Bottleneck Congestion with a Constant and Peak Toll: San Francisco – Oakland Bay Bridge

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1 Background

Roadways bottlenecks have been studied extensively in the transportation literature. A body of theoretical work has grown out of Vickrey's [9] proposed equilibrium model which captures traveler responses to dynamic queuing at recurrent bottlenecks. In the face of congestion, it is supposed, each user will choose what time to arrive at the bottleneck in order to minimize their own travel time. Subsequent work by economists and engineers have shown how equilibrium patterns will be affected by various pricing strategies including a coarse toll that is higher during a peak period than off-peak [1]. Recent studies have also extended this theory to address the dynamics of the equilibrium when travelers can choose between driving and using transit [8, 4]. This study presents an analysis of real traffic patterns at the San Francisco – Oakland Bay Bridge making use of this theory to estimate relevant bottleneck and demand properties.

In addition to travel delay and deviation from desired schedule, travelers also experience costly uncertainty in their travel times from day to day. In fact, research suggests that travel time reliability is a factor that commuters consider, and variability affects not only the cost of their trip but also when people choose to travel [6].

The San Francisco – Oakland Bay Bridge in California is a tolled freeway that carries heavy commuter traffic into San Francisco during the morning peak hours. On July 1, 2010, the Bay Area Toll Authority switched from a fixed toll of $4 per vehicle to a weekday time-dependent toll charging $6 per vehicle during the morning (5am–10am) and evening (3pm–7pm) peaks. Many aspects of the transition from fixed to time-dependent tolls have been studied [3]. This paper presents a focused analysis on how traffic patterns on the Bay Bridge compare to the theoretical deterministic equilibrium and quantifies travelers' value of time as well as the reliability of travel times approaching the bridge.

2 Methodology

The methodology for this analysis is to make use of available information from loop detectors and Electronic Toll Collection (ETC) transponders in order to analyze the peak congestion for several days before and after the transition to time-dependent peak tolls. The data allows for only a limited view of the queuing that develops at the Bay Bridge, because there is a freeway interchange shortly upstream of the toll plaza that is insufficiently equipped with detectors to track all vehicle flows. However, there is enough data to identify the vehicle flows, the specific start and end times of peak queuing, and to track the evolution of queuing and travel times on the lanes leading to the toll plaza.

The observed data for each day can be used to estimate the relevant parameters of a bottleneck model: bottleneck capacity, duration of the rush, earliness and lateness penalties. For peak period pricing, the traveler's value of time can also be estimated based on the pattern of arriving vehicles [1]. The value of time cannot be estimated using only data during the constant tolling, because there is no change in price for comparison. Seven midweek days were analyzed from April 2010 (during constant tolling) and from September 2010 (during peak period tolling). The results are compared to identify the extent to which congestion patterns repeat from day to day and to determine changes that resulted from implementing time-dependent tolls.

3 Findings

A first comparison is made between the travel patterns by cars and rapid transit (BART), as shown in Figure 1, and the theoretical travel pattern that is expected to arise for a bottleneck with transit [4]. Clearly, The total demand shown in Figure 1 greatly excedes

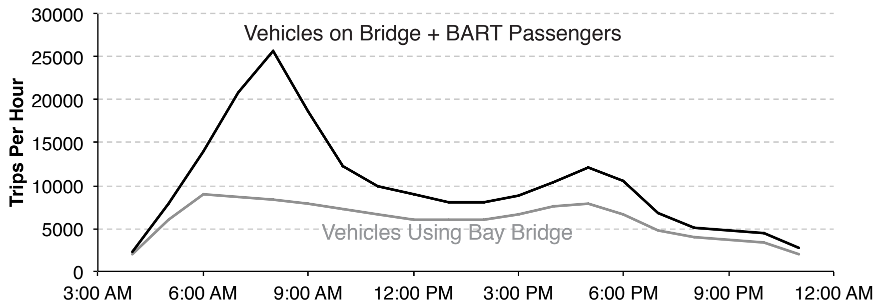

Figure 1: Mode use by time of day for westbound trips across San Francisco Bay [3, 5].

the capacity of the bridge reported in Table 1.

We can also compare the times when queuing develops and dissipates in the Bay Bridge toll plaza, and the results are summarized in Table 1. Two features are interesting to note. First, a comparison of the standard deviations shows that the time when congestion starts is more consistent than the time when congestion clears each day. This suggests that arrival patterns are consistently repeated from day to day as would be expected in equilibrium, and the variability of queue clearing time is likely due to the propagation of traffic disturbances and the increased proportion of non-work trips later in the rush. The declining proportion of vehicles using ETC over the course of the morning peak supports this hypothesis. This variability is also reflected in the increased variation in travel times over the course of the rush as shown in Figure 2 where a marked increase occurs after the toll drops at 10am. A second comparison of the duration of queuing shows that significant peak spreading occurs even though the total demand in September was within 2% of the demand in April. The effect is particularly great at the end of the rush when travelers have an incentive to travel later in exchange for a reduced toll.

Table 1: Bottleneck Properties Before and After Peak Tolling

Parameter	Constant Toll (April 2010)		Peak Toll (Sept. 2010)	
	Mean	Std. Dev.	Mean	Std. Dev.
Bottleneck Capacity (veh/hr)	7896	1467	8164	318
Queue Starting Time	6:34am	16 min	6:14am	3.8 min
Queue Clearing Time	10:11am	58 min	10:51am	46 min
Value of Time ($/hr)	N/A	N/A	23	2.2

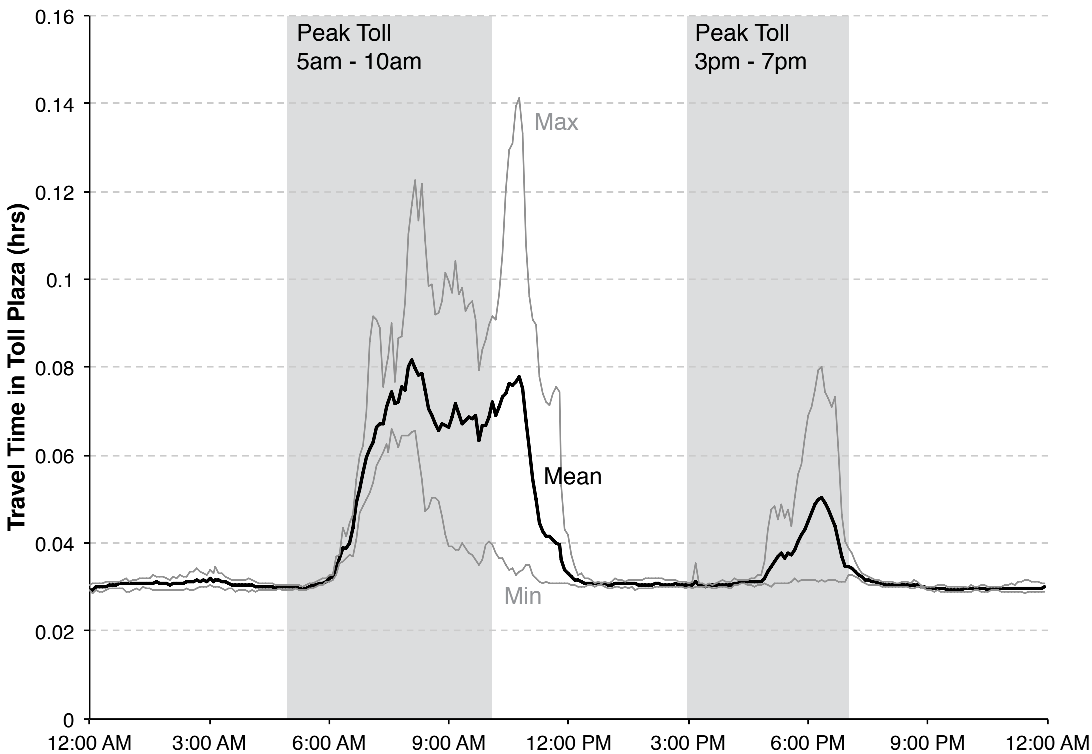

Figure 2: Travel times in the toll plaza for sampled weekdays in September 2010 [5].

Finally, the value of time can be estimated by observing the consistent recurring drop in demand immediately preceding the toll increase at 5am each day. This drop implies the number of users that choose to depart earlier than they otherwise would in order to avoid paying an additional $2 of toll. On this basis, the average value of time is consistently estimated to about $23 per hour for commuters in the early morning. Preliminary analysis was also conducted to estimate the value of earliness and lateness. Using only available data at the very onset and end of queuing, we would expect to observe the behavior of the least sensitive commuters and that is why these estimates are extremely low. Furthermore, the variability of travel times from day to day, especially at the end of the peak, suggest that analyzing how commuters value earliness and lateness in a deterministic way may not be particularly meaningful.

The results of this paper show how equilibrium theory can be used to make sense of traffic data and to estimate useful parameters that describe the bottleneck congestion. The results also show some limitations of using deterministic models to describe real systems with heterogeneous users and variable traffic conditions. This can be used to develop improved pricing strategies and coordinate transit service.

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