An Investigation of the Operation of the Metering System at the San Francisco Oakland Bay Bridge (SFOBB)

[Modified version]

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ABSTRACT

The westbound direction of the San Francisco-Oakland Bay Bridge (SFOBB) is one of the most heavily travelled tolled freeway facilities in the nation. A metering system is used to maintain the entering flow at capacity on the bridge and facilitate the merging of 20 traffic lanes at the toll plaza into five travel lanes on the bridge. This paper presents our assessment of the operating performance of the SFOBB and its metering system based on an analysis of the database of loop detector data, video recording, tollbooth counts, and metering logs. There are active bottlenecks that reduce the throughput on the bridge. A number of weaknesses are observed in the current metering strategy. Proposals are formulated to improve the operating conditions at the bridge including re-arrangement of travel lanes for different vehicle types at the toll plaza, and advanced control ramp metering algorithms.

Keywords: Congestion, bottlenecks, metering, control, Bay Bridge
INTRODUCTION

The San Francisco-Oakland Bay Bridge (SFOBB) is part of Interstate 80 connecting San Francisco and Oakland, two large cities in Northern California. The 4.5 mile bridge crosses San Francisco Bay in two spans: the eastern span from Oakland to Yerba Buena Island, and the western span from the Island to San Francisco. It has five lanes in each direction. During the morning commute hours, traffic congestion on the Oakland approach stretches back to the bridge’s three feeder highways, Interstate 580, Interstate 880, and Interstate 80 toward Richmond, California.

At the east or Oakland end of the bridge in the westbound direction, a 20-lane toll plaza collects tolls from westbound drivers (toll lanes are numbered left-to-right). A metering system located approximately 0.18 miles downstream of the toll plaza is used to control the flow at or below entering the bridge and to facilitate the merging of vehicles from 20 into five lanes. Figure 1 shows the layout of the SFOBB toll plaza approach [1].

The ramp metering system at the SFOBB was installed in 1974 [2]. The metering rates are manually controlled and the main goal is to have no congestion at the merging area, after the metering lights. Typical waiting times to cross the tollbooths and metering lights range between 20 and 30 minutes on incident-free weekday peak periods. The metering system allows high occupancy vehicles (HOVs with 3+ occupants) to bypass the metering lights during the AM peak (5:00 to 10:00 AM), thereby providing major time savings by avoiding the long queues on the other lanes. HOVs also pay a reduced toll.

The SFOBB is one of the region’s most heavily travelled corridors, with over 280,000 vehicles and 500,000 people per day crossing its two decks [1], and among the ten most congested freeway facilities in the nation [3]. It is therefore important to ensure that the bridge operates with maximum efficiency. Previous studies on the SFOBB focused on an evaluation of variable tolls introduced to improved traffic performance [4], and an assessment of the performance based on the metering and tollbooth counts data [5]. A simulation study proposed a metering control algorithm to maximize the capacity of the corridor [6]. The findings of the operational studies may not be currently applicable because of the design features in the newly constructed eastern span of the SFOBB. At the same time the recent installation of sensors, surveillance and communications equipment on the new span offers an opportunity to assess the bridge operations based on more extensive field data.

The objective of the research described in this paper is to perform a systematic empirical analysis of the traffic on the SFOBB based on data from multiple sources and to use the analysis to propose strategies to improve performance.

The paper reports the work performed and the findings to-date from this ongoing research effort. The next section describes the data types and sources. The next section discusses the data analysis and findings on the operating conditions on the bridge and the performance of the metering system. The final section summarizes the study findings and outlines the next steps in the research project.

DATA COLLECTION

We collected data from the following locations and sources:

a) Loop detector data: Dual loop detectors are installed on each lane of the bridge starting at the beginning of the five-lane section after the merge area past the metering lights. The loop detector data are sent to a 170 controller and then stored in the PeMS database [7].
There are 11 loop detector stations on the westbound span of the SFOBB placed approximately 0.19 miles apart from the base of the bridge up to the Yerba Buena Island (a total length of 2.1 miles). The detector locations are shown in Figure 2. Detector data (flow, occupancy, speed) are collected every 30 seconds and aggregated to 5 minutes in the PeMS database. PeMS diagnostics confirm no detector malfunctions or missing data for the period of data collection.

b) Video data: The SFOBB study section is equipped with 13 analog video surveillance cameras that provide good coverage of this section. The video images are transmitted via optical fiber to the SFOBB administration building. The images are recorded and stored in a server.

c) Tollbooth counts data: As shown in Figure 1, each vehicle needs to pass a tollbooth before entering the bridge. Of the 20 tollbooth lanes, four (Lanes 1, 2, 19, 20) are dedicated to buses and High Occupancy Vehicle Vehicles (HOVs) in the morning peak 5:00 AM-10:00 AM. (Lanes are numbered left to right.) After 10:00 AM lanes 1 and 2 are open to all vehicles, whereas lanes 19 and 20 are further restricted to buses only. Nine lanes (3-6, 12-16) are open to vehicles with cash paying drivers, and the remaining seven lanes (7-11, 17-18) are reserved for vehicles equipped with electronic toll collection Fastrak RF ID tags [8]. We obtained from Caltrans the tollbooth counts data for the entire month of May 2015; the data give the exact time, lane, and type of each vehicle crossing the tollbooths. From this data, we obtain the number of vehicles leaving the toll booths by type (HOV, Fastrak and Cash) every 5 minutes.

d) Metering lights exit rate: The Caltrans SFOBB metering operator manually logs the metering rate (in vehicles/min) for the time periods during which ramp metering is operational. From the metering log information we obtain the number of vehicles exiting the metering area every 5 minutes. As noted above HOV vehicles do not stop at the metering lights in the AM peak. The remaining 16 Fastrak and Cash lanes merge into 12 lanes after leaving the tollbooth (see Figure 1). Vehicles on these 12 lanes are metered. After the metering lights, vehicles from the 12 meters lanes and the 4 HOV lanes merge into 5 lanes in the merging area before the base of the bridge (see Figure 1). Data were collected for the month of May 2015, checked for accuracy and stored in a server. Error checking and processing routines developed for the PeMS system were used to check and process the detector data.

DATA ANALYSIS AND FINDINGS

We carefully analyzed the data from different sources to a) assess the operating conditions on the bridge and possible presence of bottlenecks, b) effectiveness of the metering system and c) impact of difference vehicle classes (HOV, Fastrack) on bridge operations. The findings of the analysis are presented in the following sections.

Figure 3 shows three plots of traffic variables at all detectors for a 7-hour time period (5:00 AM to 12:00 NOON) on May 18th 2015. The direction of travel is from detector 1 toward detector 11. The top plot shows the contour map of the traffic flow recorded by detectors. Each cell represents the flow at 5-minute interval for each detector for the selected time period. The color bar at the right hand side shows the value of the aggregated flow per 5 minutes for each color. The second plot shows the % occupancy values for the same time and detectors. The bottom plot shows the speed contour map for the same time and location interval. We can observe is a short duration congestion at about 5:30AM at the base of the bridge, where the flow and occupancy
are high. At that time, the metering lights are still off, so the number of cars that enter the bridge is equal to the number of cars that crossed the tollbooths. We further discuss this bottleneck occurrence and possible mitigations in the next section.

Based on the plots in Figure 3, it is clear that starting approximately 9:00 AM a queue grows from the island all back to the base of the bridge. The % occupancy is high in the queue, flow is low, and speed is less than 30 mph. The queue begins dissipating around 10:00AM. Figure 4 shows the speed contours for all weekdays in May 2015. While each day has its unique traffic behavior, in most workdays a queue from the island toward the base of the bridge starts to form around 8AM-9AM and disappears around 10AM-11AM. These plots clearly indicate that there is a recurrent bottleneck downstream of the island but data are not currently available to clearly identify the location and cause of bottleneck. Observations by the research team indicate possible causes for the bottleneck location are the lane changing maneuvers of exiting vehicles, vehicle and/or driver composition. The metering system, however, may affect the duration and size of the queue.

Figure 5 shows the flow, occupancy, and speed by travel lane at the first three detectors over the 7-hour interval, where lane 1 is the most left lane. At the first detector the middle lane has higher occupancy, lower speed, and higher flow compared to the other lanes. In the downstream detectors 2 and 3 the flow is almost uniform among all the lanes and it is slightly higher in the most left lanes, which are the speeding lanes.

The higher flow at the middle lane at the base of the bridge is due primarily to the lane changing. Twelve lanes leave the metering lights and become 5 lanes. Moreover, HOV lanes are entering the bridge from the most left and most right lanes. Also, Cash and Fastrak lanes are not uniformly distributed and there are more Fastrak lanes in the middle section. This is further discussed below.

Next, we compared the tollbooth counts against the metering exit rate, i.e., the entry flow (input) to the bridge and the exist flow (output). Figure 6 shows the scatter plot of the exit rate of the metering light versus the car flow at the tollbooths at 5-minute intervals. The tollbooth flow varies frequently, while the metering exit rate remains constant for long time. Clearly, there is a very weak low correlation between the two sets of values (R² equals 0.35 on May 18th and only R² equals 0.04 on May 20th). These results indicate that the metering rate does not correspond to the number of cars entering the metering area from the tollbooth. As a result, a large number of vehicles is stored in the metering area during the peak hours.

Figure 7 shows plots of the aggregated flow per 5-minute interval from the tollbooth counts and metering rates on May 18th and 20th days. The blue curves show the metering flow and the green ones show the tollbooth counts. Note that the metering starts and ends at different times each day. There are times that the metering rate is much higher than the tollbooth counts; i.e., the exit rate of the metering area is higher than the entrance rate. Contour maps show that on May 18th a queue starts around 9AM and reaches the base of the bridge around 10AM. However, in the metering and tollbooth flow plot, the metering is only active until 9:25AM. At the same day, before 9AM despite the contour maps show no queue on the bridge, the metering rate is below the capacity (834 cars/5min) of the bridge. On May 20th, the metering rate changes quite often and sometimes it is as low as 600 cars/5min. The metering rate is even below the capacity around 6:30AM, when there is no sign of existence of a queue on the bridge based on the contour maps. These observations indicate that the metering rate does not match the traffic condition of the bridge.

Figure 8 shows the number of vehicles per type (cash, Fastrak, and HOV) crossing the tollbooths in 5 minutes. The Fastrak vehicles experience the largest reduction at the activation of metering. Figure 7 shows that right before metering lights activation, number of cars that passed the tollbooths is much larger than the bridge capacity (834 cars/5min). This may explain the cause of early bottleneck at the base of the bridge shown in Figure 3, and the high flows in the middle.
lane shown in Figure 5(a). The congestion at the base of the bridge may be due to the large number of Fastrak vehicles entering the bridge from the middle lanes. While cars in the Fastrak lanes pass the tollbooths with a high rate, cars in the cash lanes are waiting in the queues behind the tollbooth and enter the bridge in a much lower rate. Video recordings confirm the hypothesis about the pre-metering congestion at the base of the bridge. Figure 9 shows screen shot from the metering area at May 20th, before metering light activation. As it is shown in the picture, there is a queue at the middle lanes, which started at the base of the bridge and grow up to the tollbooth. This queue grows very fast and in less than 5 minutes it reaches the tollbooths and blocks Fastrak cars from passing the tollbooths. As congestion in the middle lane grows, queues start to form in other lanes as well. However, the outer lanes queues do not reach the tollbooths.

HOV lanes are in operation until 10:00AM and after that they are open to all the vehicles. Figure 8 shows that there is a significant reduction in the number of HOV vehicles after 9:00AM (~100 cars/5min for 4 lanes = ~25 cars/5min/lane). Therefore, the HOV lanes are underutilized after 9:00AM, and could be potentially made available to the rest of the vehicles.
DISCUSSION

In this paper, we presented the findings of an ongoing research study to investigate the operating performance of the SFOBB. The analysis of loop detector data, video recording, tollbooth count data, and metering logs reveals some significant insights into the Bay Bridge westbound traffic.

There is an active bottleneck between 9 and 10 AM that originates west of the Yerba Buena Island with congestion extending more than two miles upstream to the base of the bridge.

There is a bottleneck early in the morning at the base of the bridge, even when there is no sign of congestion on the bridge. This is likely due to lane changes and the large difference in flows in the middle and outer lanes among vehicle types.

There is little correlation between metering rates and tollbooth exit flows. Sometimes the metering exit rate is much lower than the capacity of the bridge, even when there is no sign of congestion on the bridge.

After 9:00AM the HOV lanes are underutilized and after 10:00AM few vehicles use those lanes.

The next step in the research involves further empirical analysis of operating conditions and development and testing of strategies to address the problems diagnosed.

We are continuing the field data collection and analysis to determine the exact location and cause of the downstream bottleneck. We will investigate the use of mobile data to supplement the limited infrastructure-based data from the western span of SFOBB.

We will investigate the possible activation of metering lights prior to queue formation to prevent the early morning congestion at the base of the bridge. Furthermore we will study changes in the placement of HOV, Fastrak, and cash-only lanes and modification of the metering strategies to avoid the congestion at the merging area.

We will develop new traffic responsive algorithms for the metering lights on the bridge. The goal is to develop an efficient control system that adapts to the traffic condition of the bridge and increases the throughput while preventing congestion in the merging area.

We will investigate ways to avoid underutilization of the HOV lanes while preserving the priority of HOV vehicles and improving the operating performance of the entire traffic stream.
REFERENCES


Figure 1: SFOBB Tollbooths and Metering Lights Configuration [1]
Figure 2: Detector Locations – WB Direction Bay Bridge
Figure 3: Flow, % Occupancy, and Speed at All Detectors WB SFOBB --May 18, 2015
Figure 4: Speed at All Detectors WB SFOBB May 2015
Figure 5: Lane-by Analysis – May 18th 2015
A) May 18th, 2015

B) May 20th, 2015

Figure 6: Scatter plot of metering vs. tollbooth count with the best-fitted line
Figure 7: Metering rate and Tollbooth counts curves
Figure 8: Tollbooth Counts for HOV, Fastrak, and Cash
Figure 9: Screen shot of the video for May 20th, at 5:34AM