW	Local Government	TRAX
in-car (mobile), and fixed-location (control station) radios/ accessories)	TCPW VHF	15 VHF portables / 61 VHF mobiles / 1 VHF control station		$33,000 / $218,000 / $7,000		
	TCPW UHF	61 DMR mobile radios (for GPS location-based services)		$163,000		
	TRAX UHF	16 UHF DMR mobile radios / 1 UHF DMR control station				$38,000 / $5,000
Subscriber Radios – Upgrades to Existing Radio	Upgrades to 11 TCSO portable and 34 mobile radios		$61,000			
Vendor Implementation Services	Vendor services for design, licensing, staging, shipment, installation, configuration, testing, training, cutover, and project management		$1,194,000 (Shared among all agencies)			
Professional Services	*Development of Procurement Specifications, Assistance with Procurement and Negotiations, Management of Deployment, Testing, and Transition to Operations*		*$125,000* (Shared among all agencies)			
Total Project Capital Costs			**$5,241,000**			

Subsystem	Category Components	Budgetary Estimate (Separated, Where Possible, By Agency)			
		TCSO	TCPW	Local Government	TRAX
* The costs for subscriber radios for local government agencies are not included as the quantities of those radios are currently unknown. Radios for TCSO to be capable of encryption. Costs for all agencies include accessories, programming, and installation (for mobiles)					

The costs of the infrastructure for this project total to approximately $2,300,000 and that amount is typically distributed over the deployment timeframe of the project to deploy that equipment. Different vendors have different expectations for the amounts and the timing of payment milestones and these can often be adjusted during the negotiation of a purchase agreement; however, the table below shows a distribution that we have seen as typical for projects of this scope. It also shows an estimate of the timing of when each milestone will occur – this is shown as an expected number of months from the initiation of the project (which occurs at the signing of a contract with the selected vendor).

Project Milestone Event	**Typical Milestone Payment %** As a % of Total Budgetary Estimate of Infrastructure of $2,300,000)	**Estimated Milestone Schedule** # of Months from Start of Project
Contract Signing	15%	0 months
Completion of Detailed Design Review	15%	3 months
Shipment of Infrastructure Equipment	25%	15 months*
Installation of Infrastructure Equipment	15%	18 months
Completion of Acceptance Testing	20%	24 months
Resolution of Project Punchlist	10%	26 months

** Note: This estimated milestone schedule accounts for longer than usual lead times for equipment procurement and delivery (i.e., global supply chain issues arising since 2020/2021).*

8.1. Ongoing Services Budgetary Cost Estimates

The following table shows the budgetary estimates for the ongoing costs to support and maintain the System as described above.

The set of services included in our estimates have been chosen to meet the user need of "ensuring that any future replacement or upgraded radio system has an appropriate and cost-effective set of support and maintenance services for its long-term sustainability."

Some services must be procured from the System's vendor (or their authorized service provider) and those outsourced services are shown with an annual estimated cost. These are totaled at the bottom of the table into an estimated annual service/maintenance cost.

Note that some services can be provided by in-house staff and those are shown with an estimate of the number of staff days per month required to perform those tasks.

Important Point	Not included in these estimates are those costs for: i) internal staff, ii) radio site leases, or iii) any future expansions of the system beyond the capabilities described in this report.

Support / Maintenance Service	Service Description	Ongoing Support Budgetary Estimate (Annual)	In-House Estimated Efforts (days/month)
Radio System Administration	Overall planning and management of radio system performance and budget; radio database management, also liaison to users and external partners	n/a	1.5-3 days / month
Infrastructure Security & Software Patches	Provide and install as-needed software patches to address security updates, incremental operating system updates, bug-fixes, or other regular non-feature-enhancement updates.	$16,000	n/a
Infrastructure System Upgrades	Provide all hardware and software required to bring entire system to a current level of system- and product-release, to include enhancements and/or corrections to existing features as well as any new features for which vendor does not charge an additional cost. These costs are paid annually but upgrades typically occur every 2-3 years.	$42,000	n/a
Infrastructure Telephone Technical Support	Provide a toll-free phone number with trained staff to assist client in recovery from failures in the system or its components and to diagnose operational problems in accordance with agreed-to response times based on issue severity.	$10,000	n/a
Infrastructure Network Administration	Monitor and manage network resources; adjust network configuration to meet performance and security needs.	n/a	1-1.5 days / month
Infrastructure On-Site Repair	Dispatch on-site resources to restore operations of a component or the system those resources to repair or replace any failed component and shall work to restore	$42,000	n/a

Support / Maintenance Service	Service Description	Ongoing Support Budgetary Estimate (Annual)	In-House Estimated Efforts (days/month)
	system operations with agreed-to arrival and restoration times based on issue severity.		
Infrastructure Depot Repair	Upon determination that a component has failed, provide services for that component's return to vendor's repair depot where vendor shall: i) save the component's as-received configuration, ii) perform available operational checks to determine the nature of the failure, iii) repair the failed component, iv) test the repaired component to confirm that it is returned to operational specifications, v) return the repaired component, and vi) throughout the process track and report on repair status.	$13,000	n/a
Infrastructure Database Management	Edit and maintain the databases of system configuration and operation as necessary to reflect current usage (including additions/ deletions/changes to talkgroups, user radios, aliases, features, etc.) Backup the configurations and databases of system components and retain such backups so that they may be quickly retrieved should they be needed to restore system operations.	n/a	0.5-1 days / month
Infrastructure Equipment Preventative Maintenance	Test performance of repeaters and tune to factory specification, physical inspection of other components.	$17,000	n/a
Infrastructure Site Maintenance	Provide regular inspection, upkeep, and repairs to site shelters and grounds including to fences, landscaping (grass cutting, weed removal), and shelter physical facilities (protection from environmental ingress). Also, conduct regular tests of backup power supplies.	n/a	1-2 days / month
Subscriber Radio Preventative Maintenance and Repair	Test, calibrate, and clean subscriber radios to manufacturer's specifications. Install new programming/configuration files or subscriber firmware if either are available at time of preventative maintenance. Repair	$35,000	n/a

Support / Maintenance Service	Service Description	Ongoing Support Budgetary Estimate (Annual)	In-House Estimated Efforts (days/month)
	radios when broken (assumes 5% of radios require repair per year).		
Total System Support & Maintenance Costs		**$175,000/yr**	**4-7 days / mo**

9. Next Steps

We envision the next steps for this project are a review of this report by the representatives of TCSO, TCPW, and TRAX in order to understand the technologies, the way they are applied to create our conceptual design, and the ability of that design to meet user needs. Additionally, we hope the budgetary estimates can be used to assist in identifying possible sources of funding and in allocating funds to a multi-year project.

In parallel to the review of this report, CDX Wireless will assist TRAX in developing a Request for Information (RFI) to gather the current landscape of vendor offerings for intelligent transit applications. This will involve releasing a set of questions to vendors of such applications (through the RFI), collecting their responses, and compiling the answers received from vendors into one report. Vendors will also be asked to provide budgetary pricing for their offerings so that TRAX can likewise develop plans and budget for funding for an intelligent transit application.

10. Appendix A – Coverage Maps

The following table lists the maps included in the following pages. If there are no additional pages, please see separate file: CDXW TRAX,TCSO,TCPW Alternatives & Recommended Soln Report Appx A, Maps (24Mar2022).PDF"

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<tr><th colspan="3">Radio Subsystem 1: For TCSO's Dispatch Operations – A Two-Cell, Voted-Multi-Cast, Analog, Conventional Simulcast Subsystem</th></tr>
<tr><th>Map Number & Description</th><th>Sites Included</th><th>Operational Scenario</th></tr>
<tr><td>Map #1a, TCSO Dispatch East Side Simulcast (Portable Radio on Street)</td><td>Repeaters at Morgan Summit, Inskip Butte, and TCSO Dispatch – additional voting receivers at Rancho Tehama and Tomhead</td><td rowspan="2">95% coverage reliability and DAQ 3.4 to/from a portable at hip level operating outdoors (at street level)</td></tr>
<tr><td>Map #1b, TCSO Dispatch West Side Simulcast (Portable Radio on Street)</td><td>Repeaters at Rancho Tehama and Tomhead – additional voting receivers at Morgan Summit, Inskip Butte, and TCSO Dispatch</td></tr>
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<tr><td>Map #1d, TCSO Dispatch West Side Simulcast (Mobile Radio)</td><td>Repeaters at Rancho Tehama and Tomhead – additional voting receivers at Morgan Summit, Inskip Butte, and TCSO Dispatch</td></tr>
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<table>
<tr><th colspan="3">Radio Subsystem 3: For TCPW – A VHF, Analog, Conventional P25 Subsystem</th></tr>
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<tr><td>Map #3, TCPW (Mobile Radio on Street)</td><td>Single-site repeater at Inskip Butte (with no additional voting receivers)</td><td>95% coverage reliability and DAQ 3.4 to/from a mobile radio</td></tr>
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<tr><th colspan="3">Radio Subsystem 5: For Local Government – A VHF, Analog, Conventional P25 Subsystem with Voting Receivers</th></tr>
<tr><td>Map #5a, Local Government (Mobile Radio on Street)</td><td rowspan="2">Single Site repeater at Inskip Butte with additional voting receivers at Morgan Summit, TCSO Dispatch, Rancho Tehama and Tomhead</td><td>95% coverage reliability and DAQ 3.4 to/from a mobile radio</td></tr>
<tr><td>Map #5b, Local Government (Portable Radio on Street)</td><td>95% coverage reliability and DAQ 3.4 to/from a portable at hip level operating outdoors (at street level)</td></tr>
</table>