San Francisco-Oakland Bay Bridge (SFOBB) Metering Lights System Upgrade Project

Concept of Operations

Prepared for:

BAY AREA TOLL AUTHORITY

EA 0K220

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LIST OF ACRONYMS

AET	All Electronic Toll
ACTC	Alameda County Transportation Commission
ATMS	Advanced Traffic Management System
BATA	Bay Area Toll Authority
BCDC	Bay Conservation and Development Commission
CCTV	Closed Circuit Televison Cameras
CHP	California Highway Patrol
CMS	Changeable Message Sign
CTC	California Transportation Commission
FHWA	Federal Highways Administration
HOV	High-Occupancy Vehicle
ICM	Intergrated Corridor Management
ITS	Intelligent Transportation System
ML	Metering Lights
MLMS	Mainline Metering System
MPO	Metropolitan Planning Organization
MTC	Metropolitan Transportation Commission
OHSS	Overhead Sign Structure
ORT	Open Road Tolling
SEMP	Systems Engineering Management Plan
SFOBB	San Francisco-Oakland Bay Bridge
TMC	Transportation Management Center
VDS	Vehicle Detection Station
WBS	Work Breakdown Structure

Document Control Panel				
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1. PURPOSE

The Concept of Operations (ConOps) describes the current and proposed operations of the San Francisco-Oakland Bay Bridge Metering Lights (SFOBB ML) System. This document describes how the system functions, how it operates in different scenarios, and the roles and responsibilities of internal and external stakeholders. The Concept of Operations (ConOps) is a needs-driven document that lays the foundation for future requirements definition and traceability throughout the Systems Engineering process. The ConOps focuses on system operations. It does not describe software design or integration and is technology neutral.

The Concept of Operations is a stakeholder intensive development process in order to understand the operations from the viewpoint of the stakeholders. Stakeholder interviews were conducted to collect project needs. Site visits were also used to observe operations in the field and at the Caltrans Transportation Management Center (TMC). The ConOps chronicles the existing operations of the system as a baseline for operations and to understand the needs and goals of the Upgrade Project. The proposed operations will be vetted with the stakeholders in a ConOps workshop process to confirm and elicit discussion and consensus on proposed system operations. The ConOps is intended for the stakeholders of the system and will be used as the basis of design for the System Integrator.

2. Scope of Project

2.1 High-Level Project Scope

The SFOBB ML Upgrade Project will upgrade the metering lights (ML) system and its associated field and system equipment. It will provide for redundancy of the system in the event of failure. The updated SFOBB ML System will be integrated into the existing Caltrans ATMS. The Project will also replace existing Changeable Message Signs (CMS) located on the metering lights structure and add CCTV cameras. It will repair or close existing gaps in the communication system and repair or enhance existing detection as needed for an automated and adaptive metering system.

The new SFOBB ML System will integrate existing traffic monitoring stations in the vicinity of the Toll Plaza to respond to traffic both upstream and downstream of the metering lights. The system is expected to be a customized software.

2.2 Systems Engineering Process

The design, development, and implementation of the SFOBB ML system will follow the systems engineering process shown in Figure 1 below.

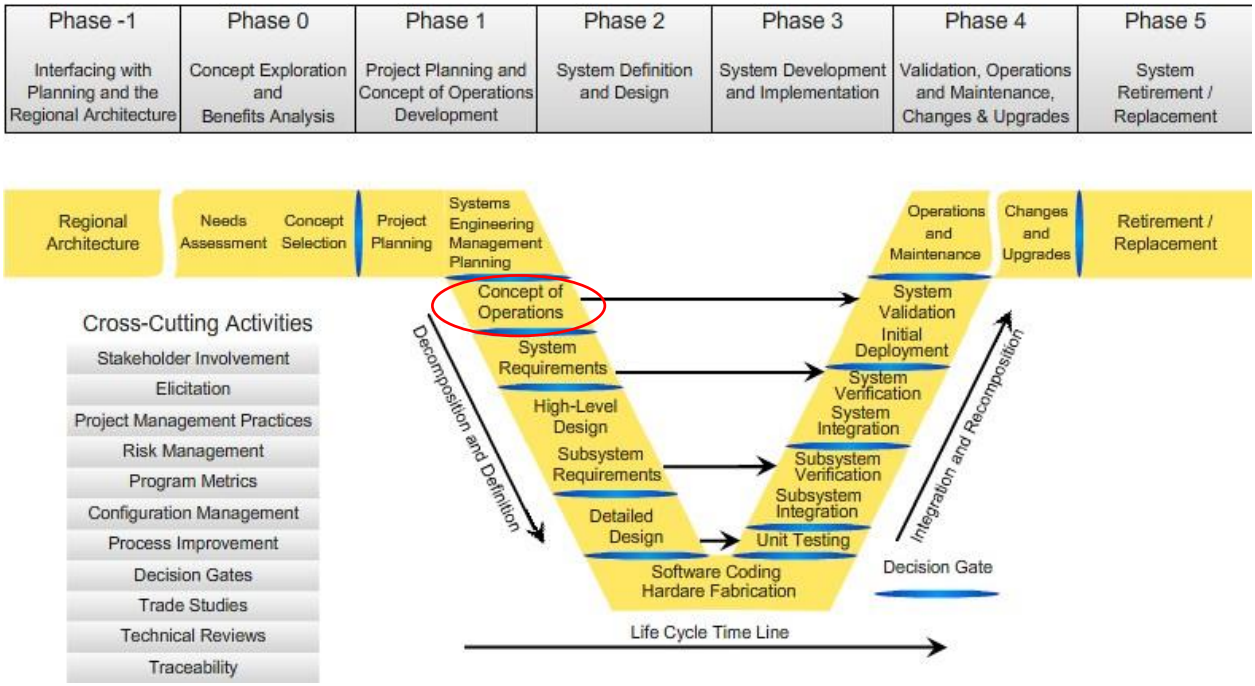

Figure 1- Systems Engineering Process

The Systems Engineering process is a best practice for implementing ITS projects to mitigate risks associated with technology implementation. The objective of the process is to prepare a well thought out plan approved by stakeholders in an effort to reduce project risk by considering the full life cycle of the project throughout each step and to define the big picture first, before defining the details. The Concept of Operations is a critical step in the development

of the Systems Engineering documents. As part of the ConOps development, the project team has interviewed stakeholders to assess needs and develop operational strategies. A stakeholder workshop will be held to confirm the proposed system operations. These provide the foundation for the future requirements development, the next step in the Systems Engineering process.

2.3 Referenced Documents

The Concept of Operations was prepared primarily using the following reference materials:

- Caltrans SFOBB ML project kickoff August 20, 2015
- Caltrans scoping meeting with Caltrans District 4 staff Rod Oto (Traffic Operations), Alan Chow (Chief, Traffic Systems), Sean Coughlin (Traffic Systems), Kenneth Young (Project Manager), September 15, 2015
- Caltrans scoping meeting with Caltrans District 4 staff Hector Garcia (TMC support), Kane Wong (Manager, TMC), Michael Lee (Chief, Electrical Systems Hardware), Miguel Egea (Detector Systems), Kenneth Young (Project Manager), October 2, 2015
- Caltrans scoping meeting with Caltrans District 4 staff Charles Price (Chief, Electrical Systems), October 13, 2015
- Toll Plaza meeting minutes with Toll Plaza staff Jagjit Dhillon (Toll Captain) and Carl Crosby (Toll Plaza)
- Metering Operations Observations dated November 4, 2015
- Mainline metering sequence table
- Bay Bridge As-Built plans
- San Francisco- Oakland Bay Bridge Review of Existing Metering Operations Final Report prepared by Cambridge Systematics, dated April 2010
- *Freeway ramp control using fuzzy set theory for inexact reasoning*, Leon L. Chen, Adolf D. May, David M. Auslander, Transportation Research Part A: General Volume 24, Issue 1, Pages 15-25 (January 1990)
- SFOBB Ramp Metering Upgrade Systems Engineering Management Plan Framework dated November 13, 2015 prepared by Kimley-Horn and AssociatesBay Bridge Toll Evaluation: Final Report, University of California Berkeley, November 2011
- SFOBB Metering Lights Upgrade – Project Delivery Options Memorandum dated November 5, 2015 by Kimley-Horn and Associates
- Metering for the Bay Bridge, 1990

3. BACKGROUND

The original metering system on the SFOBB was deployed in 1974, controlling 15 metered lanes with a program running on a Data-General Nova 1210 minicomputer modified for traffic control use. Traffic-responsive metering was performed using a station of wired magnetometers – one per lane -- at the foot of the bridge incline as the control point; operators could override with a fixed rate when an incident on the SFOBB occurred.

The software was ported to the Model 170 controller in 1980. Various enhancements were added over the next 10 years as part of the SFOBB Traffic Management System, which instrumented the upper (westbound) roadway of the SFOBB with VDS, CCTV cameras and single-line CMS. In addition, the HOV lanes were re-located from the center of the roadway to the right-hand side, adding a 16th metered lane.

The 2 single-line CMS on the OHSS were available for motorist information of incidents on the upper roadway, but would preempt any message when needed by the MLMS – either at the startup or shutdown of metering. In addition, there are existing CMS on the Metering Lights Structure that have been non-operational for many years. These CMS were intended to display messages warning drivers to prepare to stop shortly before the metering lights were set to turn on, or when there were incidents on the bridge that impacted traffic at the toll plaza. The existing CMS were originally operated from the toll plaza and the messages were selected from a pre-determined library by an operator using the same standalone workstation that controlled the MLMS.

In 1990, Caltrans staff added a fuzzy logic-based corridor algorithm that took into account traffic conditions on the upper deck to further adjust the metering rate. This algorithm gave favorable results, but due to problems with maintaining the VDS on the SFOBB, the algorithm was deactivated, reverting the operation to manual operations.

The Toll Plaza has a total of 20 approach lanes including 16 toll booths and 4 open road tolling (ORT) lanes (two of which are HOV only lanes). During peak commute hours, Toll Booths 1 and 2 are designated as HOV only lanes. In the current configuration, all of the approach lanes converge to 16 lanes at the existing metering lights, which is approximately 1000 feet west of the Toll Plaza. During the peak commute hours, only 12 lanes are controlled with the metering lights, the HOV lanes (four lanes total) are not metered.

The existing metering operations utilize a priority scheme for FasTrak™ users where FasTrak™ - only lanes are given higher metering rates. This results in more FasTrak™ vehicles being released in comparison to cash paying vehicles. The figure below illustrates the current configuration of the Toll Booths and Metering Lights approaches.

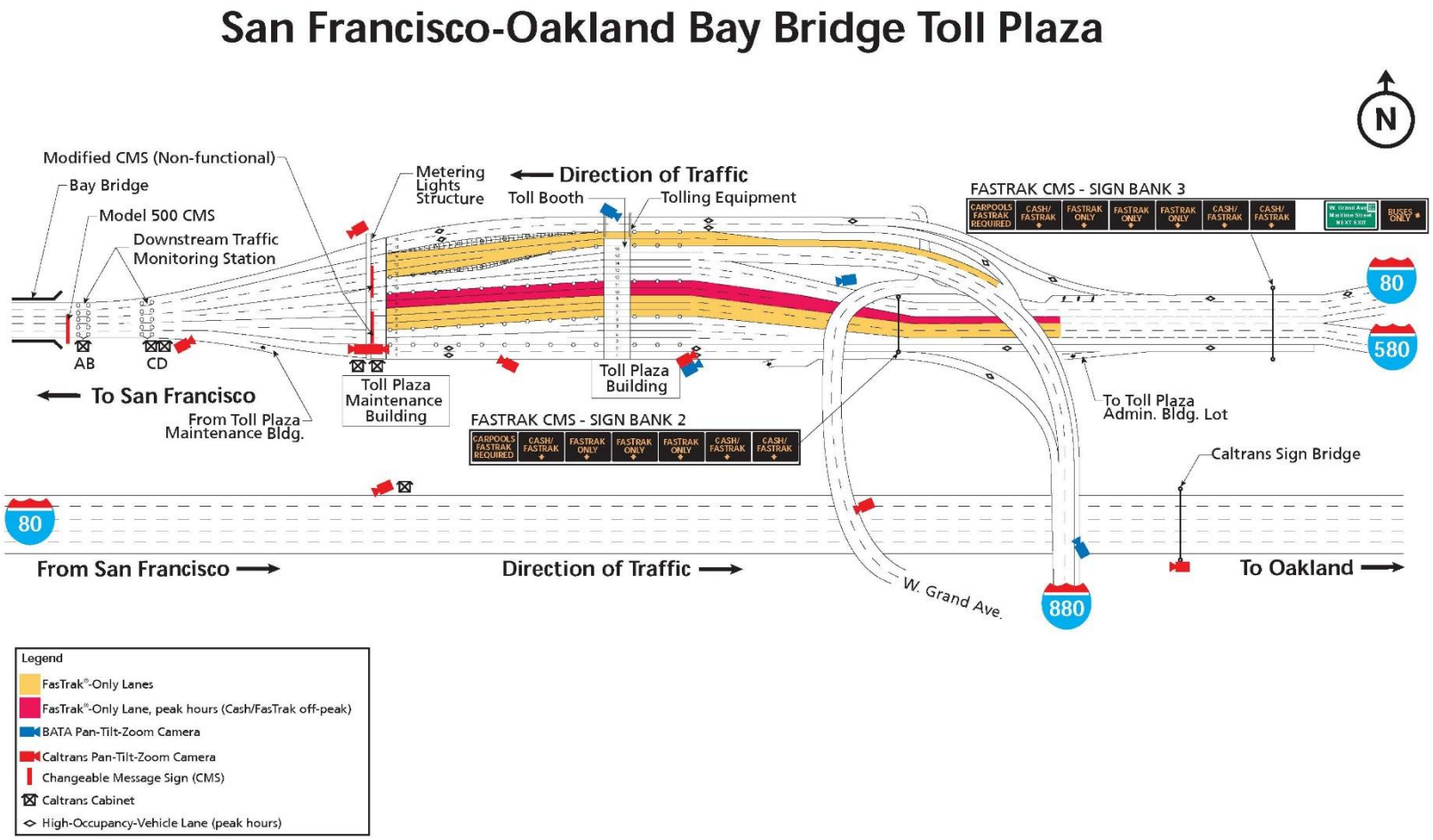

Figure 2 - San Francisco Bay Bridge Approach – Existing Lane Configurations in Peak Period and Field Equipment

The system was designed to operate in a fully automated mode, but tends to break down when there are incidents or other non-recurring events on the bridge or in the vicinity of the toll plaza. In those instances, the lack of available data from current detector loops upstream or downstream from the metering lights means the system is not responsive to incidents or rapidly congestion and metering rates are not effective. In addition, data from detector loops further upstream from the toll plaza including approaches from I-580 and I-80 are currently not used as input for metering rates.

Currently, operators in the Caltrans TMC will manually adjust the metering rates based on queue and traffic approach observations from CCTV cameras in and around the toll plaza area and the immediately east of the Bay Bridge. The manual operations of the metering system presumably contributes to inefficient traffic operations by not responding quickly enough to traffic conditions. Automated and adaptive metering will have faster response times to changes in queueing and traffic conditions while coordinating with FasTrak™ lane metering to maintain safe merging conditions.

In addition, there are existing CMS that are currently non-operational and need replacement. These CMS were intended to display messages warning drivers to prepare to stop shortly before the metering lights were set to turn on, or when there were incidents on the bridge that impacted traffic at the toll plaza. The existing CMS were originally operated from the TMC and the messages were entered from an operator using a software that interfaces with the CMS interface. The CMS were not integrated or connected to the metering software in any way. The existing CMS will have to be replaced with new CMS that will then allow the new system to automatically display ramp metering messages.

Because the system is controlled manually today and most of the central equipment and field elements are old and antiquated, there is a need to replace most, if not all, of the central metering light elements and install a more automated and adaptive metering system that will not only improve traffic flow onto the Bay Bridge, but will result in more effective and efficient staff operations of the metering system at the Caltrans District 4 TMC.

4. NEEDS, GOALS, AND OBJECTIVES

4.1 Needs Assessment

The SFOBB ML project strategy was built upon an internal needs assessment developed by examining the existing system and discussing alternative approaches to the project delivery. The needs assessment was also based on observations of metering lights operations during the AM peak period at the Toll Plaza and at the Caltrans D4 TMC. In addition, PATH is performing a parallel study on the operations of the Bay Bridge that has verified and confirmed portions of the project.

The high-level list of needs for the System Integrator project are:

- Implement an "adaptive" metering algorithm that adjusts metering lights dynamically lane by lane
- Implement a fully automated system;
- Upgrade and replace existing system hardware;
- Design and upgrade associated network and detection systems as needed;
- Integrate the new system into the Changeable Message Sign (CMS) system to provide traveler information;
- Integrate the new system into the Caltrans ATMS;
- Develop standard operational procedures for metering operations to guide staff on how to operate the system, when to override it, and how to deal with failure situations;
- Install work stations at the TMC, BATA offices and the Toll Plaza. The BATA office will only have read only access to the Metering System.
- Operate redundant system during failures
- Integrate with other existing or planned systems (ICM, Ramp Metering, Express Lanes, and All Electronic Toll (AET) Operations etc.)
- Provide improved metering lights operations reports to Toll Plaza staff to coordinate staffing needs as well as reporting and archived data for metering lights operations
- Provide visual CMS message confirmation at the ML Overhead Sign Structure by displaying "Metering Lights On" messages.
- Automate CMS to turn on/off when the metering system turns on/off
- Utilize detection, constructed by the Civil Contractor in the project area
- Display additional CCTV cameras from the ATMS to confirm traffic patterns and CMS messages

- Ability to go ALL RED, in order to allow CHP to clear out stalled vehicles or to allow restricted vehicles (e.g., trucks carrying hazardous materials) to cut across all lanes and get over to Toll Plaza parking lot to turn around.

- Ability to monitor performance metrics associated with the features of the new ML system.

4.2 Project Goals and Vision

The planning for the SFOBB ML System upgrade will be focused on reducing queues and delays, improving travel times and travel speeds through the Toll Plaza and optimizing traffic flow across the SFOBB. The goal of the project is to improve traffic operations across the corridor and to deploy an adaptive metering system. Additionally, another goal of the project is to replace the current metering system which is antiquated and whose capabilities are limited.

The project's vision statement is:

The project vision is to provide an up-to-date and secure adaptive metering system that enables real-time traffic management and operations that will allow optimized and efficient traffic flows across the SFOBB.

5. STAKEHOLDER ROLES AND RESPONSIBILITIES

5.1 Stakeholders

The SFOBB ML Upgrade project has several key stakeholders responsible for project planning, implementation, and operations. The key stakeholders are described below and shown in Figure 3 and described below.

Primary Stakeholders

Metropolitan Transportation Commission (MTC) is the transportation planning, financing and coordinating agency for the nine-county region in the Bay Area. MTC functions as both the regional transportation planning agency and as the region's metropolitan planning organization (MPO).

Bay Area Toll Authority (BATA) of MTC has the responsibilities of administration of toll revenue and joint oversight of the toll bridge construction program with Caltrans and the California Transportation Commission (CTC).

BATA currently funds day-to-day operations, facilities maintenance, and administration of the San Francisco-Oakland Bay Bridge as well as long-term capital improvement and rehabilitation of the bridge. The toll schedule for manual or electronic collection is established by BATA and the California Legislature. BATA is also responsible for the operation of the FasTrak™ Electronic Toll Collection program. BATA will contract with the appropriate firms to complete the project.

BATA will be responsible for procurement of a Systems Integrator as a professional service. The Systems Integrator will provide input on the design of the construction plans and will also design, develop, implement, and test the metering lights system.

BATA will be responsible for procurement of a Construction Contractor for the completion of the design plans, the installation of field elements including conduits, pull boxes, cabinets, signal heads, poles, conductors, and any other field elements for the metering lights system upgrade.

Caltrans owns, operates, and maintains the state-owned bridges and is responsible for day-to-day operations, maintenance and toll collection of the San Francisco-Oakland Bay Bridge. Caltrans will provide oversight of the design of the project. Caltrans will provide oversight and technical assistance on the scoping of the project. They will also provide design reviews and will issue the construction permit for the civil elements of the new system. They will also provide oversight working closely with the System Integrator during the implementation of the new system.

California Highway Patrol (CHP) is responsible for the enforcement of the all State Highway assets including the SFOBB. It is anticipated that they will be a stakeholder in the system design.

BATA and Caltrans Project Working Group includes staff members from BATA and Caltrans responsible for the project development and delivery

Executive Project Steering Committee includes executive management team members from BATA and Caltrans responsible for overall project direction.

Secondary Stakeholders

Kimley-Horn performs the role of the Project/System Manager and Civil Designer. It is responsible for developing/monitoring a comprehensive work plan at the project scoping that includes a list of project tasks, scheduling requirements, staffing requirements, and equipment and material requirements necessary to complete the scope of work tasks on time and within

budget. The work plan will be continually monitored and revised as the project proceeds to meet time and budget constraints. It is also responsible for providing guidance on technical issues/topics, and reviewing deliverables/conducting testing. Kimley-Horn will develop the initial set of design plans to be used for procuring the construction contractor. The design plans will be completed by the Construction Contractor and the Systems Integrator.

HDR will provide environmental support for BATA and Caltrans including a review of environmental constraints information available for the project area as well as a review of pertinent state and federal regulations, policy, and guidance. HDR will help develop an environmental and permitting strategy for the project based on the sensitive environmental resources in the area of the proposed design.

San Francisco Bay Conservation and Development Commission (BCDC) has regulatory responsibility over development in San Francisco Bay and along the Bay's nine-county shoreline. It is guided by the McAteer-Petris Act, the San Francisco Bay Plan, and other plans for specific areas around the Bay. It is necessary to obtain a BCDC permit prior to undertaking most work in the Bay or within 100 feet of the shoreline, including filling, dredging, shoreline development, and other work.

Federal Highways Administration (FHWA) will provide technical assistance as requested by BATA.

Alameda County Transportation Commission (ACTC) as the Congestion Management Agency is deploying an Integrated Corridor Mobility (ICM) system along I-80 which directly feeds the SFOBB. Its involvement will be for the most part focused on the interaction between the I-80 ICM and the SFOBB ML Systems.

System Integrator will be responsible for the delivery and implementation of the upgraded SFOBB ML System including the central hardware and software.

Civil Contractor will be responsible for the construction and integration of the Civil/ITS improvements within the Caltrans right-of-way.

The project organizational chart is shown below.

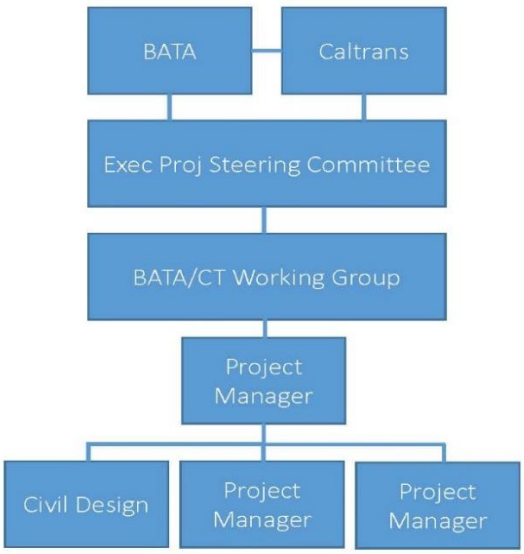

Figure 3 - Project Organizational Chart

5.2 Roles and Responsibilities

The roles and responsibilities of the major stakeholders will largely remain the same when the SFOBB ML system is upgraded. The following table illustrates that fact.

Table 1- Stakeholder Roles and Responsibilities

Stakeholder	Existing Roles and Responsibilities	Proposed Roles and Responsibilities
MTC	MPO; Provides input to major transportation initiatives.	Same as Existing.
BATA	Provides project funding; Responsible for Toll Plaza Operations; Contract oversight for ML Upgrade project and all contractors involved. Staffing for toll plaza operations, which must respond to whether the metering lights are on or not.	Same as Existing. May provide input into the algorithm to determine metering rate preference for FasTrak™ customers.
Caltrans	Manually operates and maintains the SFOBB ML system.	Will continue to operate and maintain the system. The proposed system will operate automatically with less manual intervention.
BCDC	Permitting agency. Not involved in system operations.	Same as Existing.
CHP	Enforcement for Bay Bridge and State Highway.	Same as Existing.
FHWA	As-needed technical oversight for project development.	Not involved in operations of proposed system.
ACTC	Stakeholder in project planning as it relates to I-80. Not actively involved in SFOBB ML operations.	Same as Existing.
Project Contract Team – System Manager, Designer, System Integrator, Construction Contractor	Responsible for Designing, Permitting, Constructing, Integrating, Testing, and Implementing the Project.	Same as Existing.

6. EXISTING OPERATIONS

The SFOBB ML system is manually operated from the Caltrans TMC. Metering lights operations are initiated based on observed queues on the bridge. The metering cycle begins at roughly the same time during each peak period, but start times may fluctuate slightly based on traffic conditions.

The operator uses the existing MLMS legacy software application to operate the metering light system. The operator initiates the metering cycle by opening an application window at their workstation and changing the metering action from "REST IN GREEN" (all signal indications are green on all lanes) to "FIXED RATE" (fixed metering rate manually input by the TMC operator). There are two primary functions the TMC operator can change:

- "Metering Rate" – the per minute vehicle throughput rate for all lanes. Ranges from 40 to 199 vpm.
- "Metering Sequence Table #" – Adjusts pre-set allocation of metering throughput across lanes (FasTrak™ vs cash lanes)

The TMC operator makes changes to the Metering Rate and to the Metering Sequence Table based on video feeds from CCTV cameras in the following locations:

- In parking lot of Tow Service Building at Toll Plaza west with view of metering lights structure (on Operator's main screen)
- On top of OHSS looking west with obstructed view of merge area (on Operator's main screen)
- At the incline looking east with view of merge area (on Operator's main screen)
- On top of Toll Plaza Admin Building looking east with view of queue approaching toll plaza and view of maze (on Operator's main screen)
- On east span skyway curve looking west with view of conditions downstream of metering lights
- On east span tower looking east with view of conditions downstream of metering lights
- On east span mid skyway looking west with view of conditions downstream of metering lights

The metering lights are turned back to "REST IN GREEN" when the TMC operator confirms the end of the queue is sufficiently downstream of the OHSS. Following this action, the TMC operator observes the queues downstream of the OHSS for a period of time in order to determine whether the metering cycle needs to be re-initiated. If queues on the bridge continue to grow and reach the metering lights structure, the TMC operator will re-initiate the metering cycle. As soon as the metering lights are turned back to "REST IN GREEN", the queues downstream of the metering lights structure grow immediately, but they typically dissipate within 10-15 minutes. The key for the TMC operators is to balance the queue on the bridge with the queue backing up from the metering lights. Because the system is operated manually, TMC operators react primarily based on experience accompanied by training by other operators for consistency.

The following is a summary of field observations at the Toll Plaza during a typical peak period:

- In the field, the metering rates seem to take up to almost 5 minutes to adjust after the command was initiated in the TMC.

- The metering rates seem to fluctuate between extremes. Because of the delay between when the metering rates are adjusted at the TMC and when the metering rates actually go into effect in the field, the rates did not seem to react to traffic conditions efficiently. The metering rates seemed to be either too slow or too fast.
- Overall, the HOV lanes are underutilized in comparison to the other lanes. HOV usage increases around 6:30AM. However, the lanes still appear underutilized. HOV lanes are free flow and are not metered.
- FasTrak™ lanes were observed to have preferential treatment for metering. In the TMC, the operators adjust the Metering Sequence Table to increase metering rates in the FasTrak™ lanes based on the extent of queueing with the "FasTrak™ ONLY" lanes upstream of the toll booths.
- Metering lights operations are manual and reactive. The operators are adjusting metering rates based on observed congestion on the bridge and the incline. In the field, the changes to metering rates appeared to fluctuate, and in some instances the fluctuations were substantial.
- Cars seemed to be released in platoons with gaps in between the platoons.
- Congestion at the metering lights backed up to the toll plaza and beyond.

6.1 Existing System Overview

The existing metering lights system consists of the following field elements:

- 16 metering signal heads mounted on the OHSS
- Stopline loop detectors (demand and passage) in each lane at the metering signal OHSS
- Two CMS mounted on the OHSS
- One CCTV camera mounted on the OHSS
- Two loop detector traffic monitoring stations downstream of the OHSS (stations "AB" and "CD") that are currently not operational

Only the mainline VDS are accessible from the TMC. Currently, the metering lights signal controller communicates back to the TMC via wireless GPRS leased-line connection. When the TMC operator makes an adjustment to the Metering Rate or the Metering Sequence Table Number, that command is sent from the TMC to the GPRS modem in the metering cabinet, and then to the metering signal controller which then controls the lights. Similarly, the downstream traffic monitoring stations, "AB" and "CD", transmit data back to the ATMS server at the TMC via a separate wireless GPRS connection.

The CCTV camera on the OHSS (using Opt-E-Man) is accessed remotely via a wired connection; however, that connection is not through the GPRS modems used by the metering lights controller or the traffic monitoring stations.

There is an existing fiber optic cable connection between traffic monitoring stations "AB" and "CD", the CCTV cabinet near the metering lights OHSS, and the Toll Plaza Building. Even though the fiber cable is present in the traffic monitoring station cabinets, the CCTV cabinet, and the metering signal cabinet, only the CCTV camera data is on the fiber.

The CCTV cameras are on fiber between the CCTV cabinet in the field and the Toll Plaza Building. The communications link between the Toll Plaza Building and the TMC is a leased-line high-bandwidth connection (AT&T Opt-E-Man).

Figure 4 below shows the existing system diagram and Figure 5 shows the existing system elements including the communications connections.

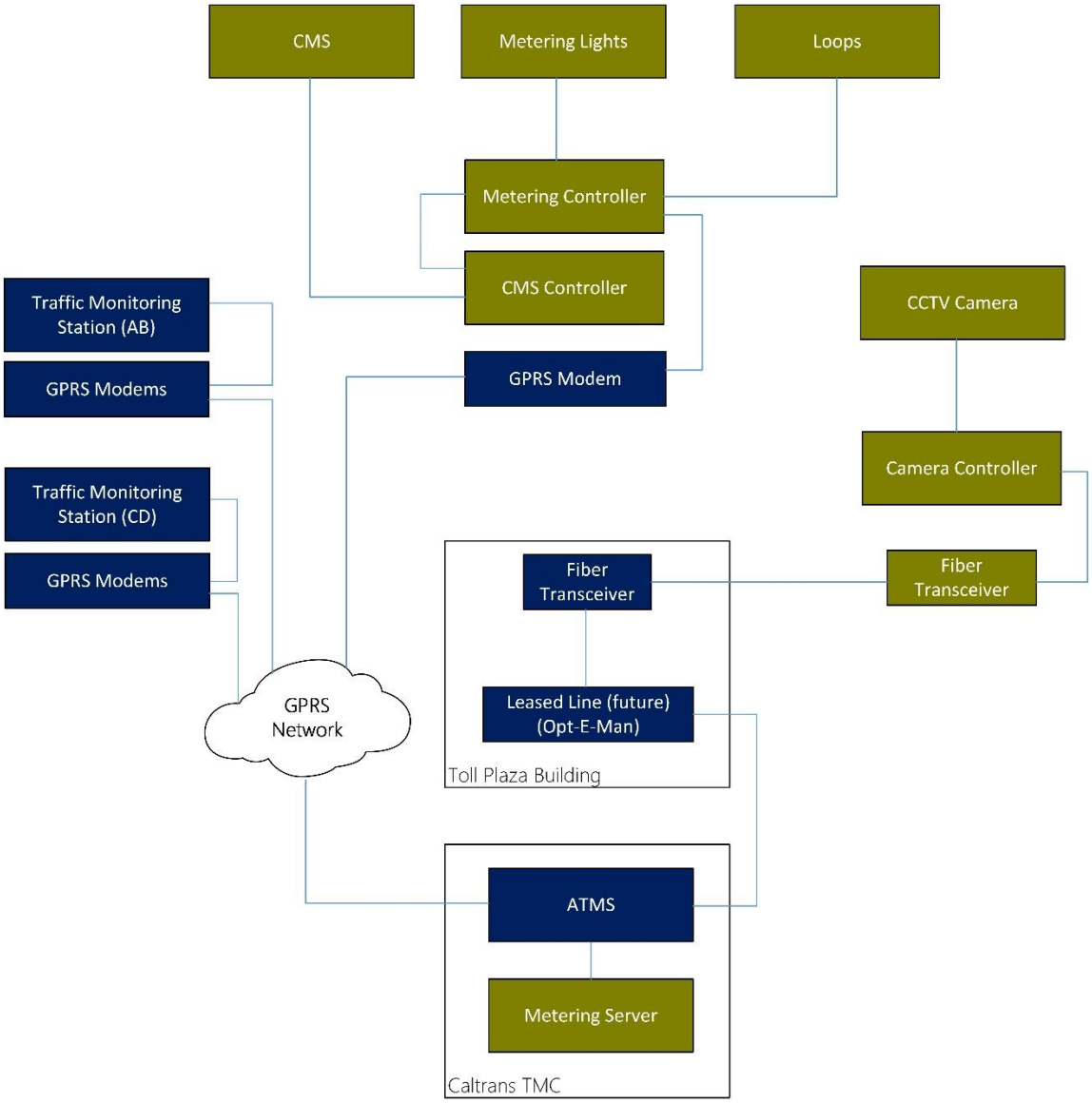

Figure 4 – Existing System Diagram

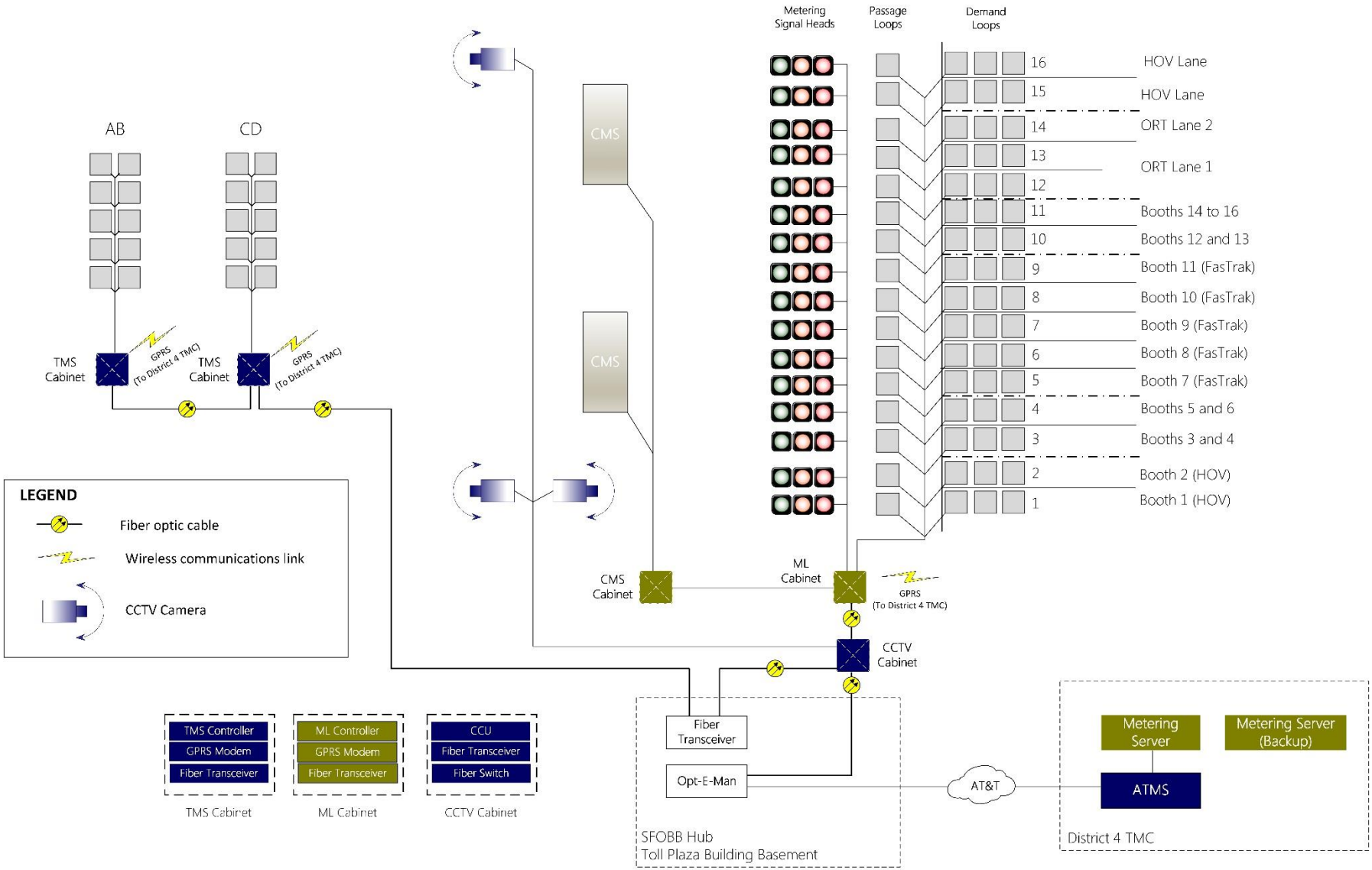

Figure 5 – Existing System Elements

7. SYSTEM OVERVIEW

The proposed ML system consists of adaptive metering software, lane-by-lane detection, additional CCTV cameras for viewing traffic, and replacement CMS on the OHSS. The system will operate 24 hours a day 7 days a week. It will be operated and maintained by Caltrans District 4 TMC staff with training and support from the Systems Integrator for a defined period of time. The new system will operate in parallel with the existing system during the burn in and testing period. It will have specific fall back procedures outlined for failure.

7.1 Alternatives to the Existing System

The existing ML System is currently being operated beyond its useful life. The hardware to run the system is outdated and difficult to maintain; the software is problematic to update. The CMS have been non-functional for years. Overall, the system is not meeting the expectations of the users. It is impossible to replace the existing system with a new system of the same nature because it doesn't exist anymore. In addition, the existing system is not able to perform operations that are standard in other places and is not able to meet the demands of new technology.

Because of the ML system solution for the desired enhancements, it is expected that the new system will be a customized software solution. To meet the requirement of an adaptive system, the software must utilize real-time data from system detectors. Several alternatives are being considered in terms of utilizing existing detection and supplementing that with new detectors if necessary. The details will be shown in the design phase. The CMSs will be replaced with similar units that perform the same functionality.

In addition, other operational improvements are being explored with the goal of improving congestion on the SFOBB and in the vicinity of the Toll Plaza. These other projects may include several operational changes proposed by PATH to reconfigure lanes, change lane utilization, and enhance operations by improving the merge areas. Other projects that are being considered are All Electronic Toll (AET) operations, Express Lanes and integration of several Integrated Corridor Management (ICM) projects into the ML system. These projects are not part of the ML Upgrade project and are not included in this Concept of Operations.

7.2 Operational Environment

The proposed SFOBB ML System and subsystems are described below. As the project evolves, the proposed System Architecture will be updated.

Caltrans ATMS – The Caltrans ATMS is the central system for District 4 to control and monitor Caltrans field elements. It is used to monitor and respond to incidents and events. The Ramp Metering System will be integrated into the Caltrans ATMS. The proposed new CMS, repaired detection and existing CCTV for the metering lights will be integrated into the ATMS.

Mainline Detection System – The Mainline Detection System will be monitored through the Caltrans ATMS. It will provide volume and occupancy data to the SFOBB ML System upstream and downstream of the metering lights.

Metering Lights Detection System – The ML Detection System will provide call and passage detection for vehicles at the stop bar of the metering lights. These detectors will provide the actuation for the metering lights. It is anticipated that the metering lights detection and mainline detection will provide the data inputs to the SFOBB ML System as part of an updated metering algorithm.

New SFOBB ML System – The new SFOBB ML System will control the metering lights. The ML System will use data from mainline detectors and customized algorithms that will allow lane-by-lane control of the metering lights. The new SFOBB ML System will be able to be viewed and operated from the ATMS at the D4 TMC, BATA offices and the Toll Plaza.

The proposed system will include a new metering software system that utilizes existing communication and detection infrastructure where possible, supplemented by upgraded hardware.

Existing SFOBB ML System – The existing system will continue to operate in parallel with the new metering system through the testing and acceptance testing phase. Once the new system has been fully tested and accepted and after the initial burn-in period, the existing metering system will be retired by the System Integrator.

Figure 6 shows the proposed system diagram and Figure 7 shows the proposed physical system elements.

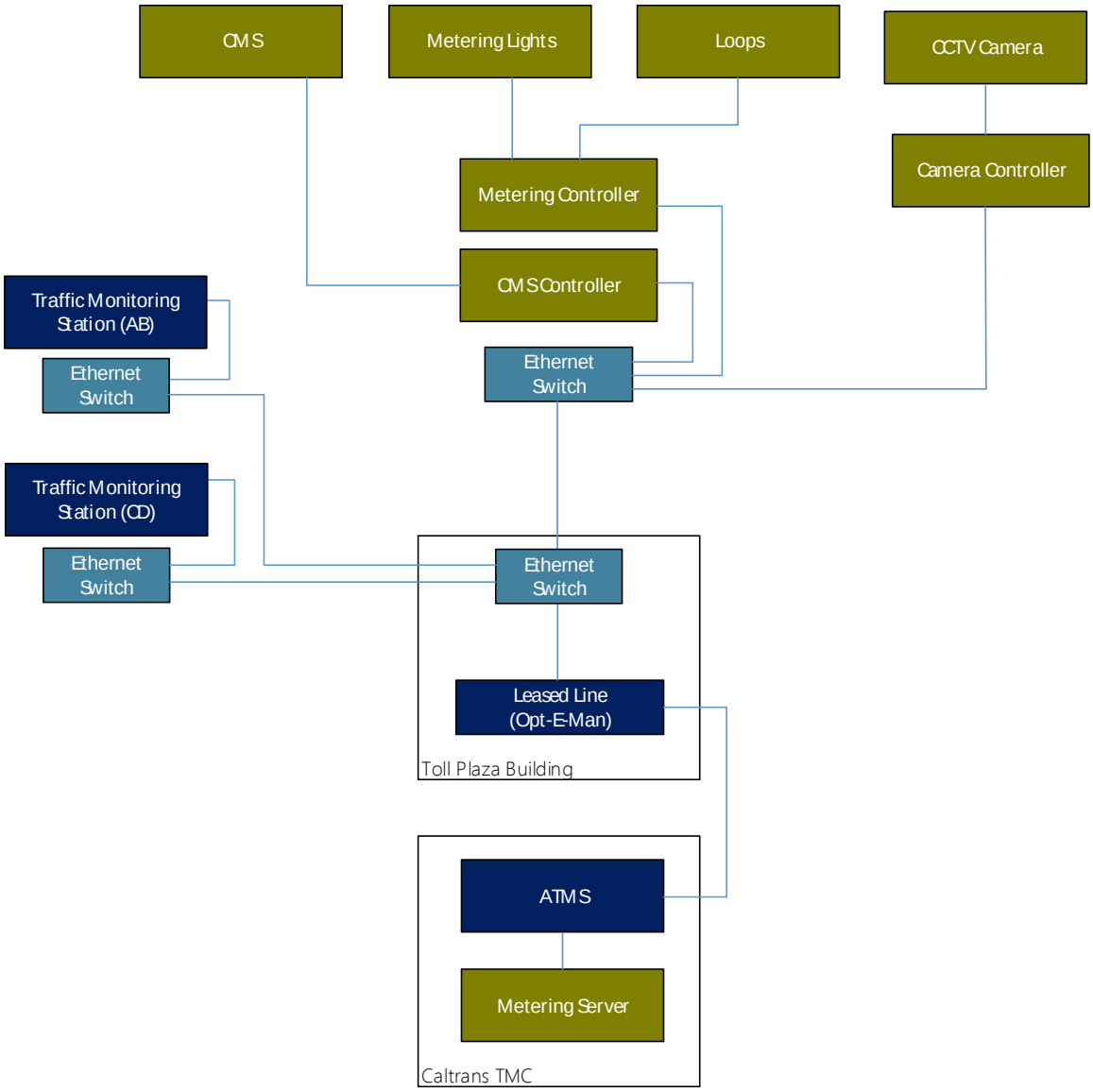

Figure 6 – Proposed System Diagram

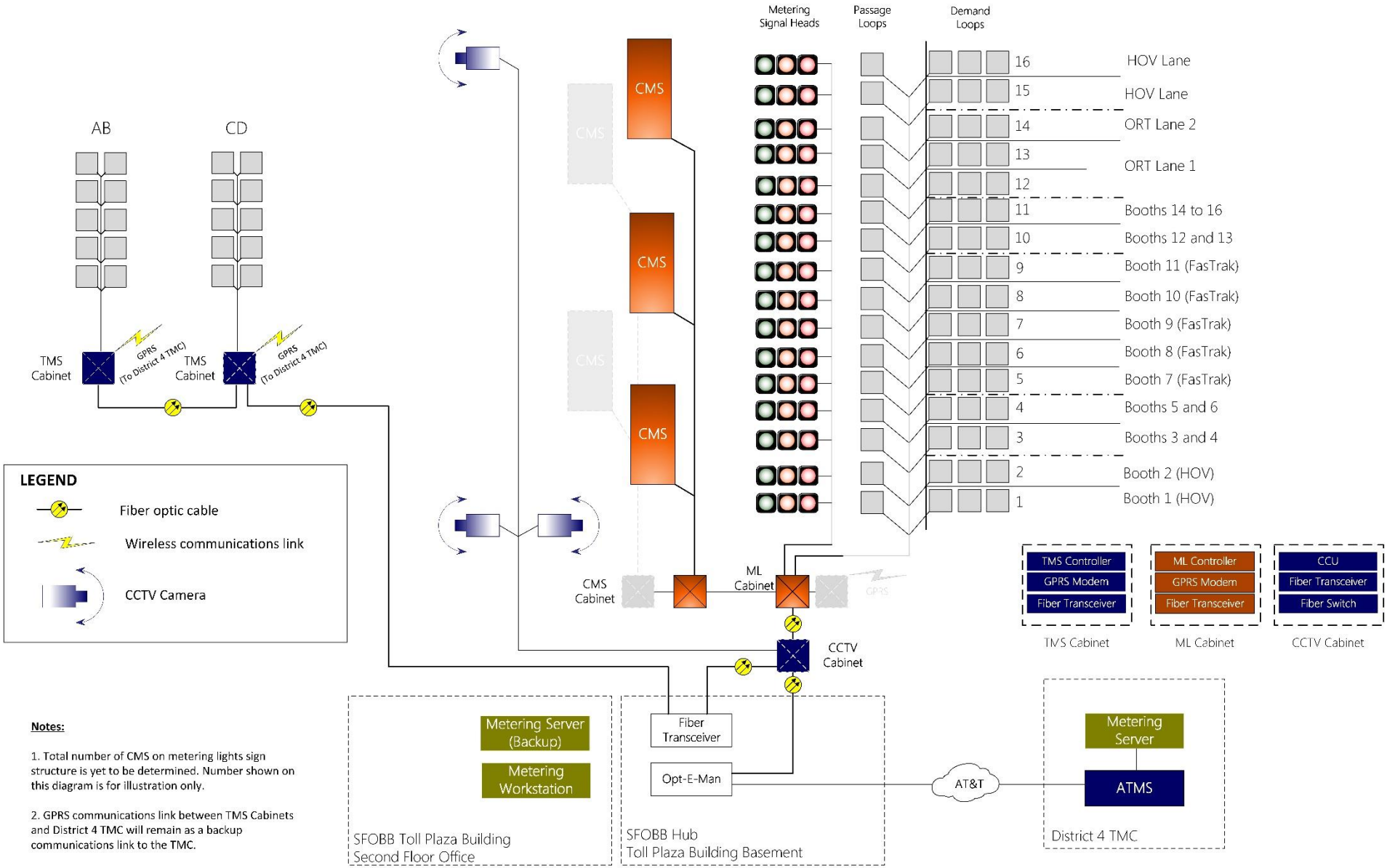

Figure 7 - Proposed *System Elements*

The Metering Lights system will be integrated with the ATMS at the Caltrans TMC. It will have a backup server for redundancy, also located at the TMC. The Metering Light System Upgrade project will provide a new metering lights signal controller and cabinet located in the vicinity of the existing metering lights signal controller and cabinet adjacent to the Toll Plaza Maintenance Facility. In addition to the metering lights signal controller, the new cabinet will house the communications networking equipment. Existing downstream traffic system monitoring stations identified as "AB" and "CD" detection will provide data to the Metering Lights system via GPRS modem.

The ML system will be installed in the Toll Plaza server room using existing and availbale server racks. A new metering lights 2070 controller and cabinet will be installed in the vicinity of the existing metering lights controller cabinet adjacent to the Toll Plaza Maintenance Facility. The ML system will communicate with the Caltrans District 4 TMC using an existing AT&T leased-line connection. There will be workstations for ML system operations located at BATA offices, the Toll Plaza Building, and Caltrans District 4 TMC. The CMS will be procured by BATA and will be installed on the existing OHSS.

Caltrans D4 TMC staff will operate the ML system at the D4 TMC. A training plan will be developed by the System Integrator that outlines the scope and support necessary for training staff on how to operate the new system. The system will operate automatically 24 hours a day, 7 days a week with D4 staff overseeing operations during weekday AM, PM, and mid-day peaks and on weekends during regular operations. Operations procedures for the new ML system will replace the procedures used currently to operate the existing system. Because the operations of the ML will not require as much manual intervention, the operators will be able to perform their other duties to over see operations of the rest of the District's assets.

7.3 Support Environment

The ML system is expected to be supported by the System Integrator who will provide maitnenance and operational assistance for an agreed upon contract length after the system has been accepted. BATA will provide ongoing oversight of the system.

8. OPERATIONAL SCENARIOS

The operational scenarios describe the operations of the system using "use cases". These operational scenarios will become the foundation for the requirements development. The operational scenarios take the point of view of various stakeholders involved with the operations of the SFOBB ML system.

8.1 Existing Operations

The existing SFOBB ML system is a manually operated system using traffic trends and visually observing CCTV cameras in the vicinity of the ML OHSS and the Bay Bridge approach. The following operational scenarios describe the existing operations from the stakeholders' point of view.

8.1.1 Normal Operations – TMC

On a Wednesday morning, Paul, an Operator at the Caltrans District 4 TMC observes traffic conditions in the vicinity of the SFOBB Metering Lights using Caltrans CCTV cameras near the Toll Plaza and the Skyway. Traffic begins to back up from the Bridge towards the OHSS. This is Paul's indication to turn on the metering lights.

Paul initially turns the metering lights to the slowest rate to be conservative. He observes traffic queuing immediately at the metering lights. The traffic on the Bridge begins to clear so Paul increases the metering rate to a higher rate in order to prevent further queuing to the toll plaza. Paul notices there is a delay between the time he initiates the change in the system to the time the metering lights change rate in the field. Paul balances the queue on the Bridge approach with those at the metering lights structure by adjusting the metering rates.

The Metering Sequence Table is used to determine the preset preference given to FasTrak™ lanes as a regional policy to encourage electronic tolling. Paul is able to adjust the parameters for FasTrak™ preference within the confines of the Metering Sequence Table. He changes the Metering Sequence Table when the cash lanes are noticeably different from the FasTrak™ lanes and are experiencing queues that are negatively impacting toll booth operations. Paul performs the metering operations based on experience and rough guidelines used for consistency among operators. He uses camera feeds and CHP Computer Aided Dispatch (CAD) reports to determine the changes he must make to metering operations. There is no connection to detection or information from ATMS in the ramp metering system.

Paul turns off the metering lights when there is a queue on the Bridge that can be manageable without metering. The metering lights are turned off at roughly the same time every day. Paul uses his experience observing conditions to determine whether the metering lights can remain off and the peak period traffic has ended.

8.1.2 Normal Operations – Toll Plaza

Chung is a Toll Plaza Commander. He is in charge of toll booth staffing and general operations of the toll facility. He uses the ATMS to view Caltrans cameras to review traffic conditions in order to determine the staffing of the toll booths. When the metering lights are on, Chung makes sure that all of the toll booths are staffed. Chung uses his personal experience based on recurring traffic conditions and a schedule of events he has compiled from area attraction websites to determine the approximate times the toll booths will need to be fully staffed. He sees that the metering lights have gone on earlier than normal so

Chung immediately staffs all of the toll booths and logs the time the metering lights turned on. He observes the queues from the metering lights backing up to the toll booths for the cash lanes. He then observes the metering rate on the cash lanes increasing slightly to allow more cash customers. Chung sees when the metering lights are turned off and closes down some of the toll lanes.

Chung receives a phone call from a concerned citizen asking when the metering lights will begin operating on Saturday. Chung answers that they are typically turned on around 10AM, but he directs the callers to the Caltrans District 4 TMC for additional information.

8.1.3 Normal Operations – Commuter

Amy leaves her apartment in Oakland to begin her commute to San Francisco in her car. She arrives near the toll plaza at 6 AM and waits in traffic. She does not have a FasTrak™ pass so she merges over to the cash lane. After she pays her toll, she waits in the metering queue. She becomes frustrated as she notices the adjacent FasTrak™ lanes being discharged past the metering lights while she is waiting for her turn. She notes to herself that she should sign up for FasTrak™ . Once through the metering lights, she commutes to San Francisco to her job.

8.1.4 Event/Incident Operations – TMC

On a Thursday morning, Pradeep, an Operator at the Caltrans District 4 TMC observes traffic conditions in the vicinity of the Bay Bridge Metering Lights using Caltrans CCTV cameras placed strategically near the Toll Plaza and the Skyway. From the CHP CAD system, Pradeep's partner, Luna, sees that there is an accident on the Bridge and notifies Pradeep. Pradeep begins to observe traffic backing up at the foot of the bridge at 5:20 AM. This is Paul's indication to turn on the metering lights. Because of the accident, the metering lights are turned on earlier than they typically are at 5:30 AM.

Pradeep turns the metering rate to one of the highest rates to prevent traffic from going on the Bridge. Luna continues to give Pradeep updates on the accident from the CHP CAD feed. When the incident has been cleared, Luna tells Pradeep who then lowers the metering to start to clear the queues at the toll plaza.

8.1.5 Event/Incident Operations – Toll Plaza

The operations at the toll plaza during an incident are the same as during normal operations.

8.1.6 Event/Incident Operations – Commuter

Gwen leaves her house in Berkeley to commute to San Francisco. She knows from checking 511 that there is an incident on the Bridge. She approaches the toll plaza with her FasTrak™ pass and waits in the severe queue. After passing through the toll plaza, she waits in the metering lights queue. The metering rate appears quite slow, but her lane is advancing faster than the cash lanes. By the time she gets on the Bridge, the accident is gone.

8.1.7 System Maintenance

Caltrans maintenance staff own and maintain the field devices and communication network that are used to operate the Metering Light system. Maintenance is done in a responsive manner primarily. BATA owns and maintains two cameras that they use for internal purposes that Caltrans has access to, but can't control. BATA maintains the IT equipment in the Toll Plaza separate from Caltrans. The Metering Lights software maintenance is done by the Software Manager in Traffic Operations. Server updates and maintenance is done regularly

by Caltrans Operations staff. Updates to the metering algorithm in the Excel spreadsheet are rarely done due to the complexity of the system.

8.1.8 System Failure/Redundancy

In the event of a failure of the Metering Lights system at the Caltrans TMC, the system must be operated directly from the controller in the field at the Toll Plaza. There have been instances when the system could not be operated from the controller. When that has happened, there is no metering system.

8.1.9 System Reporting

The Metering Lights system does not have any automated reporting or tracking. When Metering Rate is adjusted, Operator manually logs the time of rate change, adjusted metering rate, metering table used, and reason for rate change in a spreadsheet. This spreadsheet can be used for training purposes or to review previous data. There are currently no alerts set up for the system.

8.1.10 System Integration

The metering lights system operates independently from the Caltrans ATMS. There is no direct integration with other systems, although the Metering Lights System is a separate application on the ATMS workstation.

8.1.11 System Ownership

Caltrans owns the Metering Lights system. They do not pay license fees or maintenance fees to the developer of the software. All changes to the system are done in house.

8.2 Proposed Operations

The proposed SFOBB ML system will be operated from a central system using real-time information from detectors in the study area. The metering rates will adjust dynamically based on pre-determined parameters for priority by lane. The following operational scenarios describe the proposed operations from the stakeholders' point of view.

8.2.1 Proposed Operations – TMC

David is an operator in the Caltrans District 4 TMC. He logs into the standalone Metering Light system on the Caltrans ATMS work station using his operator log in and password, which allows him to adjust metering rates if needed. The new Metering Light system now runs 24/7 and continuously monitors the traffic conditions. Looking at the CCTV cameras, he observes normal traffic conditions for the weekday AM commute. He reviews a report that he has scheduled to be compiled every morning at 5AM that shows the previous day's ramp metering activities and performance measures. He notices that yesterday at 5AM the metering lights were activated earlier than normal and the AM peak queue discharge rate was much lower than normal.

As David is reviewing the previous day's activities, he sees an alert in the metering lights system that the metering lights have turned on at 5:38 AM. He also receives a notice on his cell phone saying the metering lights have been activated. He verifies in the ATMS that the CMS on the metering lights structure have been turned on as a result of a command from the Metering Light System and show the metering lights message. As he reviews the traffic conditions across the region, he sees the metering light system is adjusting the metering rates based on input from detection downstream of the metering lights. David continues to allow the system to operate automatically.

David sees that the system is using the predetermined FasTrak™ priority rates. However, there is one cash only lane that seems to be experiencing a major backup at the toll plaza. David manually adjusts the metering rate for the number 7 cash only lane to give it a higher discharge rate similar to that of the FasTrak™ lanes. He sets the parameters in the system to return to automatic operations once the queue has dissipated. The Metering Light system would have responded automatically to the real-time traffic conditions at the number 7 lane, but the system will only make incremental changes. David intervened because he wanted to clear the queues quickly. The system continues to adjust metering rates per lane and logs any changes in the report for David to review tomorrow.

8.2.2 Proposed Operations – Toll Plaza

Stephen is the Commander at the Bay Bridge Toll Plaza. Soon after he arrives at work, he receives an email alert that traffic conditions are beginning to back up on the Bridge signaling that the metering lights may be activated soon. He immediately readies the personnel needed to staff all of the toll booths. Five minutes later, Stephen receives an email alert that the metering lights have been turned on. He has logged in to the Metering Light system using his "Read Only" privileges. He can view the CMS at the metering lights structure and also downstream of the toll plaza using the ATMS. With the new Metering Light System he does not have to log changes manually anymore. Stephen reviews the metering lights report from the previous day to see when the metering lights were turned off to verify time changes from his staff. He receives a call from a citizen asking if one of the metering lights is broken because he has been sitting in the queue for a long time. Stephen checks the system and verifies everything is running correctly and reports that to the Citizen.

8.2.3 Proposed Operations – Commuter

Betty, a local Oakland resident, is taking the Bay Bridge into San Francisco for a meeting in the morning. She takes the Bay Bridge regularly, so she has a FasTrak™ transponder in her car. She arrives at the toll plaza at 7 AM and merges into the FasTrak™ lane, which moves faster than the cash lanes. After the toll plaza, she encounters more heavy traffic. The overhead CMS confirms that the metering lights are turned on ahead indicating "Prepare to Stop." She regrets not carpooling with her two coworkers when she sees that the HOV lanes are free flow. The traffic at the metering lights is cleared at regular intervals in small increments. As she expected, the FasTrak™ lane discharges faster than the cash lanes through the metering lights. Soon enough, Betty is at the front of the queue and the metering lights allow her to continue on the Bay Bridge.

8.2.4 Proposed Event/Incident Operations – TMC

Jennifer is an operator in the Caltrans District 4 TMC. She logs into her account in the standalone Metering Lights system for the Caltrans ATMS workstation using her operator log-in and password. The new Metering Light system now runs 24/7 and continuously monitors the traffic conditions. She monitors the CCTV cameras to observe traffic conditions on the Bay Bridge. At 6:30 AM, the CHP CAD system alerts the TMC that a major incident has occurred. Jennifer uses the CCTV camera feeds to find and confirm the incident. Once the incident is confirmed visually, she checks the Metering Lights system. The system has detected a backup on the bridge and has automatically applied an adjusted metering rate based on traffic conditions. Jennifer continues to monitor the event until the traffic incident is cleared, seeing that she does not need to manually interfere with the system. The system then responds to the cleared event by gradually adjusting the metering rates to allow more vehicles through the bridge.

8.2.5 Proposed Event/Incident Operations – Toll Plaza

The operations at the toll plaza during an incident are the same as during normal operations.

8.2.6 Proposed Event/Incident Operations – Commuter

The operations from a commuter's perspective during an incident are the same as during normal operations, except that the traveler may receive a 511 alert if she/he is signed up to MY511, to avoid the Bay Bridge in the event of an incident.

8.2.7 Proposed System Maintenance

Software maintenance will be done by the System Integrator for the contract term. Maintenance includes regular software updates, security patches, and calibration. After the period of performance for the System Integrator, Caltrans and BATA will be responsible for performing the software updates and routine maintenance, both preventative and reactive., Caltrans and BATA will be responsible for any changes to the calibration of the metering system, and responsible for updating any pre-set or pre-configured parameters for the system using the GUI.

8.2.8 System Ownership

The proposed Metering Light system software ownership will be governed by the terms and conditions of the agreement between BATA and the System Integrator.

8.2.9 System Failure/Redundancy

The new Metering Light system now runs 24/7 and continuously monitors the traffic conditions. In the event the proposed Metering Light system fails at the Caltrans ATMS there are redundant work stations for operations within the TMC, in the Toll Plaza, and at the BATA offices. The operators would use the work stations in that order. The Caltrans operators will coordinate directly with BATA and Toll Plaza staff should a failure occur. The system will be designed to have an interim failure plan where it defaults or fails back to the old Metering Lights system until BATA and Caltrans determine one system can remain operational. The system shall have built-in redundancy in the event of server failure.

If the detection system fails, the proposed Metering Light system shall be able to operate in fully manual mode or using pre-set time of day plans based on historic trends.

8.2.10 System Security

The proposed Metering Light system will require a secure log in to access the system. Users will have different security privileges depending on roles that can be configured by the Caltrans Administrator. The roles may include:

- Caltrans Administrator – all rights and privileges,, push software updates
- User – Read Only – access to reports and can observe the operations of the system. Cannot make changes to metering rates or lane preferences,
- Operator – can access reports and make changes to metering rates, lane preferences, and CMS operations.

8.2.11 System Reporting/Performance Monitoring

The proposed Metering Light system will produce automated reports that be accessed on demand or run on a preset time schedule (daily, weekly, etc.). The reports will be generated

in Word or Excel and PDF formats for easy manipulation and archiving. The system shall archive data every 180 days. The reports will include details of metering lights operations not limited to:

- Date/Time the metering lights are turned on and off
- Metering Lights Plans used (time of day, adaptive).
- Metering Rates per Lane and time of change of rates
- Manual or Operator intervention in Metering Lights operations
- Security credentials – users, change logs be user, security breaches (rejected log in times).
- Server and software updates
- Performance metrics.
- CMS messages and override
- Downstream traffic volumes and speeds per lane

The reports can be accessed by all users of the proposed Metering Lights system.

The proposed Metering Light system will have an alert function where users can define user-specific alerts that are sent to an email or mobile phone. The alerts may include failures, queue length, large delta in metering rates within X minutes, security breaches, etc. The system will also have a dashboard that displays real time and historic performance metrics.

8.2.12 System Integration

The proposed Metering Light system is a separate, standalone application that exchange information with the Caltrans ATMS for operations. The proposed Metering Light system will use detector data from the ATMS to trigger the metering rates. The proposed Metering Light system will also exchange information with the CMS system so that when the metering lights are turned on, the CMS will automatically display a message indicating "Prepare to Stop." When the sign is not in use for metering, Caltrans operators using the ATMS to display alternate messages about congestion, incidents, and Amber alerts. The proposed Metering Light system can be operated independently on non-ATMS work stations and through remote access.

The proposed Metering Light system will have the ability to integrate with additional systems in the future including other ramp metering systems, Express Lanes systems, and ICM or Connected Corridors systems. The purpose of the additional integration is to make a more robust metering lights system to improve operations in the vicinity of the SFOBB and to promote regional traffic operations. The extent of the integration will be determined at a later date.

9. SUMMARY OF IMPACTS

The following table compares the operations of the existing and the proposed system to highlight the major changes between the two systems in terms of operations. The proposed ML system will be an automated system that uses real-time information from detectors to adaptively change metering rates. The system will be designed to be flexible with any future changes to lane configuration, lane utilization, or AET. It will also be designed for future integration of additional systems such as ICM, additional ramp meters, or Express Lanes and utilization of additional upstream or downstream detection. The major constraints on system development are cost and time to develop the software. These risks will be managed according to the risk management plan. The metrics for assessing system performance will be determined during the requirements development. It is anticipated they will be queue length, speed, travel times, number of manual interventions, etc.

Table 2 - Existing and Proposed Operations		
Use Case	**Existing Operations**	**Proposed Operations**
Normal Operations - TMC	• TMC operator manually observes queue lengths on CCTV feeds and turns metering lights on and off in response to observed traffic • Operator sets metering rates manually based on the Metering Sequence Table, with preference to FasTrak™ lanes • Metering rates may vary based on operator judgment based on experience and rough guidelines	• TMC operator manually observes traffic conditions on CCTV feeds to validate automatic metering light operations. • Metering lights turn on and off 24/7 and automatically in response to traffic conditions • Metering rates are set automatically based on input from detection with a priority given to FasTrak™ per the requirements • Operator may override automatic operations and make metering rate changes based on observations
Normal Operations – Toll Plaza	• Toll Plaza is manually staffed by the Toll Plaza Commander based on traffic conditions viewed in the ATMS • Commander experience and known event information will affect staffing levels • Commander records and responds to metering lights activation and deactivation • Commander has no detailed real-time information on metering lights operation	• Toll Plaza Commander receives automatic email alerts when traffic conditions will warrant forthcoming metering lights activation, allowing the Commander to ready personnel needed • When metering lights are on, Commander receives email and staffs all booths. Changes are logged automatically. • Commander may view Metering Lights system to verify metering lights operation and view historical data
Normal Operations - Commuter	• FasTrak™ commuter has priority and HOV is not metered • Metering rates may be observed to respond slowly to actual conditions	• FasTrak™ commuter has priority and HOV is not metered • Metering rates are adjusted in small increments and responsive to traffic • CMS message to indicate metering lights are on in addition to other messages
Event/Incident Operations - TMC	• Incidents are detected manually by CHP CAD and by CCTV cameras • TMC operator responds to incidents by turning on metering lights and adjusting the metering rate to the highest setting	• TMC operators are alerted by CHP CAD of incidents and confirms by CCTV cameras • Metering lights and rates are changed automatically based on traffic conditions • Metering lights can be overridden by TMC operators
Event/Incident Operations – Toll Plaza	• Same as normal operations at Toll Plaza	• Same as normal operations at Toll Plaza
Event/Incident Operations - Commuter	• Commuter checks 511 manually before trip	• Commuter is automatically alerted of incidents on route by 511 if they use MY511
Maintenance	• Caltrans staff owns and maintains field devices and communication network	• Caltrans staff owns and maintains field devices and communication network

	• Maintenance is done in response to failures • Software maintenance is done regularly by Caltrans • Updates to metering algorithm is rarely done due to complexity	• Devices are actively monitored for issues, and maintenance is responsive and as scheduled • Software maintenance will be done regularly by the System Integrator for the contract term • Caltrans and BATA are responsible for calibration changes and updating pre-sets
Failure	• Failure at the TMC will require manual operation from the controller in the field • If controller is unresponsive, then there is no metering system	• Redundant workstations at the TMC, Toll Plaza, and the BATA offices are available in event of failure at the Caltrans ATMS • An interim failure plan is available • Server redundancy is available • Detection system failure will activate fully manual mode or pre-set time of day plans
Reporting/Data Collection	• No automated reporting or tracking • Operator manually logs information • No alerts set up for system	• A real-time dashboard continuously report conditions and actions • Automatically generated reports are highly configurable and are available on demand are highly configurable • Alert function can send user-defined alerts to an email address or mobile phone
Integration	• Independent operation from Caltrans ATMS • No direct integration with any other systems	• Metering Lights system exchange information with Caltrans ATMS for operations • System exchange information with Caltrans CMS • Future integrations with additional systems is possible

10. HIGH LEVEL REQUIREMENTS

The following high-level requirements will guide the development of the proposed Metering Lights system. These requirements will become the minimum requirements for the System Integrator and will be broken down and detailed further in the Requirements Documentation.

High Level Requirements	
ID	**Requirement**
System Software	
1.1	The Metering Light System shall operate 24/7.
1.5	The Metering Light System shall exchange detector data with the Caltrans ATMS.
1.10	The Metering Light System shall exchange on/off data with the Caltrans CMS to display metering related messages in real time.
1.15	The Metering Light system shall use real time volume, speed and occupancy data from detectors to automatically adjust metering rates.
1.20	The Metering Light system shall implement the metering rate in the field within X seconds.
1.25	The Metering Light System shall allow secure remote access.
Metering Algorithm	
2.1	The Metering Light System shall adjust metering rates by lane.
2.5	The Metering Light System shall use pre-defined parameters to adjust metering rates by payment type/lane.
2.10	The metering rates shall vary between X and y.
2.15	The metering rates increases and decreases shall be user configurable, e.g., not increase or decrease by more than 10% every 2 minutes.
Graphical User Interface	
3.1	The Metering Light System shall allow users to adjust metering rate parameters using the GUI.
3.5	The Metering Light System shall provide a dashboard with real-time conditions and actions as well as historical and predicted conditions (based on historical data).
3.10	The Metering Light System shall allow the viewing and exporting of reports.
Network Security	
4.1	The Metering Light System shall be a secure, encrypted system.
4.5	The Metering Light System shall use secure log in credentials for access.
4.10	The Metering Light System shall have customizable roles with variable level of access.
Failure	
5.1	The Metering Light System shall have a redundant server for failure operations.
5.5	The Metering Light System shall be able to roll back to the existing system for the first 6 months of operations after Acceptance.
5.10	The Metering Light System shall send alerts to registered users when the system fails.
Maintenance Support and Warranty	
6.1	The Metering Light System shall have a 2 year warranty for all maintenance and technical support needs.
6.5	The Metering Light System software shall be owned by BATA.
6.10	The Metering Light System shall have a perpetual license for BATA and Caltrans.

11. NEXT STEPS

The next step in the System Engineering process is to develop the detailed requirements and vet those requirements with the key stakeholders. The key stakeholders for the requirements development will be BATA Project Management staff, BATA IT staff, Caltrans Traffic Operations, Caltrans Maintenance, and Caltrans IT. The requirements will be used in the procurement documents for the Request for Proposal for the System Integrator.

APPENDIX A – EXISTING SYSTEM PICTURES

Existing Metering and TOS Cabinets

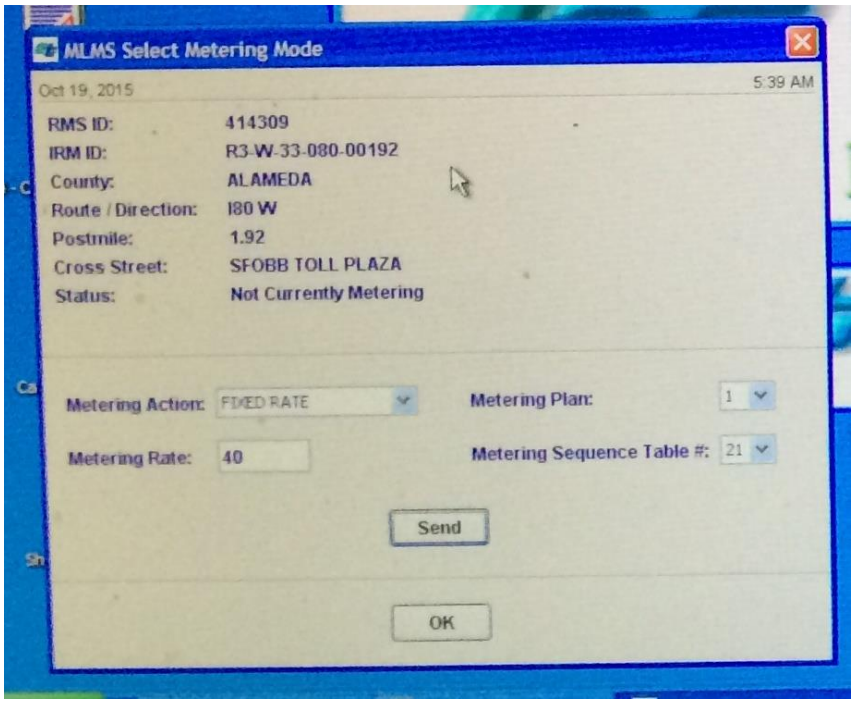

Figure 8 - Existing Metering System Interface

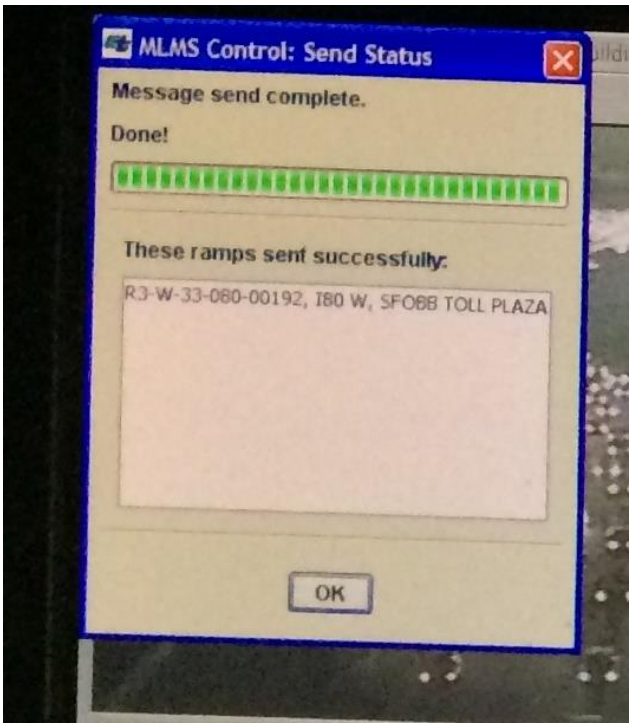

Figure 9 - Existing Metering System Message

Figure 10 - Existing Non-Functional CMS