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Searching for induced travel: Elimination of a freeway bottleneck and subsequent effects on rail and freeway volumes

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ABSTRACT

The removal of a freeway bottleneck in California has allowed researchers to investigate short-term induced travel and a potential mode switch from rail transit. This particular bottleneck, a double lane drop from reduced tunnel capacity, is a unique case as alternate auto routes are quite undesirable; the only other option is to consider nearby rail transit. Freeway volumes and rail ridership were examined before and after the removal of the bottleneck to estimate the extent of induced travel. Freeway volumes during both commute periods increased 10–13%, faster than other nearby locations, and rail transit ridership between stations on either side of the pre-existing bottleneck showed modest declines despite system wide increases. Differences of means testing confirmed that many of these changes were statistically significant. Examining the magnitude of induced travel is relevant when making policy decisions for removing mature bottlenecks that involve the use of public finances.

1. Introduction

In the San Francisco Bay Area, the Caldecott Tunnel bottleneck on State Route (SR) 24 had long been a flashpoint for frustrated drivers. At that specific location the eight lane freeway dropped to just six lanes passing through the three two-lane tunnel bores. The reversal of the center bore back and forth to give the peak direction four lanes, once thought to be innovative, was increasingly failing to accommodate off-peak demand with only one bore and two lanes. In November 2013, a fourth tunnel bore was completed by the California Department of Transportation (Caltrans) allowing each direction to have four lanes throughout the day for the first time. Due to the topography of the area, the Caldecott Tunnel is the only reasonable crossing through the Berkeley Hills for a significant distance on either side. Prior to the opening of the fourth bore, reverse commuters were either faced with congestion at the tunnel entrance from the lane drop or if their jobs were within a reasonable walking distance from transit, ride the Bay Area Rapid Transit system (BART). BART also passes through the Berkeley Hills at a similar location and offers congestion free travel from Oakland to expanding job centers in Eastern Contra Costa County. Although BART was originally designed to take commuters into San Francisco and Oakland, ridership had increased in the opposite direction, corresponding with the increased congestion at the reverse commute bottleneck on SR 24.

The completion of the fourth bore, removing a mature freeway bottleneck, offered researchers a unique opportunity to view the onset of short-term induced travel and study the changes in mode choice among reverse commuters who may have previously taken BART to avoid freeway congestion. Again, since the topography of the Berkeley Hills makes it quite hard for travelers on that particular commute to go any other way, it might be possible to observe a modal switch from rail transit (BART) to the automobile. Here, perhaps, we might see whether there is measurable short-term induced travel in a case where there exists a functional alternate mode; this case is not the situation of a typical freeway widening in a vacuum. In this case study, will commuters conduct a modal switch? Will more travelers use their personal vehicles?

2. Background

2.1. Definitions

Induced travel from freeway expansion has been a regular topic among researchers for nearly a century. A majority of the research

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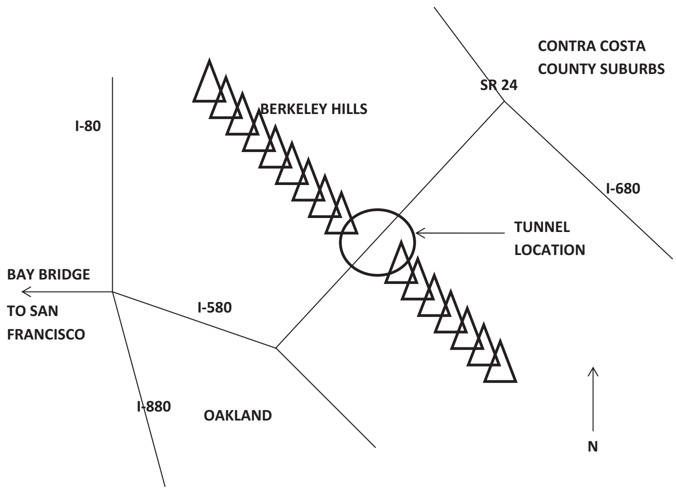

Fig. 1. Schematic of Regional Freeways.

has focused on what percentage of new traffic following freeway improvements is from exogenous (i.e. from population growth or new housing units) or endogenous factors (i.e. increased supply lowers travel cost and latent demand appears). Over fifty years ago Downs (1962) was already documenting limited congestion relief from the construction of urban freeways and stating that freeway expansion would not improve travel time due to induced demand. Researchers have proposed a simple definition that induced travel is "an increase in daily vehicles miles traveled (VMT), with reference to a specific geographic context, resulting from expansion of a highway facility." (Decorla-Souza and Cohen 1999, 251) Others have provided additional depth by breaking up induced travel into its constituent parts; Fröhlich (2003) lists the five sources of new vehicles that constitute induced travel:

1) A time of day shift by existing traffic
2) A route shift from other roadways
3) Mode shift from transit to auto
4) Change in destination choice due to reduced travel time (longer trips)
5) Entirely new trips (latent new trips)

There is commentary on whether all five of these contributions are truly *induced demand*. Cervero and Hansen (2002) stated that only the last three are induced demand while the others are merely induced travel. Noland (2001) stated that all five constituted induced travel, although he noted that mode shift has been a subject of debate as no new trips are being made. Still others follow the DeCorla-Souza model and refer to all types of 'additional demand generated by improvements in travel conditions' (Weis and Axhausen, 2009, 8) as induced demand.

Frohlich also notes that there is a question of short-term versus long term induced travel. As discussed by Lee et al. (1999), the only change in the short term is supply; new lane-miles while demand remains constant. Lee defines changes in the short-term as induced travel. However, in the longer term one should see changes in the demand curve as people change their employment or housing locations. These types of permanent decisions are what Lee refers to as true induced demand. As such, this report will be referring to any changes as short-term induced travel only.

2.2. Studies of induced travel

There have a number of studies utilizing different econometric methods to approximate the effect of induced travel. In the UK, Goodwin (1996) found an elasticity of 0.5 in the short term and close to 1.0 in the long term between reduced travel times and increased travel volume as part of a large change in the UK policy of motorway construction. In the US, demand elasticities comparing additional lane miles to VMT have been found to be between 0.5 and 0.9 by Hansen and Huang (1997) as well as Noland (2001) with long term elasticity nearly 0.9. Cervero and Hansen (2002), as a follow up to earlier works, attempted to use a more refined model and still found short term elasticity values greater than 0.5. Lower values of 0.2 found by Hymel et al. (2010) appear to be from aggregation at the state level and include more control variables. The accepted range of 0.5–0.9 was challenged by a Duranton and Turner study in 2011 which found an elasticity of 1.03 on interstate freeways in the United States, indicating no benefits from increased freeway capacity. This was followed up by a similar study in Japan by Hsu and Zhang (2014) that the elasticity could exceed 1.2, indicating the potential for a new equilibrium of travel speed that is lower after capacity expansion. In the reverse direction, Chung et al. (2012) analyzed the short and long term effects of a noteworthy freeway removal above the Cheonggye-choen River in Seoul. The study found that travel speeds returned to pre-removal values by virtue of a large drop in vehicle volume (deterred demand), changes in departure times, and mode shift to rail transit. The researchers concluded that the "anxiety about additional traffic problems due to the associated decrease in road capacity was unfounded." (Chung et al., 2012, 176).

There has been a similar research analog in regards to induced travel from changes in fuel efficiency or reductions in fuel prices, known as the rebound effect. This form of induced travel compares vehicle-kilometers per liter of fuel to increases in VMT. Sorrell et al. (2009) reviewed a number of empirical estimates and found that the average rebound effect ranged from 10% to 30%. Su (2011) found a value of 11% in the United States during the 2001–2008 period and found that the rebound effect became stronger at higher fuel prices. In Europe, when examining road freight transport, Matos and Silva (2011) determined that during the 1987–2006 period the rebound effect was 24%, higher than Su found in the United States.

It is noted that in much of the research described above, with the exception of the Korean example, examinations utilized very large data sets at the county, state, or national level. This case study differs in that we get to directly examine the induced travel following the removal of a freeway bottleneck that has no alternate routes and has a viable alternate transit mode (BART). Indeed, lower estimates for induced travel found by Cervero (2003) as well as DeCorla-Souza and Cohen (1999) were found during the examination of specific examples and by using a more detailed model of induced effects such as travel caused by time-of-day switches.

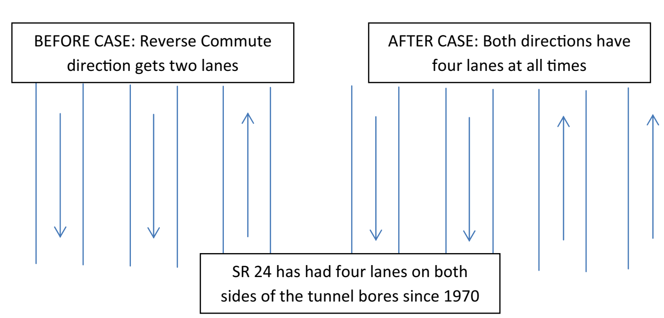

Fig. 2. Before and after November 2013 opening of fourth two-lane Caldecott Tunnel bore on SR 24.

Fig. 3. BART System Map (*courtesy of BART*).

2.3. Study area

This report focuses on travelers utilizing two sets of tunnels through the Berkeley Hills in California, the Caldecott Tunnels of SR 24 and the parallel BART Berkeley Hills rail tunnel. These tunnels connect the highly dense and urban cities of Oakland and Berkeley on the west side to the suburban communities of Concord, Walnut Creek, Lafayette, and Orinda among others on the east side. Travelers going to San Francisco from the east must also use SR 24 to access the San Francisco Bay Bridge. Fig. 1 shows a schematic of the area. To review, in the before case the reverse commute had a lane drop from four lanes to two and in the after case this lane drop was eliminated with the opening of the fourth bore. Fig. 2 shows the changes. Note each bore has two lanes.

BART's Pittsburg/Bay Point line, shown in yellow in Fig. 3, travels through the Berkeley Hills tunnel from Pittsburg stopping in downtown Oakland before continuing on to San Francisco and further to San Francisco airport. Those with other destinations in the East Bay, such as toward Fremont or Berkeley can switch trains at the MacArthur and 19th Street Oakland stations with a timed transfer. The BART Berkeley Hills Tunnel is between the Rockridge and Orinda stations and directly adjacent to the Caldecott Tunnel bores on SR 24 shown previously in Figs. 1 and 2. Rockridge and MacArthur are located within the City of Oakland.

BART has had dramatic increases in ridership from 4 million in Fiscal Year (FY) 1973 to 125 million in FY 2015 and the Pittsburg/ Bay Point line is no exception. However what makes this line unique is that many of the suburban stations to the east of Rockridge are job centers themselves and create an active reverse commute, particularly around the Walnut Creek and Pleasant Hill stations.

The analysis will also look at a smaller subset of BART ridership pairs between stations that are close to the tunnel proper, with six stations in Oakland and Berkeley to the west of the tunnel and the four closest stations to the east of it. These are shown below in Fig. 4.

2.4. Study design

This report will examine both the freeway volumes and two sets of weekday BART trip pairs (reported as turnstile exits); the entire network and between the stations close to the tunnels shown in Fig. 4. The summation of trip pairs, calculated by exiting ridership counts, was compared between August-September-October of 2012 and August-September-October of 2014. For example, in

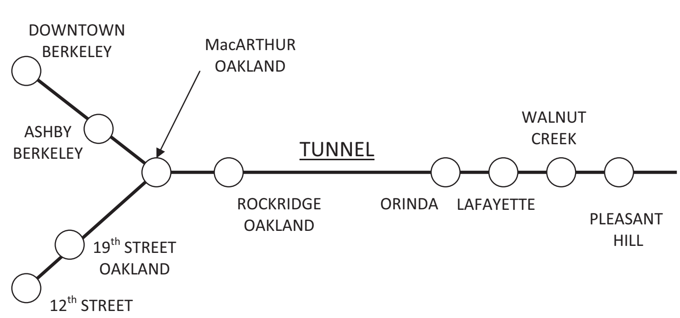

Fig. 4. Subset of BART stations immediately adjacent to the Berkeley Hills Tunnel.

Table 1
Freeway Volumes (vehicles/hour/lane), SR 24 Eastbound, AM reverse commute.

Time Period	2012 Volumes	2014 Volumes	2012–2014 volume changes
5:00–6:00	191	217	13.6%
6:00–7:00	487	523	7.4%
7:00–8:00	875	1006	14.9%
8:00–9:00	890	1016	14.0%
9:00–10:00	777	886	13.9%
AM Average	644	730	13.2%
AM Total	3220	3648	

August 2014 the average weekday trip count from Richmond to Orinda was 10 riders, meaning 210 trips were made between that pair in the month of August (there were 21 weekdays). Freeway volumes from October 2012 and October 2014 were compared during both the morning and afternoon peak by hour as well as by month. For this paper, freeway volumes were taken from detectors using information provided by the Caltrans Performance Measurement System, known as PeMS (2011).

3. Findings

3.1. Freeway

Tables 1 and 2 show the changes between October 2012 and October 2014 at SR 24 mainline freeway detectors for the two reverse commutes. In the westbound direction during the afternoon, the demand of the reverse commute exceeded the capacity of the old two-lane tunnel, causing congestion. The average amount of time with congestion (detector occupancy > 25%) is included in Table 2. Adding two additional lanes eliminated this problem in the short term.

As seen in Tables 1 and 2, both reverse commutes showed noticeable increases in volume when comparing the months of October 2012 and October 2014. The increases were the highest during the traditional peak hours (7:00–9:00 and 17:00–18:00)

Table 2
Freeway Volumes (vehicles/hour/lane), SR 24 Westbound, PM reverse commute.

Time Period	2012 Volumes	2012 Average Congested Time (min)	2014 Volumes	2014 Average Congested Time (min)	2012 to 2014 volume changes
14:00–15:00	920	0	1048	0	13.9%
15:00–16:00	982	0	1104	0	12.4%
16:00–17:00	1016	11.5	1181	0	16.2%
17:00–18:00	1040	22.5	1257	0	20.9%
18:00–19:00	902	8.5	994	0	10.2%
19:00–20:00	659	0	750	0	13.8%
PM Average	920	n/a	1056	0	14.8%
PM Total	5519	41.5 min	6334		

Table 3
Changes in Freeway Volumes (vehicles/hour/lane), Adjacent Freeways, AM commute: All changes shown in percent change.

Time Period	SR 24 Eastbound Reverse Commute	SR 24 Westbound Standard Commute	SR 4 Eastbound Pass to the North	I-580 Eastbound Pass to the South	I-680 Northbound Local Suburban Freeway
5:00–6:00	13.6	21.4	No data	−16.5	4.7
6:00–7:00	7.4	1.2	No data	−11.5	−2.8
7:00–8:00	14.9	−3.8	No data	−3.4	4.5
8:00–9:00	14.0	−0.8	No data	−4.4	12.2
9:00–10:00	14.0	9.9	No data	−2.6	24.2
PM Average	13.2	3.7	No data	−6.0	9.2

Table 4
Changes in Freeway Volumes (vehicles/hour/lane), Adjacent Freeways, PM commute: All changes shown in percent change.

Time Period	SR 24 Westbound Reverse Commute	SR 24 Eastbound Standard Commute	SR 4 Westbound Pass to the North	I-580 Westbound Pass to the South	I-680 Southbound Local Suburban Freeway
14:00–15:00	13.9	1.1	12.4	−3.4	17.3
15:00–16:00	12.4	5.4	12.7	−5.0	1.4
16:00–17:00	16.2	5.4	10.8	−3.4	4.9
17:00–18:00	20.9	3.8	9.4	−5.8	−7.1
18:00–19:00	10.2	−0.2	8.6	−5.2	−8.8
19:00–20:00	13.8	0.3	10.7	1.6	−1.2
PM Average	14.8	1.8	10.7	−3.6	1.1%

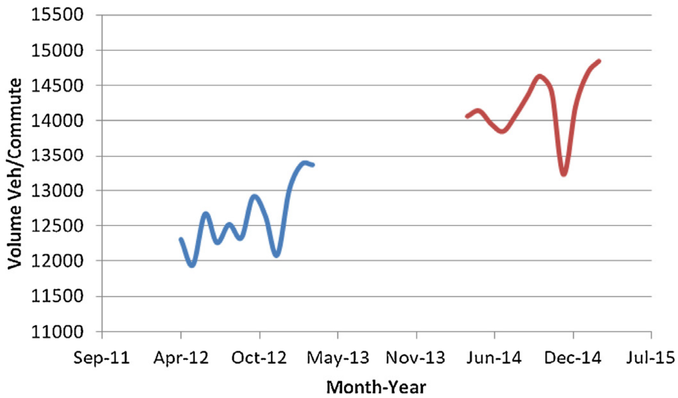

Fig. 5. SR 24 EB AM, Average Vehicles Per Commute Period (5:00–10:00) by Month [Reverse Commute].

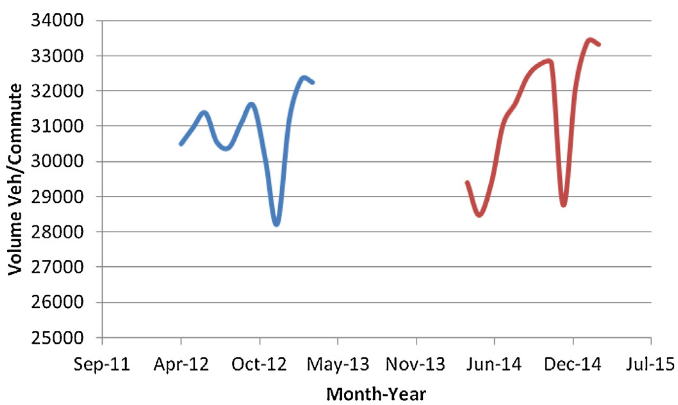

Fig. 6. SR 24 WB AM, Average Vehicles Per Commute Period (5:00–10:00) by Month [Standard Commute].

indicating possible consolidation within the commute traffic stream.

Considering the recent economic improvements in the Bay Area, as well as the decline in fuel prices, Tables 3 and 4 are included to compare the increase on the SR 24 reverse commutes with other local freeways. Note there was no data available for SR 4 during the morning peak.

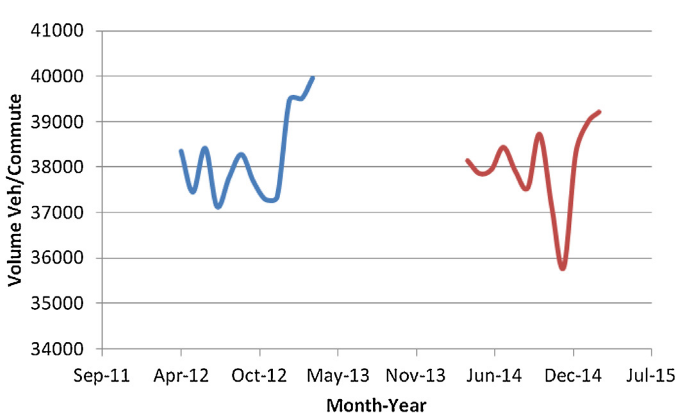

Fig. 7. SR 24 EB PM, Average Vehicles Per Commute Period (14:00–20:00) by Month [Standard Commute].

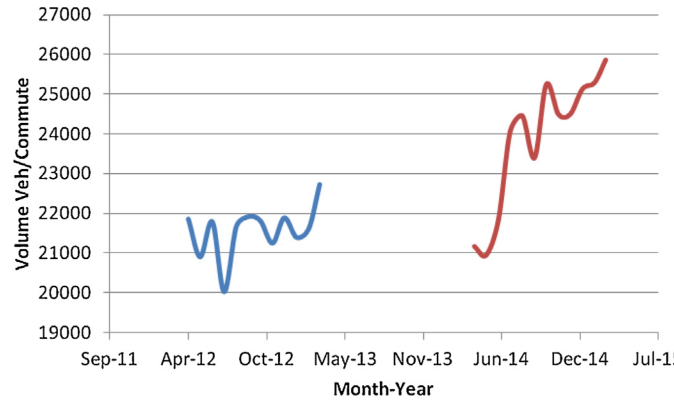

Fig. 8. SR 24 WB PM, Average Vehicles Per Commute Period (14:00–20:00) by Month [Reverse Commute].

As expected, there were notable increases in freeway volumes for the reverse commute direction and virtually no changes in the standard direction. Differences were particularly pronounced in the PM. These changes are shown in Table 5.

By contrast to the SR 24 reverse commute, many of the surrounding freeways, as well as the standard commute directions, showed much smaller increases or in some instances slight decreases. Secondarily, one can note that there were occasional sharp increases in commute volumes during the 5:00–6:00 and 14:00–15:00 h in multiple locations, possibly revealing a change in work hours to avoid heavy congestion at other bottlenecks such as the Bay Bridge and the 580/680 interchange.

The changes in reverse commute volumes as compared to volumes in the standard commute direction can be shown visually by looking at month-by-month volumes in Figs. 5–8. Although volume detectors on SR 24 were disabled between April 1, 2013 and April 1, 2014, comparing the full year before (April 2012–March 2013) and after (April 2014–March 2015) highlights the differences.

The two reverse commutes had average monthly increases in volume of 1500 and 2300 vehicles respectively, while the standard direction had either a much smaller increase or a decrease in the case of the WB PM peak period. Particularly with the very low standard deviations of the EB AM reverse commute, Table 5 strongly supports short-term induced travel associated with the opening of the new tunnel.

3.2. BART rail

There have also been significant changes in trip-pair BART volumes from 2012 to 2014. Referring to the BART map, Table 6 shows the combined total of exits the stations east of the tunnel complex (Orinda to Pittsburg), originating at all other stations with a 40,000 daily rider minimum. This table reports the average of three months, August, September, and October of 2012 and 2014.

Due to congestion on the San Francisco Bay Bridge and rising parking prices, station-pair volumes originating at the four downtown San Francisco stops of Embarcadero, Montgomery, Powell and Civic Center have increased dramatically during the two year period between 2012 and 2014. The Coliseum–Oakland Airport station was separated as October ridership varies widely due to the performance of the professional baseball team that plays at the Coliseum, the Oakland Athletics. The 2012 team played six playoff games in October and the 2014 team played zero.

Focusing on the local changes in more detail, Figs. 9 and 10 show the changes in exits on pairs referenced in Fig. 4, originating local stations just west of the tunnel entrance in Oakland and Berkeley. As a comparison, Figs. 11 and 12 show the same changes in exits but with trips originating at the four largest San Francisco stations.

Table 5
Volume changes before and after new tunnel opening.

Period	4/12–4/13 Average Month		4/14–4/15 Average Month		Average Monthly Difference	
	Volume	St. Dev.	Volume	St. Dev.	Value	St.Dev
EB AM Reverse	12617	465	14206	433	+1589	325
WB AM Standard	30872	1089	31286	1817	+414	1501
EB PM Standard	38220	961	37997	916	−223	841
WB PM Reverse	21568	652	23864	1670	+2296	1646

Table 6
Changes in Combined Exits originating at other Major BART Stations to stations east of the tunnel, 40,000 rider minimum.

Originating Station	Average Volumes Through Tunnel		% Change
	Aug-Sep-Oct 2012	Aug-Sep-Oct 2014	
Embarcadero San Francisco	420,891	430,245	2.2%
Montgomery San Francisco	384,721	431,135	12.1%
Powell San Francisco	194,979	214,914	10.2%
Civic Center San Francisco	156,622	180,590	15.3%
12th St Oakland	111,201	111,810	0.5%
19th St Oakland	103,116	103,977	0.8%
MacArthur Oakland	56,125	53,414	−4.8%
Downtown Berkeley	52,398	54,044	3.1%
San Francisco Airport	44,939	50,991	13.5%
Rockridge Oakland	43,508	40,544	6.8%
Coliseum Oakland Airport	42,067	36,358	−13.6%

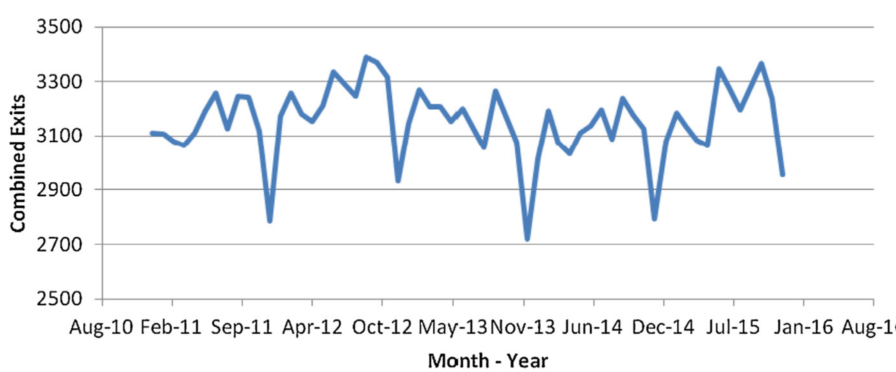

Fig. 9. Combined Exits at Orinda, Lafayette, Walnut Creek and Pleasant Hill stations originating at six local stations just west of the tunnel (shown in Fig. 4).

Fig. 10 shows the percent change in exits by individual station between October 2012 and 2014, again with all trips originating at stations in Fig. 4

Figs. 11 and 12 show the exits at the same four stations, with all trips originating at stations in downtown San Francisco.

The differences between Figs. 9 and 11 are quite stark. While trips originating at the city center in San Francisco have enjoyed steady and consistent increases over time, trips originating at the stations nearest to the tunnel complex showed a drop in exits during 2013 and 2014. Fig. 10 revealed drops in ridership form 10/2012 to 10/2014 from 3% to 6%. Although Fig. 9 shows that there was not a clean discontinuity with the opening of the new freeway tunnel in November 2013, it appears that the new capacity may have extended the decline in BART ridership and kept it artificially depressed well into 2015.

3.3. Basic statistics

A comparison of means analysis (ANOVA) was performed to see whether these changes, empirically observed, were statistically significant. The ANOVA will focus on issues raised in Fig. 10; namely to verify statistical significance of the decline in travel between stations in close proximity to the tunnels, potentially due to the expansion of the adjacent freeway tunnel. This analysis compares the daily average for the entire year, not just October.

Three out the four BART stations had statistically significant changes from 2012 to 2014, as well as the PM reverse commute.

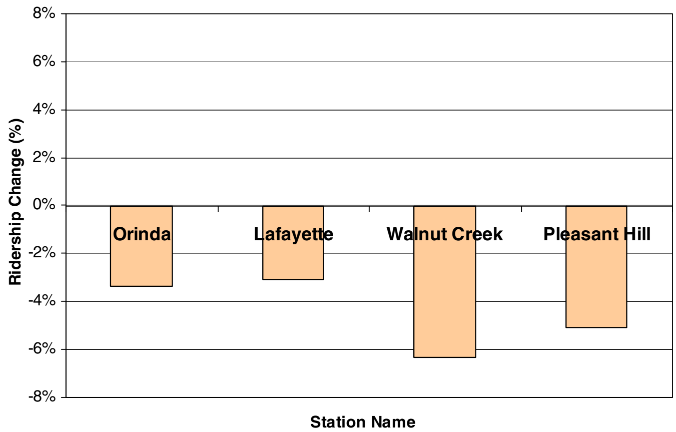

Fig. 10. Change in exits (%) originating from six local stations just west of the tunnel, October 2012–2014.

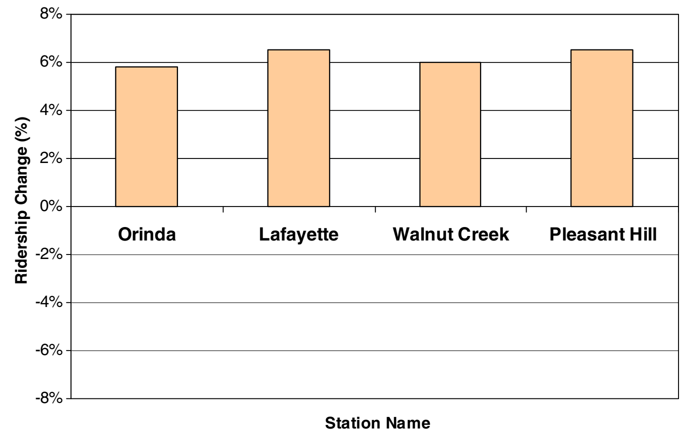

Fig. 12. Change in exits (%) originating from downtown San Francisco, October 2012–2014.

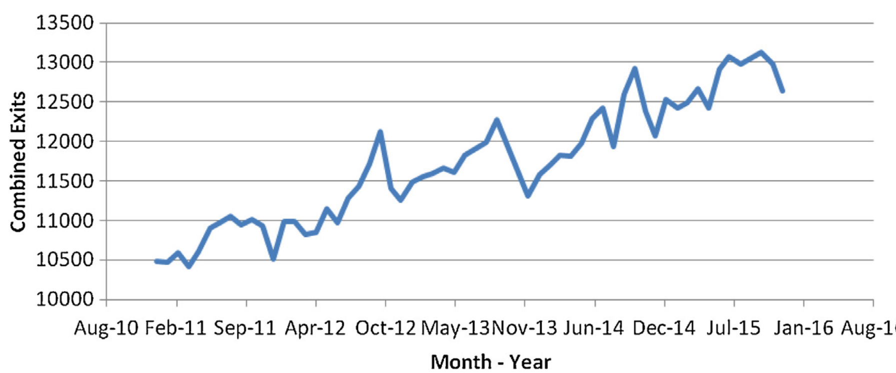

Fig. 11. Combined Exits at Orinda, Lafayette, Walnut Creek and Pleasant Hill stations originating at downtown San Francisco stations.

This may indicate for short trips originating and ending at stops close to the tunnel, some of them switched modes to automobile. Note that the increases on SR 24 were found to be highly significant. Results can be found in Table 7.

4. Discussion

The freeway data show clear and distinct changes due to the opening of the fourth tunnel bore. As shown in Tables 1 and 2, if one compares the 2012 volume with 2014, for the reverse commute there were increases at every hour during both the morning and afternoon peak periods, as high as 20% during the 17:00–18:00 h. High growth at 17:00 could indicate an increase in reliability of the trip due to the opening of the fourth bore, which allows commuters to travel closer to their optimum time. Comparing these increases with other local freeways in Tables 3 and 4, SR 4 gained the highest ridership, particularly when comparing volumes to the opposite direction (the traditional commute) and the similar direction at the nearest pass to the south (I-580). This could imply not only a mode switch but also a population of drivers who have started to drive on SR 24 instead of I-580 once the fourth bore was opened. The reverse commute volumes on SR 24 increased on average 13.2% and 14.8% respectively for the morning and afternoon peaks, as opposed to 3.7% and 1.8% is the conventional direction on SR 24.

Additionally, in terms of congestion, on average in the afternoon SR 24 westbound was congested for 41 min, while in 2014 there were no congested periods due to the elimination of the bottleneck. For a commuter, this is a very significant change, and adds more evidence to the theory that drivers could consolidate their start times due to increased reliability of commute duration, shown previously by the highest increase at 17:00–18:00.

Table 7
Summary of Analysis.

Station	2012 Daily Average	2014 Daily Average	Difference	T-Statistic
Orinda	438.3	415.2	−22.8	2.09
Lafayette	594.1	564.6	−29.5	2.78
Walnut Creek	1116.5	1050.9	−65.1	4.47
Pleasant Hill	1089.4	1068.2	−21.2	1.11
SR 24 Freeway westbound Afternoon Peak	306.5 (per 5 min)	351.8 (per 5 min)	45.2	15.74

The examination of the BART ridership does not produce as clear a result as the freeway ridership but does indicate some changes. Clearly, BART ridership originating from the stations in Downtown San Francisco has increased dramatically, with some stations (e.g. Montgomery) indicating over a 10 percent increase in just two years, shown in Table 6. This can be attributed to a number of factors including improvements in the overall economy and increased congestion on the San Francisco Bay Bridge, which may have caused a small mode shift to BART. The regional metropolitan planning organization has reported that congested conditions on Bay Bridge approaches leaving San Francisco exist for over 7 h (1:25–8:30) during the afternoon peak (MTC, 2014).

Continuing to look at Table 6, which could reveal short term induced travel on SR 24 with a switch from BART to the improved freeway, the evidence does support some movement away from BART. The two stations closest to the tunnel, Rockridge and MacArthur, both in Oakland, did report drops in westbound ridership of −6.8% and −4.8% respectively with an aggregate absolute loss of 5500 riders per day. Ridership was flat to the Oakland downtown stations (12th and 19th street), with Downtown Berkeley the only local origin station to report gains greater than 1000 riders per month through the tunnel. Fig. 10 provides perhaps the strongest evidence of a potential modal switch, as ridership is down from origin stations just to the west of the tunnel. Indeed BART itself has begun to adjust its schedule due to reduced demand in and around the Berkeley Hills tunnels, specifically the stations highlighted within this research. In September 2015, citing demand from stations at the far eastern end of the line (e.g. beyond Walnut Creek) to downtown San Francisco and a drop in the reverse commute, BART announced that in the morning some reverse commute trains would skip Rockridge, Orinda, and Lafayette stations and turn around mid-line at Pleasant Hill. By skipping Rockridge and Orinda, BART was abandoning the reverse commute trip between the two stations on either side of the rail tunnel, conceding this traffic to the newly expanded road tunnels. Riders traveling in the primary direction from these stations had complained that the trains were full by the time they left Concord en-route to San Francisco (Cabanatuan, 2015).

A closer examination of comparisons of means looked at the trip pairs from stations in Fig. 4, comparing one calendar year before the new freeway tunnel (2012) to the year after its opening (2014). Reviewing the results of the ANOVA tests from Table 7, there was weak significance in the declining ridership originating from the stations west of the tunnel to one station (Orinda), strong significance to two (Lafayette and Walnut Creek), and no significance to the fourth (Pleasant Hill). This would seem to indicate that the decline in ridership from stations in Oakland and Berkeley to at least Lafayette and Walnut Creek is not simply from natural fluctuations. Although not directly comparable, the comparison of means test found the increase in afternoon freeway volume to be highly significant.

4.1. Policy implications and conclusions

The addition of the fourth bore of the Caldecott Tunnel has presented itself as an excellent example of the effects of bottleneck removal in regards to potential induced travel.

In past research, the emphasis on induced travel has typically been on new construction and freeway expansion, sometimes in areas of rapid growth. This case study however has looked at bottleneck removal on a mature freeway that had been largely unchanged for nearly 40 years in an area that has not had significant population growth since the 1980's. Nevertheless, just one year after the new tunnel was finished there were already obvious signs of short term induced travel; in the westbound direction nearly 2300 extra vehicles in a typical afternoon, or about 375 vehicles per hour. The first policy implication is quite clear; there will need to be an expectation of new demand from endogenous sources even in a mature setting. Today, when most agencies seek to remove existing bottlenecks, the presumption is that in a mature situation the existing traffic pattern will not significantly change and induced travel will be minimal. This case study has proven otherwise that people will still change in the short-term even if the status quo has been in place for decades. As such, for other types of bottleneck removal there could be other regional changes, possibly on local streets, that are not accounted for.

All across the United States and beyond, there are plans to remove longstanding freeway bottlenecks to improve travel time and reduce congestion. In the San Francisco Bay Area, Caltrans is currently removing another famous lane drop freeway bottleneck in Marin County on US 101 known as the Novato Narrows project. Proposed construction will widen a short four lane section to meet the six lane capacity of the freeway on either side. While the removal of the narrow section on US 101 will surely reduce congestion in the short term, as it did in this case study on SR 24, there will likely be unanticipated volume increases. Furthermore, the county is also currently constructing a regional rail transit system, and ridership projections may be generously high if congestion is removed on the adjacent freeway at the same time. Similarly, in Los Angeles Caltrans is working on a 1.3 billion dollar project to widen I-5 from downtown to the Orange County line, lessening the effect of a 50 year old lane drop when entering Los Angeles County in the northbound direction (Molina, 2013). As evidenced by the Caldecott Tunnel project, not only will this bottleneck removal result in increased volumes on I-5, it could also create a mode switch from nearby Metrolink regional rail and Amtrak California, negating the environmental gains from reduced automobile congestion. Aside from the appearance of induced travel from the removal established bottlenecks, this effect might also be seen when lane closures are removed after a significant amount of time. Even if work zone congestion causes drivers to seek alternate routes, it's highly possible that these drivers will return even if the timeline is many years.

Lastly, although Fig. 9 has not revealed a clear-cut drop in BART volumes after the opening of the new lanes, 2014 volumes were lower in a statistically significant way than in 2012 for many exit stations to the east of the tunnel. This calls into question the proper traveler value of time for heavy rail as opposed to driving. In this case, BART is grade-separated, runs at high speeds, and has excellent reliability. Nevertheless, some commuters may have made a modal switch, indicating that there may need to be some changes in the assumptions concerning the travel behavior of daily reverse commuters. Recently, there has been some focus on the declines in vehicle-miles-traveled (VMT) by the current generation entering the workforce, known as the Millennial Generation. Examples of this effect being reported in the media include Badger (2013) and Schwartz (2016). In this case study, the alternative mode was a very reliable mode of rail transit. Nevertheless, the macro-effect of the new capacity at the tunnel bottleneck still overwhelmed any new cultural shift by younger generations to choose alternate modes, especially relevant since these reverse commuters were originating their trips in Oakland and Berkeley, two highly desirable places to live by Millennials. Since this case study examined the reverse commute, suburban transit connections can be difficult and if the automobile trip has just become significantly faster (shown by the reduced congestion in Table 2), one might think about switching.

While this paper focuses on modal switching and short term induced demand, there are many other factors that could be having a strong effect on changes in travel volumes such as parking changes and land development. It may be that parking rates or the number of parking spaces has changed for employers located near the stations in Oakland and Berkeley just west of the tunnel. Most importantly, while the economy has improved regionally in terms of job growth, increases in housing vary greatly from station to station, which could significantly affect the number of BART riders. It may simply be that growth is flat at stations that are seeing smaller ridership increases (or losses). Orinda and Lafayette, for example, are relatively wealthy communities with very little population growth. These unknowns are too significant to ignore when making a strong conclusion about changes from BART to the freeway, although they would not be able to explain the *decline* in ridership seen in Fig. 10.

In summary, there have been changes to volumes on both the freeway and the BART system since the removal of the Caldecott Tunnel bottleneck with the construction of the fourth tunnel bore. With the off-peak freeway congestion completely removed, volumes during both commuter periods have increased greater than many of the surrounding freeways. The highest increase was during the 17:00–18:00 h, indicating that congestion relief has changed the volume time-of-day profile with travelers potentially switching their afternoon start times to a narrower range. In terms of BART volumes, there is some evidence that volumes have dropped on station pairs when both stations are in close proximity to either side of the tunnel, and this may indicate a switch to driving for these local trips. This only applies to trips between stations immediately to the east and west of the tunnel, as BART has continued to see growth to and from stations in downtown San Francisco where employment is rapidly increasing.

This case study has shown that the removal of a mature freeway bottleneck can potentially have an effect on nearby rail transit volumes through the process of short term induced travel. These changes should be considered when making financial decisions on bottleneck relief. As freeway infrastructure projects move from expansion to reconstruction, the planning process will have to consider the implications of induced travel. Certainly future work could include looking a greater time interval, investigating the effects on downstream bottlenecks, or environmental implications.

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