Optimizing Transit Priority on a High Volume Urban Arterial: A Case Study of San Pablo Avenue

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ABSTRACT

In many urban areas, express and limited-stop bus services operate on urban arterials that also carry heavy loads of traffic. Implementation of exclusive lanes for these express services is not always feasible given limited rights-of-way, built up land uses, and costs. In this paper we use traffic operations models to evaluate alternatives for improving bus performance on one such arterial, San Pablo Avenue in the San Francisco Bay Area. Using the signal timing software TRANSYT-7F, we show that simply coordinating signal timing along the 15 mile-long arterial produces significant benefits. Because of the heavily saturated network, including cross streets, active priority signal timing schemes can have limited effectiveness. A bus-weighted signal timing scheme (passive transit priority) provides even more substantial gains, with little detriment to overall traffic flow. Using Paramics microscopic traffic simulation modeling, we look at the effects of these optimal timing plans on both the arterial's operation and on that of a parallel freeway. We also test geometric changes, in this case bus queue jumpers created through minor widening and restriping for narrower lanes at congested intersections. In this case the passive priority treatment works better than the queue jumpers for bus priority. Overall, the case study demonstrates that traffic operations modeling can be an effective transit and street design planning tool.

OBJECTIVES OF THE PAPER

Express bus services operating on urban arterials provide an important transportation alternative in many urban settings. However, when the arterial also carries a heavy traffic load, buses can be caught in congestion, reducing their functionality as an express service. Bus rapid transit designs that add a bus-only lane to such arterials are not always feasible, given street geometrics, the needs of adjacent land uses, and costs. Hence, other methods for providing bus priority are well worth considering.

In this paper we demonstrate the use of traffic signal timing and traffic simulation software in evaluating basic bus priority options for an urban arterial. These techniques can be used for both local and express bus routes. We examine the case of San Pablo Avenue, a major arterial extending over 15 miles from Oakland to San Pablo, California, running parallel to I-80. We show how traffic operations methods can be used as transit planning tools; examining operational and geometric improvements that can improve transit travel time and reduce passenger delay without significantly disrupting other traffic.

We look at both transit priority techniques for signal systems and at geometric changes that could enhance bus priority. We show that the models can be applied using data available from state DOTs and local governments, plus some easily collected field data, and that the results have valuable planning and policy implications.

Some basic tenets of this analysis were to consider the buses to be more valuable in terms of delay and stop penalty *(1,2)* recognizing that each bus carries many more passengers than a car or truck. We therefore focus on reducing person hours of delay rather than vehicle hours of delay.

In the following sections we briefly describe the San Pablo Avenue corridor, then we discuss the modeling of the corridors with two software packages, Transyt7F and Paramics. The results of alternative signal timing schemes and alternative geometric treatments are presented and evaluated.

BACKGROUND: SAN PABLO AVENUE – AN URBAN ARTERIAL

San Pablo Avenue is an urban arterial near the East shore of the San Francisco Bay. The road spans 15 miles and runs through seven cities, Oakland, Emeryville, Berkeley, Albany, El Cerrito, Richmond and San Pablo, and two counties, Alameda and Contra Costa **(Figure 1)**. San Pablo Avenue is designated as State Highway 123 from Oakland to Cutting Boulevard in El Cerrito, and continues as a local roadway to the northern terminus of the study area at Richmond Parkway in Richmond. The avenue lies parallel to and within a quarter-mile or less of I-80, and before the interstate was built it was the main North-South thoroughfare through the five cities in the study area.

Land uses and urban design vary substantially along San Pablo Avenue. Along the Oakland stretches of the avenue are many four to six story apartment buildings interspersed with one to three story commercial buildings with housing on upper floors. In Berkeley and downtown Albany, two to three story buildings, again with first floor retail and upper story housing, are interspersed with small-scale single story retail, auto dealers, and auto repair shops. El Cerrito's downtown is along the avenue, with single story retail and a small mall as the predominant land uses. Through these three cities most of the retail and housing units are oriented to the street with little setback and only occasional off-street parking. Farther north along the avenue the older single story retail is interspersed with mini-malls, fast food drive-ins and big box retail, each with its own parking lot. In the past decade or so, multifamily housing developments have replaced older retail and parking at locations scattered along the avenue.

For most of the length of San Pablo Avenue the road is two lanes in each direction with turning lanes at major intersections. Sidewalks line both sides of the street its entire length, and on-street parking is permitted in most locations. In Berkeley, a tree-lined median developed in the 1960s divides the thoroughfare and limits cross-traffic at many intersections. The City of El Cerrito has recently installed a median as well. The City of San Pablo also has a tree-lined median as well as striped bike lanes. Richmond has a striped median that is not raised.

Average daily traffic (ADT) ranges from about 15,000 at the northern terminus of the study area to 27,000 around its busiest intersection *(3).* There are sixty-seven signalized intersections along the avenue in the study area. Thirty-seven bus routes are operated on at least part of San Pablo Avenue by four different transit properties including AC Transit, WestCAT, Vallejo Transit, and Golden Gate Transit. Many of these routes also BART and AMTRAK stations. During peak periods, as many as 20 buses per hour travel on key San Pablo Avenue blocks.

San Pablo Avenue is a complex corridor where seven cities, two counties, and the state DOT all have authority over their particular jurisdiction. AC Transit, the predominant transit property for Alameda and Contra Costa County, has authority regarding bus stops. The Alameda County Congestion Management Agency (ACCMA), created in 1995 to coordinate traffic management and transportation investments for Alameda County, has built a working agreement among the involved jurisdictions through which ACCMA administers San Pablo Avenue traffic signals through its East Bay SMART corridors program *(3),* which has produced a rich field of data with which to work.

ANALYZING SAN PABLO AVENUE: TWO MODELS

Since our objectives are to both optimize the signal timing in order to minimize delay and to observe how these changes affect intersections and overall traffic flow, we need to use both optimization software and microsimulation software. We chose TRANSYT-7F as our signal optimization software because it has the ability to optimize signals while considering mixed flow bus movements. We chose Paramics as our microsimulation model because it allows us to observe these buses on an individual level, to identify travel time improvements, as well as to make geometric changes to the system and observe the changes those improvements will make to traffic flow. Here we describe each model briefly.

TRANSYT-7F Signal Optimization Software

TRANSYT-7F is a macroscopic simulation model that has been specifically built to optimize signal timing on signalized arterials and networks. It uses the input data, including traffic volumes, saturation flows, distance between intersections, cruise speeds, and signal timing data to model, simulate, and optimize arterial signal timing plans *(2).* TRANSYT-7F can also be used to develop both active priority plans and pre-timed transit priority plans by creating bus links with link information that includes distance between intersections, upstream flow speed, and upstream dwell time. This feature can aid in the implementation of a passive transit signal priority system that would allow the signals to be coordinated for bus progression as well as auto progression. The output from this model includes measures of effectiveness (MOE) such as travel time, delay, number of stops, degree of saturation, maximum queue length, and fuel consumption.

Paramics Microsimulation Software

The Paramics model is a comprehensive microscopic stochastic simulation model that can be applied to a wide set of freeway, arterial, and network situations *(4,5,6,7,8)*. The software allows the analyst to visualize simulated traffic conditions in order to identify problem areas in a network and their potential causes. Individual vehicles are modeled in fine detail for the duration of their entire trip, providing traffic flow, travel time and congestion information.

The Paramics general model input includes:

- Network characteristics: geometry, link descriptions, signposting, lane restrictions, forced lane changes
- Demand data: origin/destination zone areas, level of origin/destination demand, breakdown by time period, vehicle type and vehicle proportion
- Assignment: link cost factors, coefficients of generalized cost equations, assignment techniques
- General configuration: time step duration, speed memory, mean target headway, and mean reaction time.

The model output includes statistics at the network level (overall travel time, total travel distance, average speed), on a link-by-link basis (traffic flows, queue lengths, delays speeds and densities) or at specific locations (instantaneous detector information).

OPTIMIZATION OF SIGNAL PROGRESSION

Methodology and Data

There are two distinctly different kinds of transit priority that can be modeled with TRANSYT-7F. Passive priority relies on inexpensive geometric and signal timing changes that can significantly decrease the delay and number of stops for transit vehicles while minimizing negative effects on the normal traffic flow. Active priority uses different detection techniques to give extra green time to the transit movement when the transit vehicle comes at the end of its green phase.

Skabardonis (*1*) has developed a methodology for using TRANSYT-7F for designing and evaluating active priority strategies. Skabardonis describes the methodology as a five step process as follows.

1. Optimize the signal timing plan with TRANSYT-7F to minimize the delay and stops for the entire traffic stream with unweighted bus links coded in.
2. Select intersections for active priority based on calculations of spare green time at intersections and the examination of bus flow to determine whether active priority, or pre-emption, would actually aid the transit vehicle.
3. Re-optimize the signal timing plan while reducing the value of the cars in delay and stop calculations to zero, increasing the value of the buses in delay and stop calculations to the maximum allowable in TRANSYT, and while holding all of the other intersections as they were before.
4. Code the changes from step three into the original optimization model. These are the new pre-emption conditions.
5. Calculate the measures of effectiveness (MOEs) by calculating a weighted average of the step one optimization MOEs and the preemption MOEs.

Active priority takes green time from undersaturated cross streets. However, many of the intersections on San Pablo Avenue are highly saturated on all approaches. This reduces the effectiveness of active priority because it imposes more delay on cross street traffic and buses.

Passive priority simply requires optimizing the signal timings while properly weighting the transit movements to account for the fact that they carry many more people than do cars and trucks.

In this analysis, we selected the congested AM peak hour as our study time. For the AM peak, we have developed a fixed-time signal timing plan, making the assumption that the north and south thoroughfares already get the maximum allotment of green time. Assuming that the arterial is already allotted its maximum green time allows us to eliminate active priority strategies since their effectiveness is limited when the side streets are already receiving their minimum green and there is no green time to spare. Additionally, we have made the assumption that all of the cycle lengths will be the same in order to create a corridor with good progression and good passive transit priority. The existing cycle length varies from 60 seconds to 120 seconds while the optimized signal timing plan will have a fixed cycle length of 100 seconds.

There are a number of assumptions that we have made with respect to transit movements. There are many intersections along the corridor that have transit movements at side street approaches and there are many intersections along the corridor where other major arterials intersect San Pablo Avenue. To accommodate this, we have created the model to account for thru bus movement in the direction of the San Pablo arterial. This allows us to develop a signal timing plan that will also help the major street thru traffic movements as well as help simplify the model and results. A model could be produced to help balance the needs of these conflicting arterials. Additionally, we assumed that each time a bus stopped it would have a dwell time of 16 seconds. So, if there were three bus stops between one intersection and the next, we would code in a 48 second dwell time. Lastly, we have coded in every bus line into the system including local routes since many of the Transbay Express routes act as local buses once they are on the San Pablo arterial.

In order to create a signal timing plan that is best weighted for transit it is necessary to use Record Type (RT) 37 and 38 in TRANSYT-7F to weigh both the delay and stop penalties by 76 times the delay of one vehicle *(2).* We tested several different weighting factors in order to develop a proper weighting factor that would best help the MOEs of the transit links while minimizing the disbenefit to the MOEs of the traffic stream. For this corridor, we have determined that the proper weighting factor is 7600; this must be coded into RT 37 and 38.

The data that we used in order to perform the passive priority steps outlined above include signal timing, bus stop location, intersection distance, volume, speed, land use parcel data, and accident data. Much of this information was provided by sources *(9,10);* the rest was collected by the authors and assistants in the field.

Base Case and Alternatives

The base case is the current situation, i.e., the current signal timing plans, with varying cycle lengths at the intersections and unweighted bus links *(9,10)*. The signal timings that are currently used in the field were developed using a 'gap-out' technique that was aided by SYNCHRO, an optimization and analysis tool. We used TRANSYT-7F in lieu of using SYNCHRO to optimize the signal timing because SYNCHRO has some important drawbacks such as the inability to code transit links and an oversimplified traffic flow model.

In the first alternative, we optimized a scenario where we coded in unweighted bus links, applied the same phase order as in the existing timing plans, and changed the cycle length to 100 seconds for each intersection in the system. The MOEs for this alternative show the effects of providing progression along the arterial, without giving special consideration to buses.

In the second alternative, we added stop weight and delay weight to the bus links in the system so that we could observe the effects of passive priority on buses and, specifically, on the rest of the system as compared to the results for alternative one.

The bus links treatment bears explanation. In TRANSYT-7F, an analyst codes each lane movement as a link. An intersection, called a node in TRANSYT-7F, which has one lane for each turning movement at each of its four approaches would have 12 links associated with it. In order to add a bus link, the analyst must decide whether the bus movement is to be exclusive or shared with one of the other movements. In the case of San Pablo Avenue as it operates today the bus movements share the movements of the autos and so would be coded in as shared links. TRANSYT-7F calculates separate MOEs for the aggregate of bus links and for the aggregate of normal traffic flow links, which makes it a valuable tool in analyzing the benefits of passive priority techniques.

Existing Simulated and Optimized Results

The commentary in this section offers a comparison of the multiple cycle existing conditions, the single cycle optimized conditions with no weight bus links, and the optimized conditions with weighted bus links that were generated from TRANSYT-7F. **Table 1** shows the system total MOEs for the existing conditions, alternative one, and alternative two.

The first thing to note is that we realized significant improvements in the MOEs between the existing conditions and the single cycle length optimized conditions by simply creating a situation where there is an opportunity for good progression. While the delay and the travel time are marginally worse in the optimized alternative, the number of stops made by vehicles and transit vehicles has dropped drastically (30%).

Secondly, by adding the weighted bus links to the system, we were able to generate a signal timing plan that would provide passive priority to buses by weighting their delay and stop penalties. In so doing, we have created a signal timing plan that would not provide a significant disbenefit to the normal traffic flow while providing benefit to the flow of buses. For the buses, the delay is reduced from 10 veh-hr/hr in the existing conditions to 9 veh-hr/hr in the optimized conditions without weighted buses to 8 veh-hr/hr of delay in the optimized conditions with weighted buses for an 11% change. The total stops were reduced marginally, by 1% while the travel time was reduced by 7%. These improved MOEs came at the expense of the cross street traffic since they were giving more green to the northbound and southbound directions of San Pablo. Because more green time is given to the northbound and southbound thru directions, the main route traffic will be better off. Still, for the overall traffic, the total stops were only increased by 5%, the delay increased by 3%, and the travel time was increased by 2%. So, we see significant gains for the transit MOEs while seeing only marginal reductions for the MOEs of the general traffic.

CONSTRUCTION OF THE PARAMICS MODEL

We applied the Paramics model to simulate the AM peak traffic conditions along both San Pablo Avenue and the parallel freeway, I-80, using data provided by Caltrans and ACCMA

(9,10). Hourly traffic counts, continuous speed, travel times were provided for San Pablo Avenue and I-80. Using these data, a Paramics network was developed that included the San Pablo Avenue, I-80 freeway, all interchanges along the segment and those portions of major arterials that connect San Pablo Avenue with I-80.

A road categories file was developed based on the operating speed of roads as well as their relative importance to the roadway network. A lower cost factor was employed for freeway links and higher costs were placed on particular links of some arterial routes, an approach that results in short distance trips utilizing the arterial system and longer trips trying to use the freeway as much as possible.

For the simulation configuration, we established that there would be 5 time steps per second, meaning that calculations in the simulation are conducted every 0.2 seconds. This value was adopted based on a previous study where it was determined that high density flows often require more time steps per second to operate in a more realistic manner *(11).* From the same study, we adopted a speed memory value of 8, i.e., a vehicle remembers (checks) its speed every eight time steps, or every 1.6 seconds.

For a corridor network with a parallel freeway and arterial, such as San Pablo Avenue and I-80, driver behavior parameters are used to assess the likelihood of route switching. Here an 85%-15% split of familiar and unfamiliar drivers respectively is assigned to the network. A perturbation factor adjusts the costs of various links randomly for different vehicles, causing different route assignments for the same origin-destination pairs. A perturbation value of 5, which is relatively low, has been shown to produce good results – high perturbation values would result in abnormal routing patterns.

Paramics represents the movement of individual vehicles in the network using three basic models: vehicle following, gap acceptance and lane changing. These models are strongly influenced by two key user-specified parameters: mean headway and mean reaction time. The overall behavior of the model can be changed considerably by increasing or decreasing the mean target headway and the mean reaction time. For this network, a mean target headway of 1.0 and a mean reaction time of 1.0 was used initially; during preliminary model testing both were reduced to better match observed conditions, to a mean target headway and mean reaction time of 0.8 and 0.6, respectively. The mean target headway is a parameter that controls the distance (in time) between vehicles and the mean reaction time is the time it takes for a vehicle to react to a stimulus.

An origin-destination (OD) matrix is required to run a simulation in Paramics. A pattern matrix defines travel patterns between distinct pairs of zones. In order to generate a pattern matrix for the Paramics network, data was extracted from an EMME/2 *(12)* planning model developed by ACCMA. All nodes and links within the area covered by the Paramics network were flagged in ACCMA's EMME/2 model of the AM peak period. To define the boundaries of the sub-area, specific links were identified as gateway links and were given a special identifier, treating the gateway like a node with inputs and outputs for the sub-area. Since the ACCMA model produces separate OD matrices for single-occupancy, 2 and 3 occupancy vehicles, we aggregated the three vehicle classes into one. The final OD matrix that was extracted from the ACCMA model was comprised of 102 zones. Zone boundaries were then created in the Paramics network based on the location of the zones in the EMME/2 model.

Finally, once the network was fully built, an express bus route was inserted into the network. This route follows the San Pablo Rapid bus route (72R) operated by AC Transit from Downtown Oakland to Contra Costa County Community College in the City of San Pablo. The route and associated bus stops were entered into the model so that improvements could be measured in terms of travel time improvements to the bus service, in addition to the vehicle travel time.

We then calibrated the Paramics network following procedures documented in the literature *(13,14,15,16)*. In order to determine that calibration activities were sufficient, comparisons were made between the simulated model and field data collected along the San Pablo corridor. Flow, speed, and travel time on north and southbound San Pablo Avenue, measured in the field were compared with flows, speeds, and travel times produced by the Paramics model.

Also, the OD matrix was compared to the observed volume counts to identify traffic loading discrepancies on the network. Several of the links of the network did not have matching loading patterns and the OD matrix was adjusted to reflect the actual observed volumes.

Once this was done, the model was loaded and the Paramics Analyzer module *(8)* was utilized to obtain simulated operating speed and traffic counts for all links. Report Analyzer, a tool developed by Caltrans *(17),* was used to “translate” the Paramics speed and flow outputs into data comparable to available traffic measurements. Examination of the reports generated by Paramics Analyzer and Report Analyzer indicated that flow and congestion patterns observed under field conditions were not being replicated in the model during the first iteration, so adjustments to several parameters were made. The geometric mean headway factor that applies to the entire network was reduced to 0.8. Additionally, the mean driver reaction time was reduced to 0.6 and driver awareness and aggressiveness parameters were adjusted upward. With these adjustments, the Paramics network matched the capacity of the arterial, as well as the timing and severity of congestion.

Traffic flow comparisons were made against the actual observed flow characteristics on San Pablo Avenue. The demand periods were adjusted so that the peak flow pattern occurred at the same times as those that were observed. The GEH statistic *(14 pg. 61)*, a measure to determine if a model is within an acceptable range of existing conditions, was calculated: if the GEH statistic is less than five for greater than 85% of the observations, the model is said to be calibrated for capacity. In this case, 85% of the observations’ GEH statistics fell below five. **Figure 2** shows the compared flow rates for the observed calibration points. Similarly, The speeds were visually inspected against speed maps that were provided *(9)*. Congestion occurred in the model at the same intersections that congestion occurs in reality. Finally, travel time for the length of the corridor was compared with the travel time runs conducted by ACCMA.

The average northbound travel time during the peak period from the 20th Street/San Pablo Avenue intersection in Downtown Oakland to El Portal Avenue/San Pablo Avenue intersection in Richmond was found to be 38.22 minutes. The average travel time produced by the model for this northbound section was 36.88 minutes, with a standard deviation of 1.89 minutes. This is a difference of –3% of the observed travel time. The average existing southbound travel time was found to be 37.30 minutes. The average travel time produced by the model was 38.50 minutes, with a standard deviation of 1.51 minutes. This is a difference of -3% of the observed travel time. These travel times fall within an acceptable range to consider the model calibrated.

ALTERNATIVE CONFIGURATIONS

We used the calibrated network to produce base case measures of effectiveness, and then simulated several alternative infrastructure and signal operation improvements for San Pablo Avenue.

In the base case, because buses operate in mixed flow, their speeds and travel times are approximately the same as the mixed flow traffic (minus time spent loading and unloading during green cycles.) We compared the performance of the current system to alternative two, in which we modeled the passive priority signal timing scheme developed with TRANSYT-7F.

Using the existing signal timing scheme, the travel time of the northbound San Pablo Rapid Bus for the entire route is modeled to be 49.63 minutes. The southbound travel time is modeled to be 54.88 minutes. With the alternative passive priority transit signal timing scheme, the total travel time for the northbound Rapid Bus dropped slightly to 49.25 minutes and the total travel time for the southbound Rapid Bus dropped to 52.88 minutes. A table of San Pablo Rapid travel times for all alternatives is presented in **Table 2**.

Although the travel time for the buses improves slightly under the new signal scheme, the passive priority timing alternative does not give the express bus any advantage over cars because the bus still operates in mixed flow lanes. In order to give the express bus an advantage, we simulated another alternative in which we added a queue jumper lane at each intersection with long queues during the peak period. These are the intersections where the bus stands to gain the greatest increase in travel time.

Intersections with slow approaches and residual queues were identified using data from previous studies *(9)* and those intersections were improved by widening the approach and taking width from the existing lanes. The two thru lane, 24' cross section (12' per lane) was widened by six feet to make a three thru lane, 30' cross section (10' per lane). **Figure 3** shows a typical plan of all of the intersections where queue jump lanes are proposed. In the northbound direction, four queue jump lanes were added at the most problematic intersections (University Avenue, Solano Avenue, Fairmount Avenue, and Central Avenue). In the southbound direction, eight queue jump lanes were added at the problematic intersections (Vale Road, Potrero Avenue, Central Avenue, Fairmount Avenue, Solano Avenue, Marin Avenue, University Avenue, and Ashby Avenue). The queue jump lanes were added to the shoulder side of the roadway to facilitate easy entrance to the bus bay on the far side of the intersections. The additional space required for the queue jump lanes can be taken exclusively from the existing right-of-way by restriping, limiting on-street parking, narrowing the median, or widening the road (by narrowing the sidewalk).

All of the approaches to these intersections have three lanes (two thru and one left turn lane). In addition to the travel lanes, all of the streets have on-street parking upstream and downstream of the intersection. The total width of the approach is 42' for all approaches. The downstream cross section exiting the intersection consists of two thru lanes and on-street parking for all of the intersections considered. The total width of the downstream section is 30' for all intersections. In many areas, the on-street parking is minimal due to large numbers of driveways. Therefore, all of the queue jump lanes can potentially be designed by simply restriping the existing travel way and imposing limitations to on-street parking during peak hours near those intersections. Additionally, there is adequate right-of-way on all approaches to potentially take median and sidewalk width and still maintain compliance with the Americans with Disabilities Act (ADA)*(18).*

The queue jumpers were initially added to the Paramics model and interestingly, the queue jumpers appear to have negligible impacts on the travel time performance. The travel time of the Rapid Bus in the northbound direction was 49.75 minutes with a standard deviation of 0.46 minutes, a slight increase. The southbound travel time was 51.38 minutes with a standard deviation of 1.60. While the southbound travel time decreased, the northbound travel time actually increased by a small amount (0.12 minutes). Several problems were observed over the network slowing the buses. One reason for the slower bus operation in the queue jumper lanes are often times blocked by traffic spilling back. Additionally, because the bus is no longer in the travel lane, it is not impeding the vehicles as much, thus improving the vehicles performance. The time advantages that the queue jumps elicit are often offset by the difficulties vehicular traffic pose to the buses, resulting in a marginal net benefit.

The queue jumpers were then lengthened to correct some of the blocking issues and the model was simulated again. Although the queue jump lanes do not seem to significantly improve express bus performance in terms of end to end travel times, upon further examination there does seem to be positive effects on intermediate travel times as well as on-time performance. Looking at one intermediate trip, from El Cerrito Del Norte BART station to Broadway & 14th Street in Oakland, we find an 8.5-minute travel time decrease when queue jumps are added in addition to a much smaller standard deviation (0.50 versus 2.98). This time savings becomes even more significant given that the destinations are two of the heaviest boarded and alighted on the route *(19 pg. 21)*. The smaller standard deviations observed are also of considerable importance because they show that arrival times are more consistent when queue jumps are implemented, resulting in less disparities between the bus schedule and reality. Previous studies looking at the performance of the 72R have pointed to the on-time performance as an area of difficulty *(19 pg. 24)*. Both on-time performance and travel time performance to highly serviced areas are of main concern to express bus operators and their patrons. Despite the unimproved end to end travel times, the use of queue jumps may still be warranted as a way of improving performance over smaller portions of a route.

GROWTH FACTORS

In addition to the geometry and signal timing changes, we also simulated 5% and 10% growth in traffic to look at how vehicle routing changes under different demand scenarios. The assumption is that the San Pablo Avenue network is influenced by I-80, which runs parallel in the sense that route choices are based on the trade off between the different speeds of each corridor and the difference in travel time it takes to access a particular destination from each route.

Applying a 5% growth factor to the unaltered base network produced an almost proportional increase to flows on San Pablo Avenue (4.5%) and a smaller increase (1.9%) to flows along I-80. In contrast, the re-signalized network produced an opposite result, with larger flows to the freeway (4.0%) than San Pablo (1.2%). This may imply a relationship between San Pablo and I-80 where vehicles mainly use San Pablo as a means to access the freeway. Applying a 10% growth factor causes further changes in route choices. Flows in the base case do not increase as much as in the 5% scenario, probably due to an increase in congestion, thus lowering speeds. The re-signalized network experiences a large increase in San Pablo flows (5.8%) while maintaining roughly the same increase in flows as in the previous case (4.0%). This may coincide with our assumption on route choice; it may be the case that the maximum increase in flows lies around 3.9% and that after that, vehicles find it more advantageous to take San Pablo. Such a finding may have important implications for the future of San Pablo in lieu of increasing traffic demand on freeways. Creating more efficient geometries may make them more desirable to drivers, thus relieving traffic on freeways.

CONCLUSION AND FUTURE PLANS

In this paper we have shown that traffic signal timing models and network simulation models can be effective tools not only in traffic operations and management but also for transit planning and street design. Using data available from the state DOTs, local governments, and simple field observations, we show that alternative bus priority schemes and simple geometric improvements can be evaluated easily, once the models are calibrated. Such improvements can be a low cost, highly effective way to improve the performance of urban arterials such as the one tested here.

The case study provides evidence that bus weighted optimized signal timing can provide a significant overall benefit to transit flow while creating little disbenefit to the normal traffic flow. Such transit-friendly timing plans may be the best available option when street designs and cost considerations do not allow for the installation of exclusive bus lanes. The San Pablo Avenue case is one that is found in many parts of the US, suggesting that traffic operations tools may have significant planning application in many areas.

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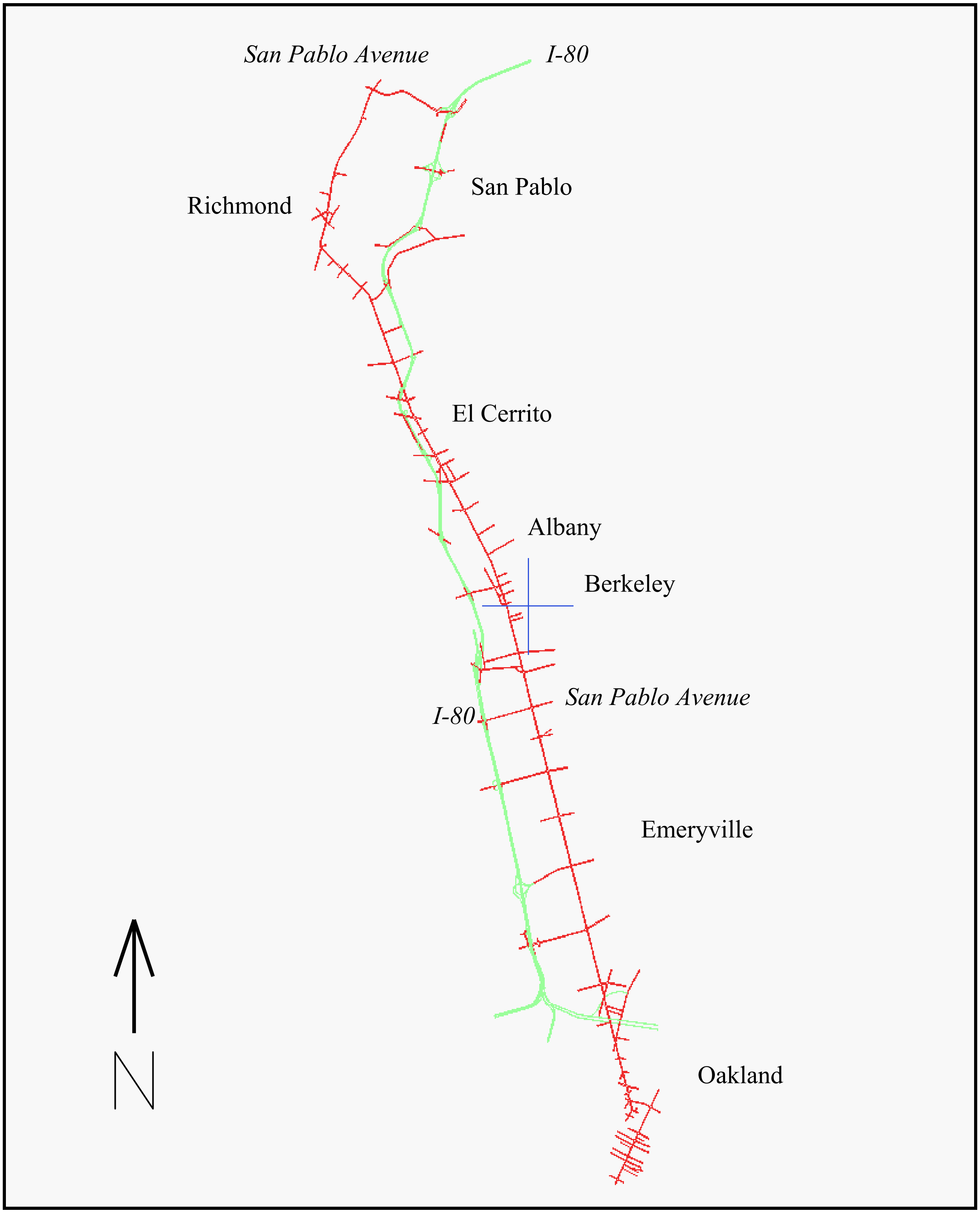


FIGURE 1 Map of San Pablo Avenue/I-80 Corridor

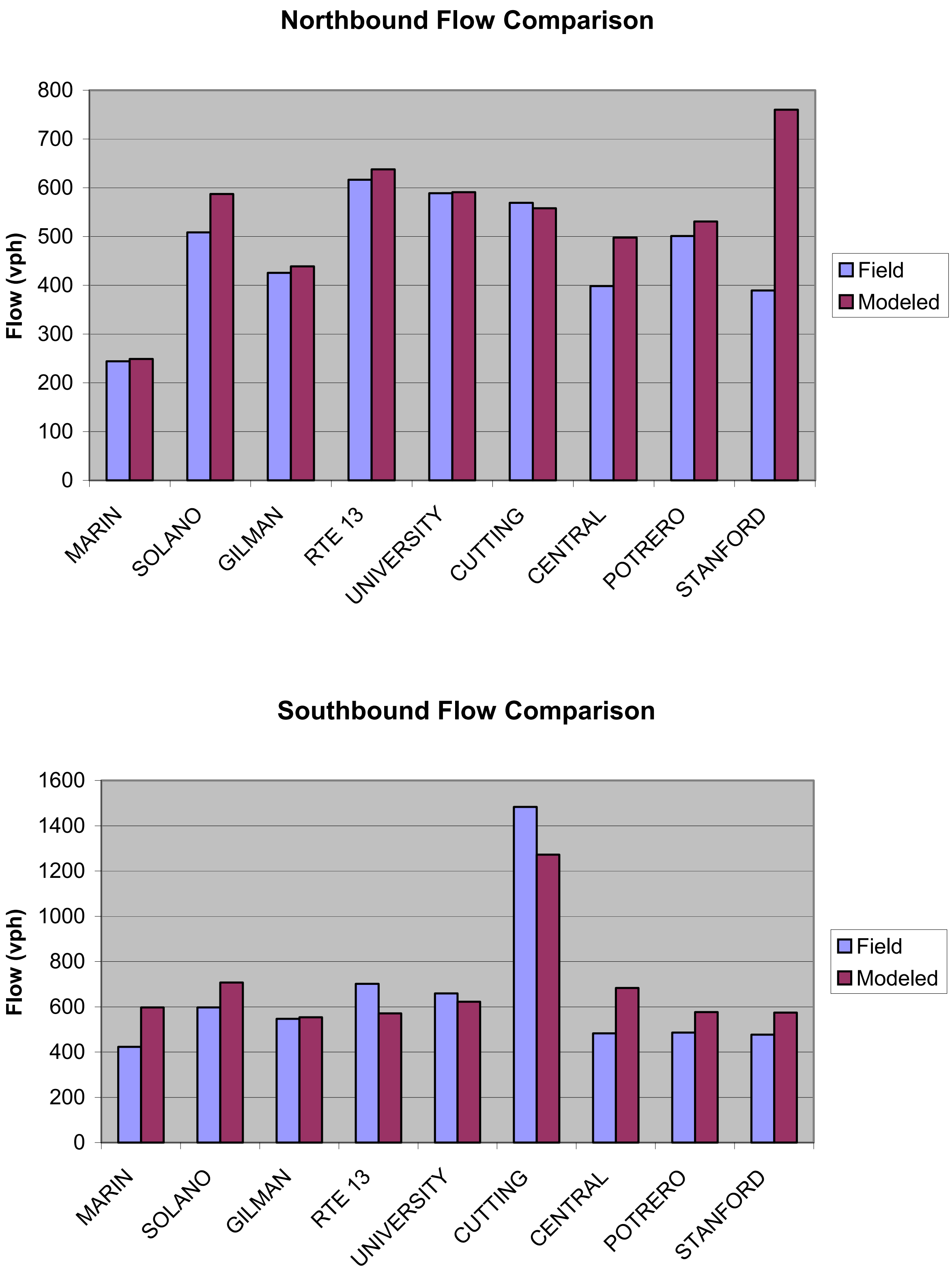
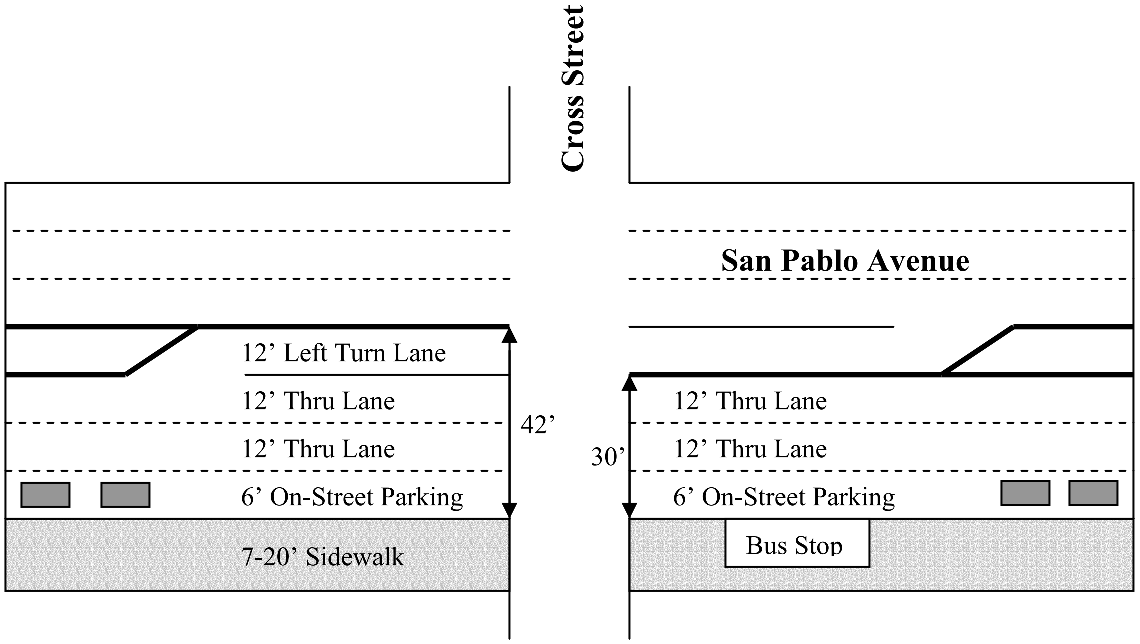
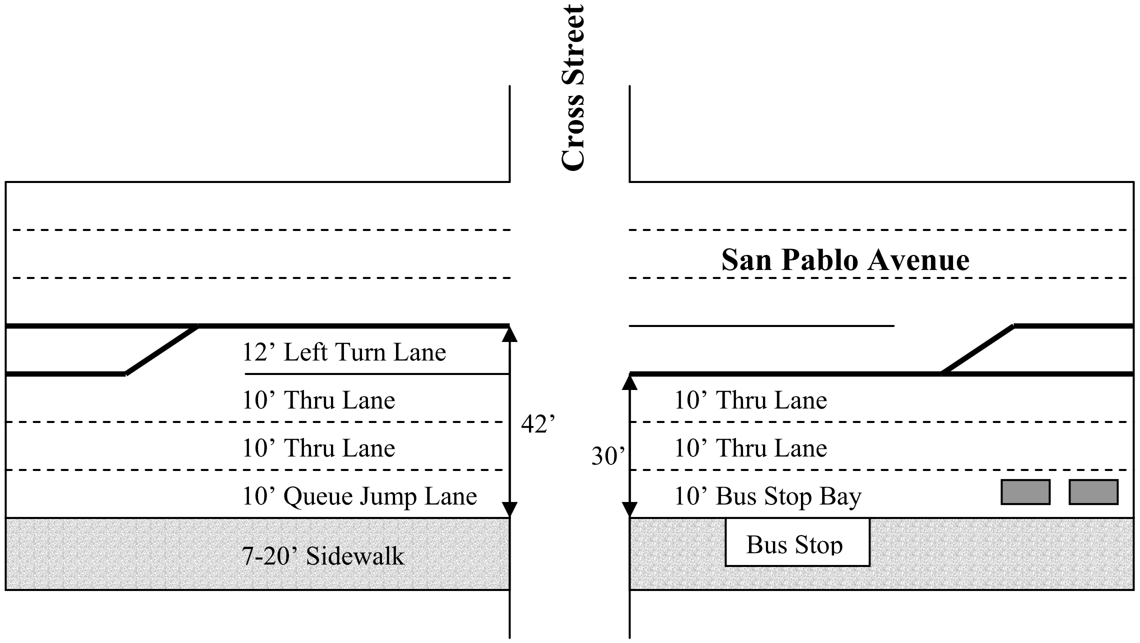


FIGURE 2 Modeled vs. Field Flow and Speed Comparison



Typical Intersection Chosen for Queue Jump Lane-Present Alignment



Typical Proposed Queue Jump Lane Alignment

FIGURE 3 Existing and Proposed Queue Jump Lane Geometry

TABLE 1 Comparison of Measures of Effectiveness Between Alternatives TRANSYT-7F

Performance Measures	**Units**	**Existing With No Weighted Bus Links System Total**			**Optimized With No Weighted Bus Links System Total**			**Optimized With Weighted Bus Links System Total**		
		Buses	Other	System Total	Buses	Other	System Totals	Buses	Other	System Totals
Total Travel Time	veh-hr/hr	25	2099	2124	27	2118	2145	25	2162	2187
Total Delay	veh-hr/hr	10	1354	1364	9	1407	1417	8	1451	1459
Total Stops	veh/hr	6836	108049	114885	3788	76677	80465	3762	80752	84514

TABLE 2: Paramics Model Travel Time Comparisons – Base Case and Two Alternatives								
	Northbound on San Pablo Avenue				**Southbound on San Pablo Avenue**			
	Vehicles		**Rapid Bus**		**Vehicles**		**Rapid Bus**	
All Times are in Minutes	**Average Travel Time**	**Standard Deviation**	**Average Travel Time**	**Standard Deviation**	**Average Travel Time**	**Standard Deviation**	**Average Travel Time**	**Standard Deviation**
Existing Geometry and Signalization	36.88	1.89	49.63	0:01:24	38.50	1.51	54.88	1.96
Passive Priority Signalization	33.38	1.41	49.25	1.16	39.25	3.49	52.88	4.05
Queue Jumper Lanes	33.38	1.19	49.75	0.46	38.63	1.30	51.38	1.60