Caltrans TDDC | Report on Transit Technology Ecosystem

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Glossary

AASHTO	American Association of State Highway and Transportation Officials
ALM	Automated Load Management
APC	Automatic Passenger Counter
BEB	Battery Electric Bus
CAD/AVL	Computer Aided Dispatch / Automatic Vehicle Location
CalFire	California Department of Forestry and Fire Protection
Cal-ITP	California Integrated Travel Project
CalOES	California Governor's Office of Emergency Services
CalSTA	California State Transportation Agency
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CHP	California Highway Patrol
CMS	Charge Management Software
CPU	Central Processing Unit
C2C	Center to Center
DER	Distributed Energy Resource
FCC	Federal Communications Commission
FTA	Federal Transit Administration
GEO	Geosynchronous Equatorial Orbit
GIS	Geographic Information System
GTFS	General Transit Feed Specification
GTFS-RT	General Transit Feed Specification Realtime
ICT	Innovative Clean Transit
ITE	Institute of Transportation Engineers
KPI	Key Performance Indicator
LEO	Low Earth Orbit
LoRa	Long Range Radio
LoRa WAN	Long Range Wide Area Network
LPWAN	Low-Power Wide Area Network
MDT	Mobile Data Terminal
MOU	Memorandum of Understanding
MVP	Minimum Viable Product
NEMA	National Electrical Manufacturers Association
NEVI	National Electric Vehicle Infrastructure
NTCIP	National Transportation Communications for ITS
NTD	National Transit Database
OCPP	Open Charge Point Protocol
PRS	Priority Request Server
RFI	Request for Information
RFP	Request for Proposal
SaaS	Software as a Service
SLA	Service Level Agreement
TIDES	Transit ITS Data Exchange Specification

TMDD	Traffic Management Data Dictionary
TODS	Transit Operational Data Standard
TSP	Transit Signal Prioritization
DOE	US Department of Energy
USDOT	US Department of Transportation
VLU	Vehicle Logic Unit
VMT	Vehicle Miles Traveled
V2I	Vehicle to Infrastructure

1. Executive Summary

Public transportation is a vital public service that many Californians depend on to get around their communities. Increasingly, technology and innovation are changing the way transit is managed, improving the delivery of services from operations to rider experience. Transit providers are interested in taking advantage of new technologies but, despite many technology companies offering services in California, face barriers to accessing and leveraging transit technologies in a modular, scalable, and competitive way. Previous work by Caltrans found that transit providers would welcome support in addressing barriers and leveraging technology to improve their service delivery.

This report identifies five transit technologies which have the potential to improve transit services but face critical market frictions limiting their use – Automatic Passenger Counters (APCs), Charge Management Software (CMS), Computer Aided Dispatch / Automatic Vehicle Location (CAD/AVL), Non-cellular Connectivity, and Transit Signal Prioritization (TSP). While the market for each transit technology is unique, the barriers facing transit providers from using them fall into five dimensions: market existence, market competition, product interactions, access to market, and market knowledge.

This report summarizes each technology and provides recommendations to cultivate a modular, scalable, and competitive transit technology market in California. While the recommendations are interrelated and build upon each other, the priority actions are to:

- **Overall |** Define standard performance metrics and incorporate these into state-level reporting requirements and grant applications to streamline efforts.
- **APCs |** Provide guidance on bundling and modular procurement based on transit provider size, needs, and capacity.
- **CMS |** Solicit feedback on types of CMS optimization, contractual requirements for interoperability, and create an industry working group comprised of public and private parties.
- **CAD/AVL |** Define core components of CAD/AVL and compare their functionality and data reporting capability with other modular technologies.
- **CAD/AVL |** Create a scope of work checklist for transit providers that want to procure CAD/AVL systems and provide boilerplate contracting language in advance of procuring state purchasing schedules for a variety of CAD/AVL systems.
- **Non-cellular Connectivity |** Publish a coverage map of current cellular and broadband networks and the anticipated build out over the next 5-10 years to identify priority transit corridors for state intervention and planning.
- **TSP |** Adopt NTCIP protocol for all signals statewide, sunset proprietary data format, and investigate the need for a data standard.

This report serves as a roadmap for where and how California state agencies can direct support to help small and rural transit providers better access and implement priority transit technologies to serve riders.

2. Context & Purpose

Public transit is a vital public service that many Californians depend on to live, work, and play. Increasingly, technology plays a ubiquitous role in the industry, with the potential to improve the delivery of this service, from operations to rider experience. Despite many technology companies offering services in California, transit providers report facing barriers to accessing and leveraging transit technologies.

Previous work by Caltrans[1] found that transit providers would welcome support from the State of California in overcoming these barriers. However, there remains a question of action: what must be done to support transit providers and eliminate current barriers? This report identifies five core transit technologies which face critical market frictions and provides recommendations to Caltrans and other state agencies to cultivate a modular, scalable, and competitive transit technology market.

2.1 California transit landscape & technology access

California is home to over 250 fixed-route transit providers and nearly 600 paratransit and non-fixed route service providers, including non-profit organizations. Together, these transit providers serve Californians' mobility needs across a diverse set of geographies and land use contexts.

The majority of California transit providers are relatively small with 87% of transit providers operating fewer than 100 buses.[2] Smaller and more rural transit providers typically have limited staff and resource capacity, making it difficult to proactively assess, adopt, and implement new technology. These structural issues mean most California transit providers are unable to take advantage of modern technology and data standards that improve service delivery, reduce operational costs, and meet rapidly evolving customer experience' expectations.

Previous research[3] established that many transit providers have a relatively small number of transit technologies, known as their technology "stack", and that these technologies often were out of date or were not interoperable, making it difficult to modernize and add technologies incrementally over time. Transit providers expressed a desire to grow their transit stack and to "future proof" their operations through interoperability principles, but lack the resources – both in terms of staff capacity and funding – to accomplish this. Respondents to a survey[4] on transit technology needs conducted as a part of the research explicitly requested technical assistance from

[1] https://www.calitp.org/assets/Caltrans.Report.on.Transit.Technology.Ecosystem.pdf

[2] Ibid.

[3] Ibid.

[4] Ibid.

California on the topic of transit technologies. The transit providers also identified priority technologies experiencing some kind of market inefficiency limiting their use in California.

2.2 Methodology

In order to identify market inefficiencies, the research team first defined the characteristics of a healthy, efficient market using five dimensions (Section 2.2.1). Using a three-step filtering process (Section 2.2.2), the research team developed a list of priority technologies and analyzed the areas of market friction (Section 3). For each priority technology, the research team engaged relevant stakeholders to explore barriers to using or offering the technology. Interviews focused on the frictions experienced by both vendors and transit providers and impacts on customer experience. The recommendations proposed in this report are aimed at alleviating these frictions through standardized, modular, and scalable solutions that support a robust transit industry in California.

2.2.1 Five Market Dimensions

The five dimensions used to define the characteristics of a healthy, efficient market are: market existence, market competition, product interaction, access to market, and market knowledge (Figure 1).

Figure 1 Five Market Dimensions

Market Existence	Market Competition	Product Interactions	Access to Market	Market Knowledge
• There is a **market with both supply and demand** that are self-sustaining.	• There are **multiple quality options** in the market that are willing and able to sell to transit providers at fair market prices and deliver the purchased product.	• The vendor product meets **interoperability principles** and is easily assessed against **standard performance metrics**.	• **All transit providers** are able to access and purchase desired products, both in standalone and bundled formats.	• Transit provider **staff understand** what they are buying and why they are buying it; and are able to negotiate based on this level of knowledge.

Market existence describes the demand and supply for the technology. Importantly, the demand and supply should be mostly equal and self-sustaining (i.e., a healthy market would <u>not</u> have significant demand but limited supply or vice versa).

Market competition describes the vendors active in the market. The emphasis lies on sufficient demand to support multiple vendors and also that those vendors are able to provide a quality technology product on an ongoing basis without strategic dilution. Additionally, these vendors must also be willing to sell products to transit providers at a market price.

Product interaction describes how a technology product interfaces with other technologies (both hardware and software) and whether standardized benchmarks are available to evaluate its performance – because understanding product interaction is crucial for optimizing usability, functionality, and user satisfaction. In a healthy market, product interaction would not require customization or additional costs (i.e., there would not be vendor lock-in). There should also be a clear method by which to measure success that is recognized by both supply and demand sides of the market (i.e., vendors and transit providers use the same methodology to calculate performance).

Access to market describes how transit providers can obtain a transit technology product. Transit providers should be able to purchase the desired product through an existing contract or via a procurement mechanism. This purchase should be possible as either a piece of a larger bundle or as a modular layer.

Market knowledge describes the transit provider's level of product understanding. Staff should have a clear idea of what they are purchasing and be able to accurately describe their needs. They should have an accurate expectation of what the product can and cannot do. This knowledge should allow staff to negotiate for a standard product that meets their needs at a reasonable price.

The research team developed diagnostic questions for each market dimension (Figure 2) to determine whether a technology product was healthy in that dimension.

Figure 2 Diagnostic Questions

Market Dimension	Diagnostic Questions
Market Existence	• Does it exist? • Is there supply? • Is there demand? • Are these balanced?
Market Competition	• Is there more than one (quality) vendor? • Are the available vendors in direct competition? • Are the available vendors able (and willing) to sign a contract? • Are the available vendors able (and willing) to deliver a product that meets the promised criteria, functionalities, and/or features? • Are the prices transparent, consistent, and market-based? • Are the prices affordable for transit providers?
Product Interactions	• If there is a standard for product interactions, is it being used?

Market Dimension	Diagnostic Questions
	• If there is not a standard, is there clear documentation[5]? • Does it meet the Mobility Data Interoperability Principles[6]? • Are there standardized performance metrics and benchmarks? • Are these metrics being used? • Can the metrics be easily verified by a non-technical staff member?
Access to Market	• Is there a consistent way for transit providers to purchase? • Is the pricing transparent? • Are there options to purchase the product as a single module? • Can transit providers get what they want/need regardless of size/location? • Are any segments of the market excluded?
Market Knowledge	• Do transit providers understand what they're purchasing? • Are transit providers able to make informed purchases? • Do transit providers know the product enough to negotiate?

2.2.2 Filtering Process

The research team used multiple steps to filter the technologies identified in the transit provider survey (Figure 3) down to technologies to be prioritized. Technologies that were deficient in one or more dimensions and not already being supported by ongoing programs at Caltrans were prioritized for further investigation.

Figure 3 Task 1 Transit Technologies

Alerts	Annunciators
Automatic Passenger Counters (APCs)	Charge Management Software (CMS)
Computer Aided Dispatch / Automatic Vehicle Location (CAD/AVL)	Data warehouse
Digital Signage	GTFS / GTFS Management

[5] Clear documentation is defined by the Mobility Data Interoperability Principles as "compatible with open standards and/or proposed open standards, free from cost and restrictions to use, and posted to a public website in human- and the appropriate language-neutral, machine-readable format." https://www.interoperablemobility.org/implementation/

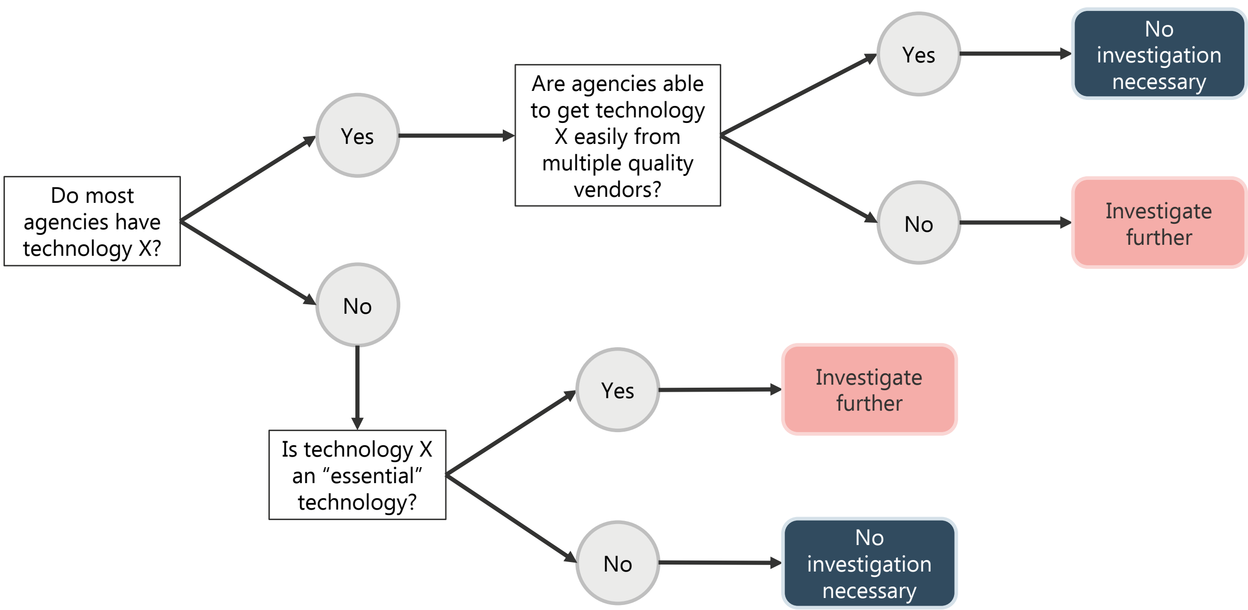
[6] https://www.interoperablemobility.org/

Head signs	Infotainment
Next stop signs	Non-cellular connectivity (ex. satellites, LoRa, etc.)
Payments (onboard fares, offboard fares, backend services)	Scheduling software
Traffic Signal Prioritization (TSP)	Web-based Trip Planner

First, the research team eliminated any technology which Caltrans is already actively addressing (i.e., through research or existing technical support). These included: alerts, digital signage, GTFS / GTFS Management, Payments, and Scheduling. To prevent overlapping efforts, these technologies were not included in this work.

Second, the research team evaluated each remaining technology based on the health of the overall market. This filtering process used a decision tree approach (see Figure 4 for an example).

Figure 4 Example Filtering Process



Technologies that were not investigated further were excluded either because of a 1) lack of a market failure or 2) lack of specialized demand from transit providers (i.e., the technology exists off the shelf in a way that satisfies provider needs). Those with market frictions were further investigated to identify causes of the market failure and areas for potential state intervention.

Figure 5 Summary of Transit Technology Categorization

Deficient Market

- Automated Passenger Counter (APC)
- Charge Management Software (CMS)
- Computer Aided Dispatch (CAD)/ Automated Vehicle Location (AVL)
- Non-cellular connectivity
  - Satellites
  - LoRa
- Transit Signal Prioritization (TSP)

Efficient Market

- Offboard rider information
  - Trip planner (web based)
- Onboard rider information
  - Annunciators
  - Head signs
  - Infotainment
  - Next stop signs

Systems that Caltrans is already researching

- Alerts
- Digital signage
- GTFS / GTFS Management
- Payments
  - Onboard fares
  - Offboard fares
  - Backend services
- Scheduling

3. Analysis of Priority Technologies

3.1 Intro

The priority technologies identified for further investigation experience one or more market failures. For each technology, this section will describe the technology and the applicable market failure(s). Recommendations to alleviate or remedy the market failure are found in Section 4.

Figure 6 Five Market Dimensions

3.2 Automatic Passenger Counters (APCs)

3.2.1 Overview

APCs are sensors placed onboard transit vehicles with accompanying software to satisfy ridership reporting requirements and to use for service planning purposes. More recently, transit providers have also used APCs to provide live crowding and customer experience information through passenger-facing information sources such as GTFS-RT feeds.

What are APCs?

Automatic Passenger Counters (APCs) are sensors typically installed at public transit vehicle doors to detect and count passengers as they board and alight. The sensor hardware is often packaged with software to facilitate data analysis and post-processing. APCs provide valuable data for transit providers as input into mandatory reporting requirements such as to the National Transit Database (NTD), service planning, ridership forecasts, and more.

The main components of APCs include:

1. **Sensor**: Detects passenger boarding or alighting. There are a variety of detection methods including infrared, stereoscopic (3D) sensors, or LIDAR sensors.
2. **Onboard logic module (in non-cloud setups):** Ingests the data collected by the sensors and interprets it to create events that result in raw datasets coming from an APC system. This contains the algorithms that distinguish between boarding and alighting events.
3. **Central Processing Unit (CPU) or Vehicle Logic Unit (VLU):** Adds location, time, date, and route information to the different boarding and alighting events. This connects to the onboard logic module. Note, VLU is typically used if a CAD/AVL system is present.

4. **Router (in some Cloud setups):** Sends the data directly to the cloud where suppliers can populate information such as location, time, date, and direction, as well as apply any additional logic. This is only present for some APC setups; when it is used, the sensors are connected to a router onboard the vehicle.

APC systems typically include two vendors: one for hardware and another for data processing. The hardware vendors supply the components above, while the data processing vendors convert the raw data received from the sensors into "clean" data (i.e., removing any anomalies). Some CAD/AVL vendors offer fully integrated services (i.e., both hardware (sourced through a third-party) and processing services) and can use their onboard VLU to connect to the APC sensors to populate event data to the time and route level.

How can APCs be used?

Transit providers receiving federal funds are required to provide information on ridership, passenger miles traveled, and on-time performance to the Federal Transit Administration (FTA) during their triennial review, as well as to submit annual reports to the National Transit Database (NTD). Transit providers are evaluated on the accuracy, completeness, and timeliness of their submissions. Historically, transit providers have used manual counting methods to satisfy these requirements. Manual counts are conducted using cameras or stationed field staff on a random sample of routes. This method is labor intensive and less accurate, especially for planning purposes, which can benefit from the near real-time, granular data collected by APCs.

APCs are an alternative to manual counting and allow transit providers to link boarding and alighting events with specific vehicle locations, time/date, and routes. To use APCs for federal reporting, the APC must be certified by the FTA to ensure its accuracy levels are compliant with the FTA's transit reporting standards. Every time a transit provider sets up APCs, it needs to be certified by the FTA (even if the APC vendor's system has been certified previously at another property) for the relevant three-year reporting period. If a transit provider submits midway through the FTA triannual period, the certification will only be valid until the end of the period. APCs must be recertified a minimum of every three years.

The certification process is typically provided by APC processing vendors for an additional fee, and includes an accuracy check and calibration, and an FTA-approved sampling methodology that is representative of fleet-wide ridership. Recalibration and testing may be done periodically during the certification period.

Transit providers also use APCs for planning purposes. In addition to some of the metrics and benchmarks that are required by funding agencies (i.e., FTA), transit providers can use APC data to identify routes and times with the highest demand, provide ridership and revenue forecasts, and cross-check farebox and validator revenue numbers. APCs today can provide granular data about ridership categories and can help transit providers evaluate their fare products (i.e., if APCs data shows a larger number of children riding the bus, a transit provider can create fare products targeted towards that group) and add or remove service from routes depending on demand.

In recent years, APC data streams have begun to integrate with other real-time passenger-facing information data such as GTFS-RT to provide crowding information. APC systems can also provide insight into other customer facing elements, such as the number of wheeled mobility devices onboard or the number of occupied bike racks. This can be used to provide important information to help riders make better-informed decisions about the route they are choosing for their journey. For example, if someone is using their bike and the bike racks are full, they can choose to wait for the next bus or finish their journey by bike. Similarly, riders using a wheeled mobility device may choose the next bus or choose another route if all designated spots are occupied.

3.2.2 Identified Market Failures

What is the problem with the market today?

Market Existence | Market Competition | Product Interactions

Access to Market | Market Knowledge

Market Competition | Competition for direct APC procurements is limited due to the bundled procurements that dominate the market

The APC market has two avenues that transit providers can procure from today. The most common avenue is to add-on an APC module to existing CAD/AVL products. In this scenario, the CAD/AVL vendor takes responsibility for the installation of APC hardware by subcontracting a hardware vendor and takes on the data processing component itself. However, this option is only available for transit providers that already have a CAD/AVL product from the vendor; transit providers that are only interested in the APC module cannot access it as a stand-alone service from CAD/AVL vendors.

Further, this avenue can be difficult for smaller transit providers that cannot afford or may not need a full CAD/AVL system. This route also makes it more difficult for a transit provider to access their APC hardware vendor to troubleshoot issues. As a result, there are few options for transit providers to procure APC systems from hardware and data processing vendors directly, particularly for stand-alone data processing services. The research team was only able to identify two.

Product Interactions | Neither raw nor processed APC data outputs are consistent across the market.

There are data standards that use APC data as an input, such as GTFS-RT. There is also a data standard for storing serialized APC data, the Transit ITS Data Exchange (TIDES). However, there aren't any open standards that are adopted by APC vendors. Since APC data has historically operated in a closed environment where the integrations were primarily between CAD/AVL vendors and APC hardware, a standard hasn't been formally or widely adopted. As APC data has progressed to also feed into other technology stacks like GTFS-RT, the lack of a standard may have resulted in increased implementation times and costs to the transit providers.

As more transit providers look to APCs to meet reporting requirements, the adoption of a standardized data specification would greatly assist transit providers with accessing and sharing their data, particularly smaller agencies without need or capacity to operate CAD/AVL systems. The Transit ITS Data Exchange Specification (TIDES) is an open-source data specification that covers multiple operational data points including passenger counts. The industry has not formally adopted this as a method of storing historical APC data.

Market Knowledge | Most APCs have historically been procured through CAD/AVL contracts, so transit providers have had a limited view of the APC market at large and use cases of the data.

Dedicated data processing vendors have introduced more specialized offerings, adding additional use cases and flexibility to what transit providers can achieve with APC data. Additionally, APC hardware has progressed considerably over the years and transit providers may be working with legacy equipment that does not use the latest sensing technology, particularly as the cost of sensors declines rapidly. APCs have become much more accurate and can be used to distinguish between adults, children, and various objects such as strollers and bikes. The external integration of APCs with GTFS-RT feeds to supply crowding data has opened additional use cases that improve passenger information and customer experience. Many transit providers are not fully aware of the latest developments in APCs, or how to maximize the usefulness of their systems.

3.3 Charge Management Software (CMS)

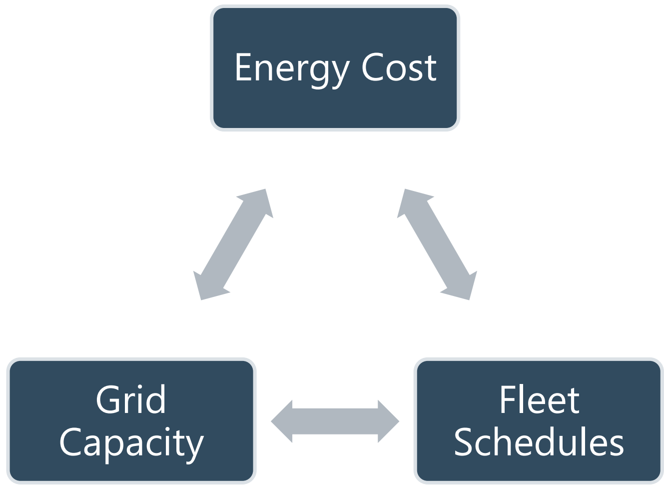
3.3.1 Overview

Charge Management Software (CMS) is an essential element of the transition to zero emission transit fleets that will continue to grow in its importance within the transit technology stack. With the California Air Resources Board's (CARB) Innovative Clean Transit (ICT) regulation in full swing, transit providers are considering battery electric bus (BEB) solutions and will need CMS to support the effectiveness of BEB operations by minimizing energy costs, reducing stress on the grid, and supporting charging schedules that allow for on-time yard pullout.

What is CMS?

Charge Management Software (CMS) is a digital platform to monitor, control, and optimize electric vehicle charging operations. It works in conjunction with battery electric vehicles and chargers and connects this physical infrastructure to a centralized cloud-based management platform. That platform – the heart of CMS – allows for real time monitoring and control of charging stations, performance, energy consumption, and operational status. Depending on the individual transit provider's goal (i.e., low energy cost, on time performance, etc.), the CMS will assist in managing the way in which BEBs are charged. CMS is a core part of electrification at scale as it allows for more reliable service, reduced operational costs, reduced capital costs, and better rider experience.

CMS can be optimized to support a transit provider with specific goals. In a simplified model, the three dimensions of optimization are: fleet schedules, grid/transmission capacity, and energy cost. In an ideal scenario, the CMS software can optimize for all three simultaneously; however, this is rarely the case and an optimization of one dimension typically requires a suboptimal outcome on another. Transit providers may prioritize different types of optimization based on their own constraints and goals. Different CMS vendors may be more or less able to support the type of optimization requested.



There are two main types of CMS products on the market: 1) standalone CMS-specific software and 2) component CMS software in a larger fleet management suite. Standalone CMS-specific software is designed to complement other existing systems but often depends on integrations to do so, while component CMS software comes pre-integrated into typically proprietary fleet management suites. There are advantages and disadvantages to both product types, summarized in Figure 7.

Figure 7 Comparison of CMS Types

	Advantages	Disadvantages
Standalone CMS-specific software	- Designed for purpose. Because the vendor is specialized, this software often performs "better" given it is a discrete focus area and product for the vendor. - More likely to be interoperable. Given the software is standalone, it is designed to work with a variety of products on the market, making it easier to layer onto an existing transit technology stack.	- Integrations can depend on other vendors, who may represent legacy systems, be hesitant or unwilling to work with the CMS vendor. - The transit provider must develop and manage another contract.

	Advantages	Disadvantages
Component CMS software	- Already integrated with fleet management, so this is just one component of a larger, bundled suite. - The transit provider has a single contract to manage. - Can be a good solution if transit provider does not already have other technology.	- Can underperform. Because this is only one small piece of what the vendor provides, and may not be their code, it is often not the focus. This can result in less-than-optimal service. - May not be able to choose between all types of optimization, depending on the vendor. - Can result in vendor lock-in. Given it is a vertically integrated solution, the vendor does not have a strong incentive for interoperability. This can make switching out software or hardware vendors very difficult or impossible.

One of the biggest differences between the two types of CMS is the extent to which each is interoperable with other software and hardware. The level of interoperability is influenced by what type of data protocol is being used and the achievement of a compatibility handshake between components that signals that different components can work together. The main protocol is known as Open Charge Point Protocol (OCPP). OCPP regulates communication between the zero-emission vehicle, the charger, and the CMS. It is an industry-led protocol, managed by Open Charge Alliance, a non-profit focused on open standards for sustainable charging infrastructure.

There are different versions of the OCPP protocol, as it is a living protocol which continues to evolve to meet market needs. Version 1.6.J of the OCPP protocol has been almost universally adopted by CMS vendors in the US market. Note that version 1.6.J does not support automated load management (ALM), which is a feature often desired by transit providers. Version 2.0.1 does support ALM and is also the minimum requirement for the US Department of Energy (USDOE) National Electric Vehicle Infrastructure (NEVI) formula program.

CMS is usually sold by "tier" based on functionality; more (or more complex) functions result in more costly software. The functions which most transit providers are likely to need or want are:

- Charge Monitoring: Real-time tracking of charging status, power consumption, and battery levels for each BEB in the fleet.
- Charger Alert System: Automated notifications for charging-related issues, such as unexpected disconnections, charging failures, or charger maintenance needs.

- Automated Load Management (ALM): Charging coordination for multiple BEBs within total power limitations (i.e., grid capacity, etc.).
- Distributed Energy Resources (DER) Integration: Capability to integrate with on-site energy generation and storage systems.
- Telematics Integration: Incorporation of real-time vehicle data, including state-of-charge, location, and energy consumption.
- Schedule Optimization: Plan charging schedules based on route assignments, energy needs, and available charging windows, if this is not available through the agency's scheduling system
- Energy Cost Optimization: Dynamic adjustment of charging patterns based on time-of-use rates and demand charges for electricity.
- Key Performance Indicator (KPI) Dashboard: Visual interface displaying crucial metrics (i.e., energy consumption, charging efficiency, cost per mile, emissions reduction, etc.).

The functions requested by transit providers – particularly ALM and DER integrations – often require a more expensive tier of CMS as they go beyond basic functionality (i.e., static management, less visibility, etc.).

This technology helps optimize the operation & charging of EVs, allowing for more reliable service, reduced operational costs, reduced capital costs, and better rider experience.

3.3.2 Identified Market Failures

What is the problem with the market today?

Market Existence | Market Competition | Product Interactions

Access to Market | Market Knowledge

Market Competition | There are several active and quality vendors in the market, but there is limited pricing transparency.

The US market for zero emission infrastructure is growing rapidly. This growth has largely happened in the personal and light-duty vehicle space. However, that trend is changing as other sectors, like freight, begin to move toward zero emission. There are several active and quality CMS vendors serving the transit space. These vendors offer services designed to fit the transit use case and the full suite of functionality described above.

Most CMS vendors appear to offer a subscription pricing model based on the number of charging plugs under management. The subscription is paid up front on a fixed interval (i.e., prior to the delivery of services instead of after services are completed). The interval of upfront payment is flexible, ranging from one year to five years depending on transit provider preference. Payment schedules more frequent than once a year are not common, and vendors seem hesitant to set up a "month to month" model. Some vendors have differentiated pricing depending on the type of charging plug (i.e., DC fast charger vs. L2 charger). There are generally one-time upfront costs related to integrations and set up.

Despite information regarding the payment model, there was little available information related to the costs and prices themselves. Transit providers reported receiving wide ranging cost proposals from vendors responding to CMS procurement requests. The research team did not find any public benchmarking reports on what transit providers should expect to pay for CMS.

Product Interactions | There is an industry protocol (OCPP) that allows for basic interoperability between components, but there is no standard on how to implement it.

There is a fundamental difference between a protocol and a standard. A protocol creates a communication system but can come in multiple "dialects" which can make communication less efficient. The difference in protocol dialect can be significant as there can be many ways to say the same thing, causing delays when needing to search for specific information or "reread" to understand fully. Protocol dialects can be different enough that vendors must create patches to smoothly communicate. A standard, on the other hand, specifies a wider range of requirements and can be more rigid than a protocol. The rigidity of a standard can make communication more efficient, as the way it is implemented in each situation is more similar (i.e., information must go in a specific order within a message, regardless of vendor). This broader approach allows for more seamless interoperability.

Because of this nuance, a product being OCPP compliant (regardless of version) is not enough to guarantee interoperability between vendors and systems. Due to the potential variation in protocol "dialect" being used, there is an additional compatibility "handshake" (i.e., with the physical charger) which must be done for the various pieces of the system needed to work together. The handshake is essentially a switch that must be turned on during the set-up process that says the pieces are cleared to work together. This handshake is a separate layer from OCPP and should be confirmed with each vendor based on the transit provider's unique transit technology stack, and can be done as a part of the procurement process.

Market Knowledge | This is still a new technology for transit providers who may not have the technical knowledge necessary to procure and support CMS deployment. Many transit providers appear to have limited understanding of CMS features and how to use them.

Transit providers across California have been working to comply with the California Air Resources Board (CARB)'s Innovative Clean Transit (ICT) regulation since its adoption at the end of 2018. The regulation requires that by 2029, only zero emission buses (ZEB) will be allowed for new bus purchases. Most transit providers have focused on how to begin construction on newly built infrastructure (ex., charging station) and how to procure ZEBs, given the amount of upfront resources required. This has left CMS to be an afterthought for many; even the providers who have already purchased CMS, such as in a bundle with other hardware or software, generally feel unequipped to effectively leverage its benefits.

Only now that ZEBs have begun to take to the road in greater numbers have transit providers come back to CMS as a potential way to manage operational costs and deployment challenges. This has caused three main consequences: 1) a general lack of technical understanding of CMS and how to use it, 2) an inability to test or measure optimization performance as part of the procurement evaluation process, and 3) a prebuilt environment into which CMS must layer. In combination, this creates a minefield for transit providers to navigate with little to no support or prior knowledge of CMS.

Additionally, calculating whether CMS is "worth it" is a difficult exercise in part due to the lack of pricing transparency combined with the wide variation in utility costs across the US.

3.4 CAD/AVL

3.4.1 Overview

CAD/AVL is a highly sought-after technology for many transit providers due to its perceived importance to operations planning and monitoring. This is especially true for transit providers that are expanding coverage, fleet size, and/or service offerings. The industry has matured to include sufficient competition. However, it has also expanded to include additional functionalities and multiple systems integrations with tangential relationship to CAD/AVL, with little room to purchase a "basic" product.

What is CAD/AVL?

Computer Aided Dispatch (CAD)/Automatic Vehicle Location (AVL) systems allow transit providers to manage operations and provide real-time vehicle location for both operational and passenger information. The services can be used in fixed route public transit settings, as well as other transportation operations that require dispatch and fleet management capabilities.

CAD/AVL systems are often tightly bundled with proprietary hardware. Most CAD/AVL systems include two hardware components as part of their core offerings:

1. **Mobile Data Terminals (MDTs):** These are ruggedized touch-screen units that facilitate two-way communication between dispatchers and drivers. These units show driver directions during routes, communicate any schedule updates or route updates in case of deviations, and provide any emergency alerts. Other systems, such as fare validators and annunciators that integrate with CAD/AVL often allow the driver to control them from the MDT interface.

2. **Vehicle Logic Unit (VLU):** An onboard computer providing a digital interface between any integrated on-vehicle systems and the CAD/AVL back-office. The VLU routes data between other integrated, onboard components such as APC sensors, fare validators, communication systems, etc.; and between the on-board components of the CAD/AVL system itself, and the CAD/AVL back-office system. VLUs typically have both physical interfaces to ethernet, audio, and the vehicle itself (usually via SAE J1708 ports) as well as Bluetooth and on-board Wi-Fi network LAN. Some VLU's contain additional hardware and capabilities within the VLU container, such as vehicle position (GPS units, dead-reckoning, etc.), audio amplifiers, radio modems, and cellular modems.

CAD/AVL vendors have extended their offerings to integrate multiple systems such as APCs, annunciators, yard management tools, and more. These add-on modules may require additional hardware and/or software, often obtained separately from subcontracted suppliers.

Regardless of the selected add-ons or separate but integrated systems, most CAD/AVL products share the following core functionalities:

1. **Dispatch:** The ability to manage and coordinate fleet operations centrally. This entails assigning routes, managing service and route changes, responding to any emergencies or reported incidents, and facilitating communication with operators.
2. **Communications:** CAD/AVL may use one or more communication channels to facilitate two-way communication between dispatchers and operators, including voice over radio networks or through the MDT interface. Dispatchers need to communicate with operators about deviations, alerts, or emergencies. Operators need to communicate with dispatchers about emergency situations or on-the-ground or in-vehicle situations that require their awareness. Sometimes, operators can communicate with other operators to coordinate timed transfers or assistance.
    a. **Panic button**: Some CAD/AVL communications modules will also include a panic button that operators can use to quickly report an emergency or issue that cannot be communicated via radio. This sends a message to the dispatch team that an incident has occurred and communicates real-time details about the impacted bus. Dispatchers use this information to manage the situation and potentially alert authorities.
3. **Real-time vehicle tracking:** CAD/AVL systems gather granular data on vehicle location, speed, and bearing by vehicle. This data may optionally include vehicle diagnostics or status information such as door open/closes, ramp deployments, bike rack deployments, etc. Vehicle tracking enables dispatchers to manage service delivery and customers to plan their journeys more effectively by publishing vehicle location data in GTFS-RT format.

Transit providers looking to implement CAD/AVL can select between an on-premise or a cloud-hosted CAD/AVL system.

1. **On-premise systems** are those in which the transit provider is responsible for supplying and maintaining the hardware and servers that physically host the CAD/AVL system. They are typically more resource intensive as in-house staff must be more involved in monitoring, maintaining, and troubleshooting the system. Today, on-premise implementations tend to be reserved for larger transit providers with higher customization needs, requirements to control software versions, sufficient in-house resources, and a stronger desire and capability to control their critical digital infrastructure, for a variety of reasons, such as security, privacy, data integrity and so on.
2. **Cloud-hosted CAD/AVL systems** have lower upfront costs and will generally have a predictable ongoing cost that runs on a Software as a Service (SaaS) model. Servers and data are hosted on the cloud and facilitated through the CAD/AVL vendor. Cloud-hosted systems require less internal staff resources since many responsibilities such as data security management and maintenance are outsourced to the vendor. While this model typically speeds the roll-out of the "latest version" of any software, transit providers typically do not have the ability to control when the upgrade happens.

Who should use CAD/AVL?

Transit providers with growing fleets, large geographic coverage, and increasing demand may consider CAD/AVL to replace or supplement manual processes used to manage their operations. When this happens, staff performing dispatch duties can more efficiently conduct their responsibilities with the tools offered by CAD/AVL systems. Real-time monitoring capabilities allow dispatchers to identify any issues as they arise and respond more effectively by rerouting vehicles or by deploying backup buses to impacted routes.

Additionally, CAD/AVL systems can facilitate additional on-board data streams (AVL, APC, AFC), that underpin metrics that are often desired or required for performance monitoring oversight, and grant funding opportunities. For example, the National Transit Database (NTD) requires transit providers to report on various performance metrics such as ridership, revenue hours, vehicle miles traveled (VMT), and on-time performance. Insights into vehicle speeds and events such as hard braking can also support compliance with safety requirements that transit providers must adhere to.

This data also helps transit providers assess their operations and more reliably forecast operational costs such as projected refueling needs and maintenance costs. Speed and vehicle usage metrics – obtained through real-time tracking data – provide insights that can support operations managers in realizing efficiencies such as fuel cost savings. The data created by CAD/AVL systems can also be used to verify other data sources in case a transit provider would like to do this. For example, ridership data can be measured against fare collection data to see if revenue aligns with expectations. These checks can be done periodically to ensure that different systems are working as expected.

3.4.2 Identified Market Failures

What is the problem with the market today?

Market Existence | Market Competition | Product Interactions

Access to Market | Market Knowledge

Product Interactions | CAD/AVL systems frequently integrate with multiple technologies, yet the industry hasn't adopted the North American standard for archival data (TIDES) or the interface between scheduling systems and CAD/AVL systems (TODS)

There are many vendors providing services in the CAD/AVL technology category. Data standardization allows different CAD/AVL vendors to integrate with other systems using a consistent methodology, making the process more efficient and predictable. Since CAD/AVL systems often serve as a hub for different onboard technology, standardization is critical.

The Transit Operational Data Standard (TODS), an extension of GTFS Schedule, was co-created by vendors and transit providers in 2022 to standardize how scheduling software exports necessary data to CAD/AVL systems which then manage how that schedule is operated. The concept of Transit ITS Data Exchange Specification (TIDES) has been circulating since the late 2000s and was realized via a TCRP project, and then formalized by an independent board of transit providers, states, and vendors. TIDES is in its infancy of being implemented but has strong momentum to become adopted as the standardized way to store serialized data about vehicle locations, passenger activity, and fare payment.

Off-board, the industry has largely adopted GTFS-RT for passenger facing information, but the industry hasn't yet widely adopted the North American standard for archival data (TIDES) or the interface between scheduling systems and CAD/AVL systems (TODS).

Access to Market | Vendors have smaller profit margins from smaller transit providers so those with fewer than 25 vehicles don't have access to the full market of vendors.

Many vendors in the industry will not bid on deployments for smaller transit providers (<25 vehicles). On-premises systems are out of reach for many small to medium sized transit providers due to the lack of resources to procure, manage, and maintain the hardware and software needed to operationalize the system. This has become less of an issue with the move towards cloud-based CAD/AVL, but implementation costs remain higher for smaller transit providers since those tend to be consistent regardless of deployment size. Knowing that this is the case, CAD/AVL vendors may decide against bidding for smaller projects because of the lower profitability of the project.

Market Knowledge | CAD/AVL systems are primarily purchased as a bundled solution geared toward medium to large transit providers and contracts.

Because these larger transit providers often request customization, customized integrations and add-on products, the core feature set of CAD/AVL is not always clear. This is particularly difficult for smaller transit providers when their staff go to prepare procurement specifications; most of the bundled products include more features than smaller transit providers need, which drives up cost and (just as important) operational complexity.

CAD/AVL systems available on the market today often include many advanced features. Vendors often sell the idea that every time an add-on or upgrade is done for one transit provider, all transit providers will receive that benefit at no additional cost. However, this has also blurred the understanding of what CAD/AVL core functionality entails, which can result in bundling more features than a transit provider needs. And few transit agencies understand the uniqueness of each integration they request. These factors, as well as the lack of internal resources specialized in IT/ITS in smaller transit providers, can lead to specifying CAD/AVL systems with a feature set that is not part of the standard core CAD/AVL offering. This drives up the cost of CAD/AVL and often forces transit providers to pay for features they neither want nor need.

It should also be noted that many of these add-ons can be procured separately if a transit provider chooses to do so. The benefits of unbundling certain features include having direct access to the vendor and selecting a product that better fits the transit provider's needs. However, transit providers should also make sure that in procuring certain features separately, they are not duplicating certain technologies. For example, procuring multiple routers or communication units.

3.5 Non-cellular Connectivity

3.5.1 Overview

Transit providers in California – particularly those serving rural areas – often experience significant connectivity dead zones, which prevent them from receiving and pushing data from a vehicle. The inability to transmit data can be a major barrier to implementing transit technology such as GTFS-RT or contactless payment. Additionally, lack of connectivity poses key operational concerns as actual bus locations are unknown, making it difficult to coordinate schedules between two different transit providers. There are roll on effects related to safety concerns as the status of a vehicle is unknown in an emergency and communication options are limited at best.

What is Non-Cellular Connectivity?

Non-cellular connectivity allows transit providers to transmit data without the cellular network, such as through satellite antennas and Long-Range Radio (LoRa) networks.

Satellite connectivity is achieved by using a satellite antenna to connect into a satellite constellation in space. There are two main types of satellite constellations –

geosynchronous equatorial orbit (GEO)[7] and low earth orbit (LEO). Most commercially available satellite vendors use a LEO constellation.

GEO constellations are further away from Earth and remain "stationary" because they move at the same velocity as the Earth. Fewer GEO satellites are needed to provide full coverage of the Earth but due to their distance, they are more difficult to launch and maintain. The distance can also cause a delay in data transmission. Additionally, there are certain latitudes which cannot be covered due to the curvature of the Earth.

LEO constellations, on the other hand, are much closer to Earth and are seen to be "moving" when viewed from the ground. Each LEO satellite has a smaller window of the Earth given its proximity, so more LEO satellites are needed to provide full coverage. LEO satellites are usually smaller, making them cheaper to manufacture, launch, and maintain. The short distance from Earth also means a negligible delay in data relay. However, LEO satellites have a shorter lifespan and can be susceptible to outages if there is an issue with a satellite in the constellation.

Long-Range Radio (LoRa) uses long-range radio waves to wirelessly transmit data over long distances, operating on a license-free band (e.g. 902 MHz to 928 MHz). LoRa is able to cover larger areas than high frequency bands because of the way the radio waves can be diffracted over obstacles and are able to follow the curvature of the Earth. This is a key advantage for rural or obstructed environments.

LoRa uses a low power, low-data rate, wide area networking protocol layer known as LoRa WAN. This protocol is recognized by the International Telecommunications Union as a standard for low-power wide area networks (LPWANs) and defines the communication rules and network architecture for devices using LoRa.

LoRa requires infrastructure investments and build out in the desired coverage footprint. These buildout costs are generally lower than those of a cellular network but are still more expensive than if a transit provider can leverage an existing network via a SIM card. LoRa is designed for low power usage and needs fewer base stations or repeaters as compared to higher frequency systems. However, it can only transmit small data packages and cannot handle any bandwidth-intensive applications, unlike traditional broadband. LoRa networks are also more suited to latency-tolerant applications.

3.5.2 Identified Market Failures

[7] Also called geostationary orbit.

Market Existence | Transit use case implementations for both satellite and LoRa connectivity are still relatively new.

Until the last few years, the satellite industry had largely catered to government and military applications due to the high cost of building, launching, and maintaining space-based infrastructure. That is changing. There is now a commercial satellite industry that, while still nascent, is growing rapidly. The transit industry would only be a small element of this market but both supply and demand appear to be increasing.

Similarly, while the LoRa and LoRa WAN market is growing exponentially worldwide, the transit sector is an underdeveloped area of application. The market for LoRa and LoRa WAN, as previously described for use in public transit, does not exist, or the market size is too small to be noticed or to be meaning. Similarly, there is little demand from transit providers requesting a LoRa network; while transit providers are asking for connectivity solutions, many do not have the technical knowledge to specifically request this technology solution.

Market Competition | There are very few vendors providing in-motion satellite connectivity and the market largely functions as a monopoly. Similarly, few – if any – LoRa vendors are looking to engage in the transit market.

While there now exists a market for commercial satellite coverage, there is very little competition. The transit use case requires satellite connectivity that functions in motion at speeds above 55 mph. To date, there is only one major vendor who can meet this need. There are a growing number of vendors able to offer residential, stationary satellite connectivity so it is the hope of the research team that the entry of new players into the market will translate into the transit in-motion use case in the coming years.

Prices for satellite-based connectivity – both for the hardware and the recurring data plans – remain significantly higher than traditional cellular networks. It should be noted, however, that even during the time in which this report was written, the price for in-motion satellite connectivity has dropped. The research team believes this indicates a positive trend of downward price pressure which may result in a more competitive and accessible market.

LoRa vendors compete for market share in the larger IoT market. There are numerous companies providing LoRa hardware, LoRa WAN software, or both. This market engages vendors around the globe. However, these vendors are not competing in the transit sector largely because it has been an ignored application for them.

Access to Market | Satellite antennas and data plans are not yet on state contracts which can make it much more difficult for smaller transit providers to purchase, as writing an RFP (assuming the transit provider has a procurement specialist) for specialized transit technology of this kind is complicated and risky for a smaller provider.

The major vendor in the commercial satellite market is not currently on state contracts or other government purchasing mechanisms available to transit providers. To date, the only way to purchase directly from the vendor is via a retail method. This can be a challenge for transit providers who may be subject to certain procurement thresholds. Resellers do exist and are more accessible to transit providers but the mark-up on price is significant with one documented instance of 8x the retail price.

Moreover, there is little to no flexibility in the Terms of Service from the vendor. Again, this can be a hurdle for transit providers that must insert a specific clause to be compliant with funding requirements. The current model is the same as a retail purchase with no room for negotiation or grant funded local agencies.

Due to the lack of a market (and competition) for using a LoRa-based network to communicate public transit vehicle positions and arrival times, transit providers do not have any ability to access and purchase LoRa-based solutions for this transit use case.

Market Knowledge | Alternatives to cellular networks are less familiar to many transit providers, particularly newer technology like satellites. LoRa networks are also seen as highly technical and difficult to implement.

There is a growing interest from transit providers about non-cellular solutions given the increasing importance of real time data transmission for operations and rider information. For many more rural providers, there is no cellular solution that can be used to fulfill this need. However given the novelty of the commercial satellite market, many transit providers do not immediately see this as a realistic – and affordable – option for them to pursue. It is often seen as an overengineered solution to an "easy" problem. As satellite antennas become more accessible, this is likely to change.

Additionally, transit providers remain unsure of how a non-cellular solution will work and interact with their existing hardware and transit technology stack. Other technology vendors also remain uncertain as to how the mechanics will work. For most transit technologies, the responsibility of connectivity falls to the transit provider, leaving them to figure it out on their own.

LoRa solutions are even more nebulous for transit providers and – in some ways – out of their purview. Put bluntly: there are technical and cost unknowns that need to be figured out first to determine the feasibility and viability of a LoRa-based network in the transit use case. Moreover, LoRa networks require some larger infrastructure investments which can be difficult for transit providers to do on their own. Once again, the lack of knowledge of this technology, how to purchase it, and how to implement leads to the perception of a difficult and overengineered solution to an "easy" problem.

3.6 Transit Signal Prioritization (TSP)

3.6.1 Overview

Transit Signal Prioritization (TSP) is becoming an increasingly popular topic among transit providers as a solution to increasing congestion and its impact on operational reliability. Beyond its positive impact on vehicular movement, TSP can also support complete streets and safety initiatives by optimizing signal timings for multimodal crossings (i.e., pedestrians, bikes, etc.) to make streets an accessible and safe space for all users.

What is TSP?

Transit Signal Prioritization (TSP) allows transit vehicles to be given priority or preemption over regular traffic by changing the signals to facilitate the transit vehicle's journey. A priority request is where the signal phase is extended or shortened to speed up the vehicle journey time. Priority requests can be granted or denied; it is not always a "given" response. Priority is the most common TSP request by transit vehicles. A preemption request is a more forceful override that is immediately granted and is mostly used for emergency vehicles, such as ambulances. The focus of this section is on priority-based TSP software.

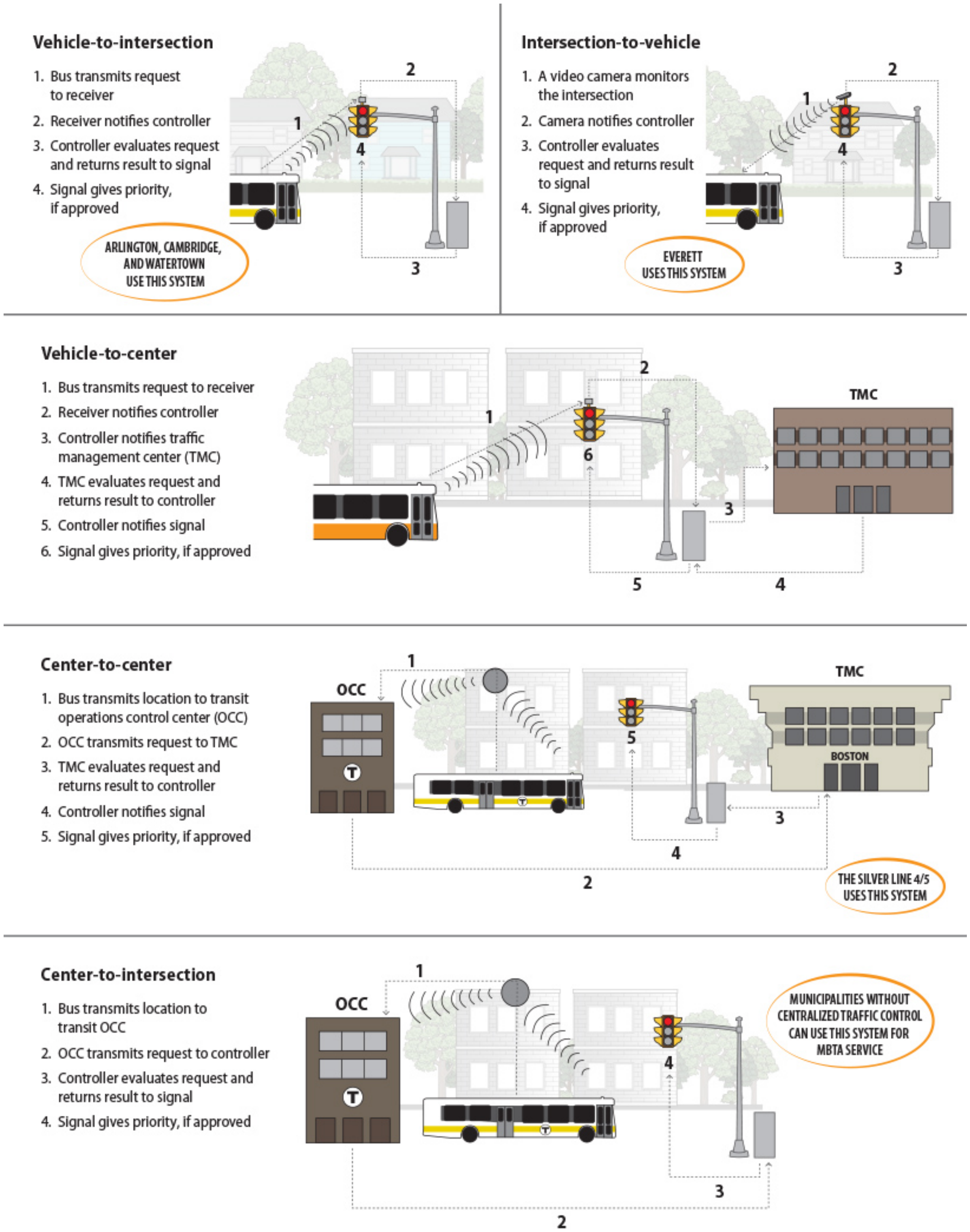
TSP is not a new technology; it made its US debut in the early 1980s and started to gain momentum in larger cities in the 1990s. These early systems came in a variety of forms – infrared line-of-sight systems, optical systems, radio-based systems – but faced challenges with visual obstruction, weather, and signal interference. GPS and AVL technology began to be used in TSP systems in the late 1990s into the early 2000s and helped provide more precision of vehicle location. Since the 2010s, TSP has been shifting toward cloud-based technology. A cloud-based system can consolidate data from a variety of sources and transmit this data over the communications network. The lag time in data transmission has decreased, allowing for more real time decision making. Cloud-based systems also enabled integrations with existing technology such as CAD/AVL and APCs.

TSP system architecture includes a detector, priority request server (PRS), and a signal controller. The detector identifies when a vehicle wants priority and estimates the arrival time. The PRS coordinates these priority requests, checks them against the business rules, and determines any signal phase changes to be implemented. The signal controller physically changes the lights based on the updated timing plan provided by the PRS.

Communication between these components is regulated under the National Transportation Communications for ITS Protocol (NTCIP). NTCIP is jointly managed by the National Electrical Manufacturers Association (NEMA), Institute of Transportation Engineers (ITE), and the American Association of State Highway and Transportation Officials (AASHTO). NTCIP is supported by the US Department of Transportation (USDOT). The specific elements of NTCIP that apply to TSP are NTCIP 1201 (signal operations) and NTCIP 1211 (TSP). Both are key pieces to the communications protocol used by the components to effectively communicate.

Broadly speaking, these components can be used to deploy the two main types of TSP priority systems, which differ in how requests are processed: distributed or centralized. In a distributed system, the communication is vehicle to infrastructure (V2I). Decisions are made at the intersection level and TSP requests are made by the vehicle as it approaches the intersection. This tends to be a "simpler" TSP deployment as it is not managing other data inputs. In a centralized system, the communication is center to center (C2C). Decisions are managed in a centralized system with multiple intersection visibility and, as such, can consider bigger picture implications of the request (i.e., impact on other intersections, overall system schedule adherence).

Figure 8: Different TSP Implementations[8]



The data used in both types of TSP systems can either be passive or active. A passive TSP system is one which cannot detect the transit vehicle in real time and/or does not have direct communications with the vehicle. For example, a passive TSP system may

[8] https://www.bostonmpo.org/data/html/studies/transit/TSP-Guidebook/TSP-Guidebook.html

have set universal rules, such as coordinating signal changes based on a transit schedule and optimized for transit speeds. This could mean pre-programmed priority requests are granted despite the vehicle being ahead or on time. An active TSP system is one that is in direct communication with the transit vehicle and/or can detect the transit vehicle in real time. For example, an active TSP system may use hardware on the vehicle and/or a real time location data feed (i.e., GTFS-RT, CAD/AVL, etc.) to communicate a location to the signal. Modifications to signal phases are then made only in the presence of a transit vehicle requesting priority and meeting the set business rule parameters. Passive priority may be a better option for areas with a high frequency of transit vehicles as the volume of requests could potentially be disruptive. Active priority systems may be better suited to more complex environments that require additional control and situation-based decision making or more rural routes with limited traffic flow.

Business rules dictate if a TSP request is granted. A transit provider could allow for unconditional priority, where all vehicles are treated the same regardless of schedule adherence or crowdedness level, for example. Even in an unconditional priority environment, the request will need to calibrate with clearance intervals for pedestrians and already moving vehicles, minimum green times, any preemption requests, etc. A transit provider could set additional parameters for consideration when granting (or denying) a TSP request. Examples of common business rules include:

- Number of seconds/minutes behind schedule
- Number of passengers (i.e., crowding level)
- Time since last TSP request
- Total TSP requests in X time (i.e., minute(s), hour)
- Local vs. express routes (including bus rapid transit)
- Type of transit mode (i.e., bus, tram, light rail, etc.)

The business rules also must define how to handle conflicting requests. The majority of existing deployments use a "first come first serve" approach, but there are other ways to prioritize. Examples include basing prioritization of conflicting requests on magnitude of schedule deviation (greatest deviation gets priority), corridor type (major road vs. side road, local vs. express), level of crowdedness (more passengers get higher priority).

3.6.2 Identified Market Failures

What is the problem with the market today?

Market Existence | Market Competition | Product Interactions

Access to Market | Market Knowledge

Market Competition | There are several active and quality vendors in the market, but there is limited pricing transparency.

There are active and quality vendors offering a variety of different types of TSP deployment – from centralized to distributed, active and passive systems, hardware or cloud-based. However, the evolution of this technology in recent decades – particularly the shift toward cloud-based technology – has changed the pricing model. Market prices now vary greatly from vendor to vendor depending on deployment type and number of integrations required.

TSP vendors appear to price per intersection, as opposed to per vehicle. This means that the price is agnostic to the number of requests made or the number of vehicles involved in the deployment. Cloud-based technology vendors are opting for a paid-up-front subscription based on a "as a service" (SaaS) model, with flexible payment terms (i.e., buy one year up front, five years up front, etc.). Vendors interviewed as a part of this research recognized that transit providers are often dependent on grants to implement TSP and that those grants vary in how they can be used (ex., operating expenditure vs. capital expenditure); vendors indicated a general willingness to work to create a payment schedule that is mutually beneficial.

Hardware-based deployments require some amount of upfront investment to purchase the hardware itself. This hardware often must exist on each vehicle, making this the main exception to the intersection driven cost model, but then also allows the project to be deemed a capital expenditure. There may be intersection hardware costs regardless of deployment type if the signals are not yet "smart."

Important to note is that one element of the cost uncertainty is the integration costs from adjacent vendors. These costs are not charged by the TSP vendor themselves. Rather, it is a required integration with a third-party vendor to receive the data required for TSP to operate (ex., a five second or less polling rate of location data). Some of these costs can be mitigated by implementing an open data and standardized transit technology stack; however, any integration work from a third-party vendor will likely come with a time and materials cost.

Product Interactions | There is an industry protocol (NTCIP) for TSP which allows for basic product interoperability, but there is no standard on how to implement. Additionally, California uses its own, proprietary format.

NTCIP is an industry lead protocol and covers many types of communications, including those related to signals and TSP. However, NTCIP itself is only a protocol – meaning that the data can be conveyed in several different ways while still being considered compliant. Vendors often must issue custom solutions to ensure their product can interact with each jurisdiction's signal type. This can make it more difficult for a transit provider to easily change vendors as there will almost always be upfront integration costs necessary to work with the type of NTCIP protocol each jurisdiction is using.

Moreover, Caltrans uses its own state specific format that de facto functions as a proprietary system; this format is not compatible with NTCIP without additional integration work. This creates significant hurdles for vendors looking to deploy TSP across multiple jurisdictions; if any Caltrans signals are involved, there is immediately additional work needed for the TSP product to work. The cost for this work is often passed off to transit providers, who must pay for the custom integration.

4. Recommendations / Interventions

The following section presents recommendations for potential interventions which Caltrans, alongside other California state agencies, could implement to mitigate or minimize the market failures identified. Some of the recommendations are technology agnostic (Section 4.1) and others are specifically targeted to an individual technology (Section 4.2). These recommendations are often interrelated, and these solutions should be implemented holistically. Without them, the transit providers will continue to face critical challenges related to vendor lock-in, reduced interoperability, and limited access to certain transit technologies which will hinder California's ability to deliver efficient and effective transit service statewide.

4.1 Overall / Technology Agnostic

Define standard performance metrics and incorporate these into state-level reporting requirements and grant applications to streamline efforts.

Performance metrics are a key tool for transit providers to use in evaluating the benefit generated by transit technology. However, some technologies do not have standard way to measure success, leaving transit providers to either come up with a methodology on their own or to not measure benefits at all. Other times, different vendors will use different formulas to achieve the same metric. This lack of standardization means that transit providers are left comparing apples to oranges that can make benchmarking difficult.

A list of general performance metrics would help alleviate this. At its most basic, the list would describe metrics based on outcomes: if you want to see X, measure Y. The way to measure Y would then be described. This would help the entire industry: transit providers, vendors, and Caltrans alike.

Transit providers often know the outcome they seek but do not know how to measure if it is happening; by making the list outcome-driven, it becomes easy for transit providers to navigate. By providing the formula for the desired metric, transit providers can easily incorporate the formula into their own procurement documents.

For vendors, this would limit the number of ways to slice data and minimize the number of custom reports that need to be built for transit providers. A statewide list of performance metrics would also set a clear expectation to the market on how success will be measured.

Finally, Caltrans would benefit by standardizing performance metrics, because it would streamline reporting requirements. Requirements – for annual reports and for grant applications – can be directly pulled from the published standard performance metrics. For transit providers using the standardized performance metrics, their data outputs would be ready to use for these submissions without any additional manipulation.

Store standardized data and create reporting dashboards for transit providers using the defined standard performance metrics.

Going one step beyond standardizing the performance metrics, Caltrans could also store the standardized input data (i.e., TIDES, GTFS-RT, etc.) and generate reporting dashboards based on the metrics. These dashboards could be used both by the transit providers themselves and by Caltrans for a myriad of reporting purposes. For transit providers for which Caltrans makes annual NTD submissions, this would streamline the process significantly. It could also streamline grant applications and allow Caltrans staff to communicate grant opportunities automatically to transit providers who qualify.

4.2 Priority Technologies

4.2.1 Automatic Passenger Counters

Investigate and provide guidance on types of APC hardware technologies and their use cases.

Many transit providers lack a comprehensive understanding of APC use cases. At a basic level, APCs provide the capability to count passengers boarding and alighting vehicles. The technology has evolved to become more accurate, reaching accuracy levels of 99% or more. APCs can process complex scenarios such as groups boarding in close proximity and can tell adults apart from children and objects. Although sensing technology is highly accurate, various issues can skew passenger counts including malfunctioning on-vehicle equipment and poor integrations with AVL systems. Newer use cases – such as crowding information – require real-time processing capabilities, something that vendors may not provide.

However, there are many sensors on the market using different sensor and processing technologies at varying price points. Some APCs use infrared sensors to create a 3D image of the person or object boarding/alighting the vehicle, while others use camera technology or simpler light breaking technology to conduct passenger and object counts. Understanding the difference between these products is necessary to empower transit providers to make informed choices on the technology they wish to procure.

Caltrans is well positioned to conduct a formal analysis of the APC ecosystem and clarify the core differences between different types of hardware and their use cases, including any cost drivers. For example, transit providers interested in collecting granular data on bike ridership may not need the same types of sensors as a transit provider that does not want that data. Providers looking to primarily use APCs for NTD reporting (without difficult sensing situations such as crowding) will not need the most advanced hardware or the full services of a dedicated data processing vendor to get accurate measurements.

Caltrans can launch a market engagement exercise to understand the different offerings and create an accessible resource that transit providers can reference as they look to procure APCs. There are various use cases that are currently available including NTD reporting, real-time information for riders, as well as transit planning. Caltrans can use the outcomes of this exercise to create materials that help providers make informed decisions about how APCs (and what types) fit into their operation as well as potentially act as SME in a state purchasing schedule procurement open to local agencies with DGS.

Provide guidance on bundling vs modular procurement based on transit provider size, needs, and capacity.

Previous sections of the report highlighted how APC hardware, and in some cases APC data processing and analytics, have historically been bundled through CAD/AVL procurements. In this scenario, CAD/AVL vendors subcontract APC hardware vendors and serve as an intermediary for the hardware while sometimes providing processing services, which include data cleansing and reporting. Any issues with the APC hardware go through the CAD/AVL vendor, which can present challenges in addressing problems in a timely and transparent manner.

Transit providers may decide that they do not need a CAD/AVL system but would still like APCs to support their ridership data collection. In this case, a modular approach is a viable option. Transit providers can procure APC hardware and select a data processing vendor that meets their needs. The data processing vendor can cleanse the data and apply their algorithms to attach stop-level data to boarding and alighting events.

Additionally, transit providers that want the full breadth of APC offerings may decide to pursue a modular route regardless of whether or not they have a CAD/AVL system. APC data processing vendors often provide a more robust offering which can include additional reports and analyses, faster response times to APC related issues, and more focused development of additional features and reports than a CAD/AVL vendor does in a bundled purchase.

In the process of developing materials on APCs, it is recommended that Caltrans also provide guidance on the different paths transit providers can take when procuring APCs. This should also include an investigation into existing master contracts for APC hardware and gaining a deeper understanding of the true cost of APC systems. Since most hardware is procured through CAD/AVL or dedicated processing vendors, it isn't clear whether there are cost savings to be realized by creating a direct procurement avenue through hardware vendors or through existing LPAs.

Provide sample contracting language for both hardware and data processing.

As Caltrans builds its understanding of the different types of APC hardware, their interactions, use cases, and contracting models, it should publish sample contract language that transit providers can incorporate into their procurements. An important component of this is including examples of Service Level Agreements (SLAs) or Key Performance Indicators (KPIs) that transit providers can include in their RFPs to enable them to specify clear service descriptions and performance benchmarks and demand better service provision regardless of the contracting method.

Investigate the need for and potential use of a data standard.

APCs normally involve two levels of data exchange: one between the hardware vendor and the data processing vendor, and another between the data processing vendor and external systems (i.e., GTFS-RT). Neither output today has a standardized data format.

APC processing vendors have not adopted a standard for structuring the data they process from sensors. The use cases for APCs are likely to continue to increase as transit providers introduce more technology to their operations. Today, APCs are being used to supply crowding data through GTFS-RT feeds. If a new use case is introduced, this will necessitate additional integrations. Standardization would make the integration process consistent for vendors, thereby reducing costs. Different technology systems can expect to receive APC data in the same standardized format, meaning one process can be applied to ingest data from different APC vendors.

Given that transit providers are interested in streamlining their reporting obligations to the FTA, Caltrans should explore leveraging these data streams by working directly with technology vendors. This approach would help ensure accurate data reporting while reducing the burden on transit providers for whom Caltrans submits reports to the NTD. To simplify this process and to facilitate other technology integrations with APCs, Caltrans should investigate the need for a standard and the official adoption of the TIDES to create a serialized historical record of APC data.

There are many potential use cases for APCs that can make this a highly sought after technology, especially as different systems become more connected. Some future use cases include automated reporting, communication with TSP systems to prioritize high occupancy vehicles, and predictive analyses for forecasting future demand.

4.2.2 Charge Management Software

Engage the market for feedback on the types of CMS optimization, contractual requirements for interoperability, and create an industry working group comprised of public and private parties.

Despite this research, there are still many unknowns related to CMS. One of the largest questions that remain is if there is a material performance difference in optimization algorithms between vendors. Are some vendors delivering better results on different types of optimization? Is there a measurable difference in the performance of different vendor's optimization algorithms? Without this understanding, it is difficult to define key performance indicators (KPIs). Market engagement – potentially in the form of a request for information (RFI) – could help Caltrans better understand the nuances of CMS optimization and hear market suggestions for KPIs that can be used in future contracts. In addition, market benchmarking – in the form of some independent evaluation of CMS system performance in different optimization scenarios – would also allow transit providers to understand the differing types of optimizations and incorporate performance KPIs and benchmark standards into their procurement evaluations, which they are currently unable to do.

Interoperability remains a core focus for Caltrans and a tenet of "future proofing" technology investments. To this end, market engagement should be conducted to more fully understand any contractual requirements which could assist in ensuring the transit provider's ability to "plug and play" CMS with any hardware or software stack. If there are key interoperability barriers which are currently immovable, transit providers would benefit from understanding how to avoid or overcome these barriers, with Caltrans support. Caltrans would also be better informed on key contractual requirements that would need to be incorporated into any potential state-wide procurement for CMS.

Market engagement would also allow Caltrans to facilitate transit-focused working groups. These working groups could focus on collaboratively tackling interoperability barriers or evaluating and creating future data standards for CMS. This type of continual industry engagement has been very successful in the past and allowed Caltrans to move the market from within, as opposed to imposing market changes from above (which has been less successful).

Coordinate between CMS and scheduling software vendors to agree on an open data exchange to support the effectiveness of both software.

CMS will need to consume schedule data to optimize a charging schedule that allows for on-time vehicle pull out and any maintenance that cannot be done while charging. However, the details of how the software interacts with CMS and how the CMS is using scheduling data for its optimization algorithm remains unclear. Caltrans should obtain a better understanding of this interaction by working directly with transit providers who have already implemented both CMS and scheduling software. Of particular importance is understanding specifically how Remix, the scheduling software purchased by CalSTA and managed by Caltrans on behalf of 90 transit providers, interacts with CMS. Given this is a state-purchased software, it should be a responsibility of Caltrans to ensure Remix can easily stack and integrate with CMS from different vendors.

The confluence of CMS and schedule data is also critical for a transit provider to assess the feasibility of its routes with BEBs. BEBs have different range constraints from traditional fossil fuel vehicles; transit providers may have to reorganize schedules and routes to accommodate charging. A successful integration between CMS and scheduling software can simplify this process.

It remains unclear at which point in the process that the CMS "tests" for the feasibility of routes (i.e., if there is enough charge for the BEB to complete the route and return to the charging station). Defining when and how this feedback loop occurs will be very important and could greatly impact the level of effort needed to optimize for fleet schedules. At this point, Caltrans is encouraged to push CMS and scheduling software providers to work to a real time open data exchange if that is not already happening.

The real time exchange can help eliminate the number of iterations required to find a solution. This will help alleviate the burden on transit provider staff.

Provide sample contract language related to ecosystem interoperability.

Once Caltrans builds out its understanding of potential pitfalls for CMS interoperability, it should issue sample contract language that transit providers can use in their own procurement. The research team has already identified that requiring OCPP 1.6.J or higher may not be enough. It will be important to require vendors – both for CMS and the chargers themselves – to commit to the compatibility handshake. By including strong language in their procurement documents, transit providers can leave more doors open to themselves by avoiding vendor lock-in and committing to an interoperable system.

However, transit providers themselves do not have the current level of technical know-how on CMS to do this effectively on their own. Offering sample contract language is an easy and meaningful way for Caltrans to offer basic technical assistance to transit providers working to meet ICT regulations with BEBs.

Investigate the need for and potential use of a data standard.

OCPP is a critical piece to CMS, and its role in building a foundation for an interoperable system should not be understated. However, given that it is a protocol and not a standard, there may be room to build onto OCPP to future proof CMS interoperability. While it may be that the sample contract language provided by Caltrans is enough to ensure product interoperability, this assumption should be investigated and verified.

If contractual language is not enough, Caltrans should investigate the potential use of a data standard. This should be a conversation with the industry and Open Charge Alliance, the OCPP maintainer, to ensure any data standard – or other standardization effort – is done collaboratively with the industry in a way that makes business sense and achieves California's interoperability goals. The working group discussed in the first recommendation could be an excellent platform through which to hold this conversation.

Investigate and issue guidance on minimum functionality for transit needs.

The research team identified that transit providers will likely need a higher tier of CMS service to meet their needs related to DER integrations and ALM. However, the functionalities of CMS and how these are grouped into "tiers" for pricing is still highly variable from vendor to vendor. Caltrans should investigate and define the minimum viable product (MVP) recommended to address transit provider needs. It is anticipated this minimum functionality may vary based on size of fleet, type of utility or DER in use, and desired optimization.

After defining the MVP for CMS, Caltrans should issue guidance to transit providers on what to look for to meet their needs. The aim of this guidance should be consumer education such that transit providers feel comfortable making an informed decision about any CMS purchases. Transit providers may decide to add additional functionality, but there will be clarity on the minimum requirement to achieve the identified needs. This will also send a clear signal to the market as to what transit is asking for, which could encourage vendors currently focused on commercial CMS to consider providing transit-oriented products.

Provide technical assistance to transit providers during the procurement process and post-procurement.

CMS is a new product and transit providers are still learning how and when to use it. Caltrans should provide technical assistance to transit providers who are looking to "go first" in procuring and purchasing CMS. By supporting these transit providers, Caltrans will be able to learn firsthand where the pitfalls and challenges are and offer technical assistance accordingly. This support will also allow Caltrans to gather data on market pricing and mitigate the current lack of price transparency. Caltrans should help transit providers understand the benchmarks for market prices in order to set expectations ahead of a procurement.

The support should not end upon contract award – there is still much technical assistance needed for the post-procurement implementation and contract management. Post-procurement implementation should also include support for CMS feature utilization to maximize value. Again, this support will encourage transit providers to be first movers knowing that they will receive staff support and technical assistance to ease their experience.

4.2.3 CAD/AVL

Formalize industry commitment to adopting the Transit Operational Data Standard (TODS).

TODS is an open standard that describes scheduled transit operational data to support sharing between software products, transit providers, and more. TODS 1.0 was released in 2022 and extends the General Transit Feed Specification (GTFS) to include additional information on personnel and non-revenue service. This helps bring the transit industry closer to achieving interoperability across its technologies by standardizing the way schedule and operations data is shared between different suppliers and software providers.

Caltrans already encourages transit providers to adopt the GTFS standard for passenger information; moving towards TODS is a natural next step. TODS adds supplemental information to a transit provider's GTFS feeds for internal schedule representation across back-office systems. Unlike GTFS, TODS files are not uploaded for public use.

While TODS has been received positively, many transit providers do not know to include this in the scope of work for their procurements or as a request of their existing vendors. To accelerate adoption, Caltrans is encouraged to:

1. Participate in TODS working groups to get feedback on effective methods of increasing adoption.
2. Create a series of webinars to engage vendors and transit providers about implementing TODS.
3. Review existing MDIP boilerplate language for incorporating TODS into Request for Proposals (RFPs) and, following any necessary changes or additions, endorse the language to increase exposure and use by transit providers.
4. Clarify use cases for adoption and identify effective methods for dissemination.

Investigate and define core components of CAD/AVL and compare their functionality and data reporting capability with other modular technologies.

CAD/AVL systems have expanded to incorporate many functions and many integrations. Their base offering typically includes two pieces of hardware: the Vehicle Logic Unit and the Mobile Data Terminal. These components help power the core functionality of CAD/AVL systems which includes:

1. Dispatching software
2. Communications
3. Real-time vehicle tracking

Most CAD/AVL vendors will include these features in their basic offering without the ability to procure them separately. However, it is unclear whether bundling these features is a functional requirement or simply a vendor preference. Caltrans should investigate these different offerings, understand any pre-requisites, and compare them with similar modular technologies which can perform the same function and/or data reporting. The purpose of this exercise is to publish guidelines for small/medium transit providers on what they should be looking for when procuring a CAD/AVL system and which features are better sourced from other vendors (i.e., unbundled).

Create a scope of work checklist for transit providers that want to procure CAD/AVL systems and provide sample boilerplate contracting language where useful.

Both vendors and transit providers alike cited limited transit provider staff capacity as a barrier during the RFP process. Small and medium transit providers typically do not have access to a technology specialist making it both difficult to write and evaluate a transit technology RFP. Transit providers in this situation often copy and paste RFP requirements, which transit provider staff do not fully understand, or omit any technical specification, allowing vendors too much leeway to offer products which may not be desired. The lack of technical specifications is also difficult for vendors who struggle to ascertain what is actually being requested. Transit providers can end up with a product that does not fit their needs, an overly customized system that inflates the cost and is not fit for purpose, or an RFP process where vendors simply do not respond. In any case, the outcomes are undesirable.

To mitigate this issue, Caltrans can develop materials that support transit providers during the scoping process. This can include sample boilerplate contract language, and a scope of work checklist that transit providers can reference during their procurement process. The goal of these knowledge products is to support transit providers in identifying the core requirements they should focus on when specifying a CAD/AVL system. As a result, vendors will also see better quality specifications from California transit providers, which can mean more interest from the vendor community and a more streamlined procurement process.

Work with industry vendors to agree on publication guidelines or a protocol to share transit provider data with Caltrans and more easily meet reporting requirements.

Transit providers are expected to provide accurate reporting on their operations to meet their funding requirements. As transit operations become more technology driven, transit providers can generate accurate data and better meet these requirements programmatically. However, the reporting process remains cumbersome and time-consuming. To make this process more effective, Caltrans should work with the industry on establishing a publishing protocol to streamline programmatic data sharing directly between vendors and Caltrans.

Implementing an agreed upon industry protocol would remove the burden in self-reporting certain datapoints such as on-time performance and yearly ridership. However, the industry must first move towards a standardized data format for sharing this information to streamline the process.

4.2.4 Non-cellular Connectivity

Publish a coverage map of current cellular and broadband network and the anticipated build out over the next 5-10 years to identify priority transit corridors for state intervention and inclusion in statewide planning.

Anecdotally, transit providers speak of cellular connectivity being an ongoing challenge for them. Realities of geography and terrain lend credence to this argument. However, there is not currently a comprehensive coverage map of California that shows both the current cellular and broadband (fiber) network and its medium-term footprint build out.

While there have been state[9] and federal[10] initiatives to map coverage, these are not comprehensive nor granular enough to be actionable. Site testing in the more rural areas of California suggests that the reported coverage may be higher than the experienced coverage. The proposed coverage map would go further than these other initiatives to show the layers of current connectivity levels, anticipated build out in 5 years, and anticipated build out in 10 years.

The map will be used to identify priority transit corridors for connectivity build out, with the goal of achieving statewide capacity for real time location data sharing. These priority corridors will be evaluated for potential state intervention and investment. To address the connectivity problem, there will likely be a need for multiple solutions working in tandem.

Additionally, the mapping exercise will assist in determining the market size. It will not only show the number of transit providers impacted, but also the demand horizon. This will be a critical data point in any sort of market engagement to illustrate the ongoing statewide demand for non-cellular data solutions. While the initial exercise should focus on transit demand, it is important to note that there may be ways to "grow" the market size; this could include expanding the scope from only transit applications to other use cases such as emergency services and first responders.

Analyze potential solutions to fill in ongoing connectivity gaps identified by the coverage map.

The coverage map will identify the key transit priority corridors for state intervention. However, it will be important to analyze what the best solution is to fill in the identified gaps. The solution for each priority corridor will likely depend on whether there is a near term build out planned or not as well as the number of transit provider vehicles that will be impacted.

A formal analysis – including a price comparison – should be conducted to confirm the path forward to implement the best solution for each corridor. For areas that will receive cellular and/or broadband network within the next 5-10 years, California should consider a short-term solution; for areas that will not receive any additional build out, California may want to consider more permanent infrastructure investment.

Engage the market to understand the challenges, true costs, and timelines to cover underserved areas.

[9] The California Middle Mile Broadband Initiative published an interactive map of its build out plan which shows project status but does not show granular impact of these projects in terms of coverage over the next 5-10 years. https://middle-mile-broadband-initiative.cdt.ca.gov/pages/statewide-middle-mile-network-map

[10] In 2021, the Federal Communications Commission (FCC) published a network map but this has yet to be updated with more recent data. Moreover, the map reports to not be an accurate representation of service, including under conditions when a "user is [...] in a moving vehicle." https://www.fcc.gov/BroadbandData/MobileMaps/mobile-map

Once the magnitude of the connectivity challenges – as well as potential solutions – have been identified, Caltrans should engage the market to gauge the interest in serving the transit use case and to better understand the barriers which have prevented these solutions from already being deployed. Overcoming identified challenges will come at a cost and that cost may be impacting a vendor's business case to serve these areas. Caltrans needs to obtain a deeper understanding of these drivers to more fully evaluate the best path forward to solving the transit connectivity problem.

Caltrans should also work to understand the true costs and timelines associated with each potential solution, separately from the individual vendor business case. These costs may be unique to each priority corridor depending on the challenges being faced (ex., topography issues vs. permitting issues vs. lack of demand, etc.). Depending on the cost and associated timeline, Caltrans may want to consider state-lead investments or may make a strategic choice not to provide connectivity in certain areas and certain providers.

Engage with higher level first responders (CalFire, CHP, OES) on the efficacy of current solutions in use and launch demonstrations for potential viability in transit.

First responders across California are already engaging with this challenge. Caltrans should collaborate with other first responders to understand the technologies that have already been researched and eliminated, the technologies which are showing promise, and the technologies that have not yet been piloted. While the use case for transit is slightly different, there is still much to learn from these cross-agency departments. Satellite antenna connectivity, for example, has been tested in stationary settings by other California agencies but the in-motion application is only now being explored as a proof of concept. This could be an excellent candidate for a collaborative demonstration with multiple state agencies to test the potential viability for in-motion applications for transit and beyond.

4.2.5 Transit Signal Prioritization

Adopt NTCIP protocol for all signals statewide, sunset proprietary data format, and investigate the need for a data standard.

Using the NTCIP protocol is a foundational step toward a fully interoperable system. Despite the fact the NTCIP protocol can come in many variations, the vendor community interviewed as a part of this report unanimously cited the use of state specific protocols, such as those employed by Caltrans, to be the more pressing concern. These state specific protocols act as de facto proprietary systems as they do not conform with the industry standard. Inconsistent usage of industry standards, like NTCIP, creates market frictions and additional cost burdens.

At a minimum, all signals statewide should adopt the national and industry standard protocol, NTCIP. Caltrans can lead by example by sunsetting the proprietary data format currently in use. In doing so, most of the "smart" signals across the state would be NTCIP compliant. Caltrans should collaborate with any jurisdictions whose signals remain proprietary to determine a path toward adoption of NTCIP protocol. This may include technical support and guidance on NTCIP applications for different types of signals (i.e., TSP use cases, non-TSP use cases, etc.).

Once NTCIP is adopted, Caltrans should investigate whether this sufficiently addressed the market friction identified in this report. If not, a data standard – such as the Traffic Management Data Dictionary (TMDD)[11] – could be a potential solution and should be researched. This research should also include potential C2C standards, given the increasing popularity of this type of TSP implementation in the medium-term future.

Provide guidance on when to use TSP.

Transit providers need guidance on when to consider TSP. Not all providers will benefit from TSP, and for the ones that do, not all of the intersections their vehicles pass through need to be equipped with TSP to derive benefits. For example, TSP typically provides greater benefits to intersections with far side stops, as opposed to those with near side stops, as it allows the vehicle to clear the intersection prior to passengers boarding or alighting. Near side stops do not receive the same benefit from TSP as delays in passenger boarding and alighting could cause the vehicle to miss the requested TSP phase. Transit providers with near side stops looking to improve headways may see greater benefits from all door boarding, for example, as opposed to TSP.

TSP vendors are hesitant to provide any profile or list of characteristics for an intersection or route that would be a good candidate for TSP, passing this responsibility off to A&E firms. Hiring an A&E firm to determine if and where TSP should be implemented is an additional cost that must be shouldered by the transit provider. Additionally, A&E firms have their own biases in identifying TSP corridors as they are often tasked with any construction work associated.

Transit providers need a neutral third party – Caltrans – to help issue guidance on when TSP should be considered and how to work with local communities to streamline planning and implementation. This guidance should go beyond TSP to provide potential alternative solutions (such as all door boarding) that may be a better fit if the intersection / route / corridor is not a prime TSP candidate. Caltrans is in an excellent position to provide this type of technical advice and help transit providers focus their resources on choosing solutions which will have meaningful impact on congestion and operational reliability.

Collaborate with state agencies to identify state priority TSP corridors.

Once guidance on if TSP should be used is published, California can turn to evaluating the corridors and intersections which fit the TSP profile to evaluate the magnitude of derived benefit. There are areas where implementing TSP will improve transit reliability,

[11] https://www.ite.org/technical-resources/standards/tmdd/

which could contribute to mode shift that leads to a meaningfully reduction in VMT. These are key goals for Caltrans and for California large. Caltrans should collaborate with its sister agencies (i.e., CalSTA, CARB, etc.) and its local and regional partners to identify the top 10-15 corridors where the implementation of TSP would have the largest impact on VMT, transit reliability, and operational efficiency; these corridors should be designated as priority corridors.

California should focus its energy on making these "big wins" happen first. This could be channeling dedicated funding to these corridors for the exclusive use for TSP, providing technical support to assist in negotiations between jurisdictions, and/or accelerating permit approvals and any required integrations with Caltrans-owned signals for these corridors.

Develop and adopt community-developed standard TSP performance metrics and benchmarks.

The transit community has not adopted standard performance metrics for TSP nor benchmarks by which to judge system performance. Without an agreed upon way to measure success, it is difficult to determine when and where TSP provides meaningful value. Similar to past efforts like TODS and MDIP, Caltrans should initiate and support a transit-communitywide effort to develop and adopt standardized performance metrics and benchmarks that account for transit performance, mobility, safety, and maintainability. Vendors should be willing to agree to reasonable benchmarks on which they can advertise their system's benefit but will be held accountable to how they are calculated based on the standard performance metric.

Caltrans should encourage transit providers to adopt these metrics and benchmarks into their own TSP procurements by marketing their existence and developing sample procurement language or checklist for TSP that can be published via channels such as the MDIP Procurement Guidelines. Eventually, having the metrics in a procurement should be a condition to receive state funds.

Provide guidance on how to implement TSP (including timing for procurement and MOU between jurisdictions, templates for state permits, etc.).

There will be transit corridors that have clear TSP benefits, based on the TSP profile created by Caltrans, which will not be identified as state priority TSP corridors. Transit providers operating in these corridors need guidance on how to implement their own TSP systems. There is significant uncertainty on what the "order of operations" should be. Feedback received from both transit providers and vendors alike identified two key areas where Caltrans could help streamline the implementation process: cross-jurisdictional agreements and state permits.

Many transit providers operate services across multiple jurisdictions and any TSP implementation will likely involve multiple parties. Because the transit provider very rarely owns, operates, or controls the signals at the intersections, it is essential to obtain the support and approval of each signal owner/operator. This can be a long and arduous process to identify who each signal belongs to (see further recommendations on this below) and obtain approvals. Caltrans should issue guidance on how to begin the MOU process, how to identify signal owners, and at what point in the MOU process to begin the procurement of a TSP vendor and conduct system design. Transit providers should start early on assembling these stakeholders. At best it will take months – if not years – to arrive at a mutually agreed upon Memorandum of Understanding (MOU) to move ahead with the TSP implementation. These can cause significant project delays if the TSP vendor has already been procured.

The other main point often cited is the time it takes to obtain permits. While Caltrans does not have a local mandate and cannot control the process at that level, it can simplify the state level permitting. Caltrans has already made great strides in accelerating the time it takes for approval; however, the permit forms themselves are not always intuitive. Caltrans is encouraged to create a "how to" guide to assist transit providers in filling out the form correctly and completely, which will in turn speed up the approval process by minimizing the need for questions or resubmissions.

Guidance should also include standardized procurement and contract language for how to incorporate the Caltrans performance metrics and benchmarks.

Publish a public-facing interactive GIS map of Caltrans-owned signals and incentivize local jurisdictions to supply data for use in planning.

In a single transit corridor, the intersection signals may be owned and operated by multiple parties. Rarely are these parties the transit provider. Feedback from transit providers indicated finding who owns each intersection signal can be difficult. To simplify this data finding process – one which is critical to beginning any TSP implementation – Caltrans is encouraged to publish a public-facing interactive Geographic Information System (GIS) map indicating all Caltrans-owned signals. Caltrans would not need to publish any sensitive internal data such as operational status, rather it would simply need to indicate which intersection signals are under its control and who the point of contact would be for a TSP implementation.

Caltrans should also encourage local jurisdictions to supply data in a specified format to be integrated into this same interactive map. Eventually, the intersection signal map can serve as the "source of truth" on intersection signal ownership. This will improve transit planning at all levels – state, regional, and local – through access to open data.

Develop transition strategies for deployments using both old and new technologies to ensure interoperability.

Some corridors will have a mixture of intersection signal types; while they may all be "smart", some may leverage GPS while others have optical or line-of-sight sensors. As the market transitions toward newer iterations of signal technology, there must be transition strategies to allow for mixed technology implementations. Within this is the need to ensure that as intersection signals are upgraded, the TSP implementation is not compromised (i.e., hardware interoperability). Caltrans should collaborate with vendors, transit providers, and infrastructure owners to understand the core pain points and potential frictions to mixed technology deployments and then develop transition strategies to support deployments in this situation. The transition strategies should also focus on how to ensure system interoperability both with a mixed technology system and during a technology upgrade. It will be critical to incorporate information and guidance related to ongoing operations and maintenance of TSP systems – as well as other related smart infrastructure – into these strategies.