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Yue Irene Li, Jing-Quan Li, Mark A. Miller, Wei-Bin Zhang

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ABSTRACT

This report proposes a generalized process for evaluating the ridership impact and traffic impact of a bus rapid transit system. The process proposed aims at providing such evaluation at the sketch planning stage and has a specific focus on two aspects -- the ridership forecast based on the implementation of various ITS technologies and the degradation of level of service that results from converting a traffic lane into exclusive bus lane for the implementation of a bus rapid transit system. The proposed process is tested on the Van Ness Blvd site in San Francisco, California. It is also implemented as a web-based toolbox that is easily accessible.

Key Words: bus rapid transit, ridership, level of service, web-based toolbox

EXECUTIVE SUMMARY

Running ways are a critical element for Bus Rapid Transit (BRT) systems. Various design options, coupled with Intelligent Transportation Systems (ITS) technologies, will offer different levels of operational performance. However, incorporating dedicated BRT lanes within the existing right-of-way is very much a challenge as conventional traffic can potentially be impacted and if not designed properly vehicular congestion will be created. ITS technologies have proven to be effective to improve the efficiency and safety for BRT operation through various deployments around the world. This research is intended to contribute to an understanding of the relationship between improvements of BRT service resulting from having dedicated bus only lanes, potential level-of-service (LOS) degradation due to the reduction in highway capacity, and potential improvements to both BRT and highway operations through application of ITS technologies.

The literature of bus rapid transit running way and bus lane priority treatments on arterials is first reviewed. For such priority treatments, numerous implementation options exist depending on the placement of the bus lane, direction of flow, mix of traffic, and traffic controls. Emphasis is placed on ways that are used to create a lane for arterial bus rapid transit use, including adding running way capacity, converting a parking lane to bus rapid transit use, and converting a travel lane to BRT use. ITS also play an important role in the operation of bus rapid transit systems and those ITS technologies that are the most relevant to BRT operations are discussed. The concept of LOS is also discussed with respect to measuring the impact that arterial bus lane priority treatments have on congestion levels of adjacent mixed-flow traffic lanes in terms of both vehicle-based and person-based expressions. Examples of California bus lanes/BRT systems are presented. The literature review provides a good understanding of the current practice and forms the foundation of the analysis methods proposed and used in this project.

Impact analyses for a BRT system are performed in two areas, including ridership impact and traffic impact in terms of corridor travel time and degree of LOS degradation. Three different approaches to forecast ridership with BRT are discussed and compared. The

four-step based demand modeling approach goes through the four steps of the transportation planning process that can provide a comprehensive evaluation of the corridor traffic condition. However, the drawback is the amount of effort required for data collection, model building, model calibration, and model application that is associated with the approach. It is not a suitable model at the sketch planning stage since typically, no such detailed data is readily available, and no such modeling effort would be warranted at this stage. Thus, the four-step approach is typically used only at a later stage in the process, when a particular project is being seriously considered and a feasibility study needs to be carried out. The direct modeling approach avoids going through all four steps of transportation planning models, and targets "directly" at estimating station-based ridership as a function of the service features of the station. It avoids a major portion of the data collection and model calibration work associated with the four-step process, but still requires data to support the regression of the ridership forecast model as a function of different combinations of various station features. The direct model only forecasts ridership, and traffic impact needs to be studied separately. The elasticity method uses current ridership on an existing transit line as the base, and estimates the change in ridership as a function of change in service characteristics (such as travel time, service frequency, fare, etc). The parameters that are associated with the service characteristics are suggested based on national experiences and thus do not require further calibration. Using the elasticity method requires that transit service currently exists along the corridor under consideration for BRT so that there is a base ridership figure. It provides only an approximate ridership estimate since the parameters are not calibrated specifically for the region and thus do not reflect fully its characteristics. Due to the purpose of this study, which is to establish a generalized toolbox for early stage estimation of the impact of a proposed BRT system, it is concluded that the elasticity method would be the appropriate approach for ridership forecasts.

For the traffic impact study, we propose a macroscopic traffic analysis process using Synchro to evaluate the impact of converting a highway lane for exclusive bus usage. "Before" and "After" models need to be built in the process. The "Before" model evaluates the current condition and the "After" model represents the scenario where highway lanes are converted to dedicated BRT lanes. Corridor wide travel time and LOS, as well as intersection LOS, are reported as output from Synchro and can be used for further analysis and comparison.

The Van Ness Avenue corridor in San Francisco is two miles long extending from Mission Street in the south to Lombard in the north. Conversion of two travel lanes into dedicated bus lanes is planned for the implementation of a BRT system. San Francisco Municipal Transportation Authority in partnership with the Municipal Transportation Agency conducted a Feasibility Study in 2006 to examine alternative bus rapid transit treatments along Van Ness Avenue. In this study, we use the Van Ness Avenue corridor as our case study site. The proposed ridership forecast method and the traffic impact analysis process are applied at the site. As recommended based on comparison of different modeling approaches, ridership analysis is performed using the elasticity method. Four different scenarios were tested, assuming the implementation of various ITS technologies (single lane BRT, TSP, precision docking). The result from Scenario 1, which is the scenario comparable with those in the Van Ness Avenue Feasibility Study Report, shows the ridership figures within 11% of those reported in the Feasibility Study Report. This demonstrates the feasibility of using the elasticity method for sketch planning level ridership estimates and supports the implementation of the method in the web-based toolbox.

With the Synchro simulation tool, traffic impacts of the BRT system are studied with different lane replacements and various levels of ITS technology implementation. It is observed that ITS technologies are very helpful in terms of decreased travel and delay times. In some cases, LOS could be maintained (for instance, with TSP and a higher conversion percentage from auto drivers to transit riders) or even improved (for instance, with TSP and precision docking, and a higher conversion percentage from auto to transit). The single bus lane alternative, however, seems to be a choice that is suitable for corridors that have very limited right of way (ROW) and cannot have a dedicated lane on each direction, since it may cause more significant increase in travel time and degradation in LOS. In general, our studies show that the performance degradation is typically within an acceptable range for many after-models, especially those with ITS techniques. Compared with corresponding results reported in the SFMTA's report, where a 3% increase in travel time is reported in the scenario with BRT lane conversion, our results show a 10% increase in travel time. Meanwhile, it is worth pointing out that the modeling approach used for SFMTA's study (microscopic simulation) and the approach used in our study (macroscopic simulation) model vehicle movement using completely different rules and should not be expected to replicate each other.

Finally, the web-based toolbox developed in this project provides Caltrans with an easily accessible tool that takes simple and basic inputs from the user regarding a planned BRT system, and then provides an estimate of future ridership. The toolbox would also take the basic inputs regarding the corridor's transportation facility (such as number of lanes, speed limit, etc) and estimate the traffic time along the corridor. This effort is the first step toward a more comprehensive toolbox that would provide a way to link directly with a microsimulation software package for more detailed traffic impact analysis.

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CHAPTER 1
INTRODUCTION

1.1 Motivation

The major advantage of Bus Rapid Transit over fixed guideway forms of transit is its flexibility and ability to be implemented in many operating environments with an implementation cost much less than rail transit. The elements that comprise any rapid transit system consist of the running way, stations, vehicles; Intelligent Transportation Systems (ITS) technologies such as fare collection and transit signal priority, various service patterns, and, identity and branding.

Running way is a key element for BRT systems. Since running way serves as the infrastructural foundation around which the other elements function, it defines the capacity and operational characteristics. Moreover, running ways should be designed to allow for rapid and reliable movement of BRT vehicles with minimum traffic interference. The level of separation from other traffic is the primary design parameter for running way. An existing mixed flow lane on an arterial represents the most basic form of running way. BRT vehicles can operate with no separation from other traffic on virtually any arterial street or highway. Increasing levels of separation beginning with operations in mixed arterial traffic, through exclusive arterial lanes (curbside or median), contra-flow freeway bus lanes, normal-flow freeway HOV lanes, grade-separated lanes or exclusive transitways on separate rights-of-way and bus tunnels add increasing levels of travel time savings and reliability improvement for the operation of BRT services. Fully grade-separated, segregated BRT transitways have the highest cost but with the highest level of performance of any BRT running way type.

To achieve dedicated BRT lanes along existing arterial highways, it may require removal of peak period parking to allow for a bus-only travel lane, replacement of conventional traffic signal control systems with transit signal priority systems, or removal of an existing curbside or center travel lane to allow for a bus-only travel lane. Moreover, such changes are likely to have impacts on the surrounding traffic environment. These impacts may include travel delays for automobile traffic adjacent to BRT lanes, impacts of traffic diversion to parallel streets, and impacts on businesses due to removal of curbside parking during peak periods. However, it is expected that some commuters will take BRT buses instead of driving private cars when a BRT system with good performance is implemented. The corresponding traffic delay is closely related to the traffic flow; it could increase or decrease, depending on the volume of commuters who shift from driving private cars to taking the BRT bus. In summary, three issues need to be considered in this project: the potential amount of the commuter shift to the BRT system and associated travel behavior changes vis-à-vis transit ridership, the potential congestion level changes in terms of LOS degradation on adjacent mixed-flow traffic lanes, and the increase of person throughput due to the BRT system.

Therefore, it is important to employ a systematic approach to understand all the issues that arise under various scenarios. In particular, the trade-off between the LOS degradation and people throughput increase will be quantified. For example, a BRT implementation decision can be accepted only if LOS degradation and people throughput increases are within certain ranges.

An easily accessible toolbox is highly desirable that helps the decision makers to understand the above-mentioned tradeoffs. At the sketch planning stage, there may not be many details available regarding the BRT system design and its surrounding environment, thus the toolbox would need to take very basic inputs of the system and be able to provide a rough estimation of the benefits and impacts for the agencies to use as a starting point to decide whether to pursue further study and implementation of the proposed system.

1.2 Objectives

The bus running way is critically important to the design of a BRT system. When the ROW is limited and the conversion of a travel lane into an exclusive bus lane is considered, the relevant stakeholder agencies would definitely want to understand the traffic impact of such a conversion since on the one hand, the lane conversion priority treatment eliminates the friction between buses and other vehicles, but on the other hand it can reduce arterial or freeway capacity, especially in the case where there is insufficient excess capacity on parallel arterials.

The objectives of the research are to identify and assess the benefits and impacts associated with the conversion of a travel lane and to implement a portion of the BRT Tool Box that assists with the evaluation of such benefits and impacts. The Van Ness Avenue corridor BRT system in the city of San Francisco is used as a site-specific case study to help provide decision support recommendations to the San Francisco Municipal Transportation Authority and Caltrans District 4 for their planning and design of the system.

1.3 Contents of the Report

The rest of the report is organized into the following chapters: Chapter 2 provides a review of the literature of bus rapid transit running way bus lane priority treatments on arterials. The concept of level of service (LOS) is also discussed with respect to measuring the impact that arterial bus lane priority treatments have on congestion levels of adjacent mixed-flow traffic lanes. Examples of bus lanes/BRT systems in California and elsewhere in the nation are also presented; Chapters 3 focus on two high priority impacts of lane conversion on arterials for bus-only use: ridership and traffic impacts. It presents different methods for ridership estimation in BRT implementations, as well as a comparison of the methods; and also summarizes simulation efforts using the Synchro tool for evaluating traffic impacts; Chapter 4 uses the Van Ness Avenue BRT system as a case study for the ridership analysis and Synchro simulation study; Chapter 5 presents the web-based toolbox designed and developed for ridership estimation and for the high-level traffic impact study of a planned BRT implementation; Chapter 6 summarizes the project efforts and future research directions.

CHAPTER 2
LITERATURE REVIEW

In this chapter we provide results of our review of the literature in the area of bus rapid transit implementation on arterial running ways and the various ways that bus priority treatments can be established in these settings using, for example, intelligent transportation systems and station and lane access control strategies. This review of the literature provides vital background material forms a basis for and related to subsequent chapters in this report, especially the focus on ridership estimation and roadway traffic analysis, because impacts on ridership and traffic are referenced in the literature review as important factors.

Bus rapid transit (BRT) systems are commonly viewed as an alternative travel mode to help make bus transit more attractive by enhancing customer level of service with an ultimate goal of increasing ridership that contributes to relieving traffic congestion. The elements that comprise any rapid transit system consist of:

- Running Ways;
- Stations;
- Vehicles;
- Intelligent Transportation Systems;
- Fare Collection;
- Service Patterns; and,
- Identity and Branding.

Running ways are the key element of BRT systems around which the other components revolve since running ways serve as the infrastructural foundation upon which the other elements function. Moreover, it is the running ways that should allow for rapid and reliable movement of buses with minimum traffic interference to provide a clear sense of presence and permanence. The types of running ways for BRT service range from mixed flow traffic operation to fully grade-separated exclusive transitways.

The remainder of this section provides an introductory description of running way priority treatments on arterials including adding a lane and converting an existing lane – the focus of the research documented in this report; their impacts including changes in travel behavior vis-à-vis ridership and level of congestion as measured in terms of level of service (LOS) on adjacent mixed-flow traffic lanes; examples of lane conversion; the use of intelligent transportation systems (ITS); and benefits and costs associated with BRT lane conversion. The literature review provides the informational groundwork for subsequent chapters of this report on the analysis of impacts for arterial lane conversion for bus-only use.

2.1 Application of Arterial Running Way Priority Treatments

Arterial bus facilities have widespread applicability because of their relatively low costs, ease of implementation, and opportunities for incremental deployment. Increasing levels of bus priority treatments on arterials that segregate buses from other vehicles include bus lanes, grade-separated lanes or exclusive transitways on separate rights-of-way. Increasing levels of separation from other vehicle traffic add increasing levels of travel time savings and reliability improvement for the operation of BRT services though at a higher cost.

For arterial bus lane priority treatments, numerous implementation options exist depending on the following characteristics:

- Placement of bus lane
  - Curb
  - Median
  - Interior lane
- Direction of flow
  - Concurrent flow (normal flow)
  - Contra-flow
- Mix of traffic
  - Mixed traffic flow with all other vehicles
  - Buses only (dedicated bus lanes)

    - Buses plus HOVs (e.g., in service taxis)
    - Buses plus special SOVs (e.g., goods delivery vehicles)
- Traffic controls
    - Turn controls
    - Parking
    - Loading and unloading of commercial motor vehicles
    - Traffic signalization

An existing *mixed flow lane* on an arterial represents the most basic form of running way in which BRT vehicles can operate with no separation from other vehicle traffic on virtually any arterial street. BRT systems generally operate in mixed traffic flow when physical and/or traffic factors preclude bus lanes or busways from being initially implemented. There are tradeoffs with implementing BRT in mixed traffic flow; advantages include low costs and fast implementation with a minimum of construction; however, mixed traffic flow operations can limit bus speeds and service reliability since the BRT vehicles have to travel in this environment *with other vehicles*; system identity can also suffer without specific actions taken to equip either or both the BRT vehicle and the BRT stop/station with a BRT brand identity.

There are several examples of BRT systems implemented in California that currently operate in mixed traffic normal flow all of which having a distinctively unique brand identity associated with their buses and bus stops, as follows:

- Los Angeles County Metropolitan Transportation Authority's Metro Rapid Lines with the first two lines implemented in 2001 on Wilshire and Ventura Boulevards.
- AC Transit's San Pablo Rapid traveling on State Route 123 (San Pablo Avenue) between San Pablo and Oakland
- Santa Clara Valley Transportation Authority's Rapid Line 522 along the El Camino/Santa Clara Street/Alum Rock Avenue corridor (State Route 82), which provides service along the east-west length of Santa Clara County between San Jose and Palo Alto.

- Sacramento County's Regional Transit Line 50 E-Bus on the Stockton Boulevard corridor

Of all arterial bus priority treatments, *normal flow curb bus lanes* are the most common; they are generally considered when it is not practical to install other arterial on-street bus service options. Normal flow curb bus lanes are the easiest to implement, have the lowest installation costs because they normally involve only pavement markings/restripings and street signs, and have minimum impact on intersecting driveways and street routings. However, experience in the U.S. has shown that they are least effective when compared with other bus priority treatments in terms of travel time saved, image and brand identity, ability to be enforced, and that they may impact curb access requirements such as deliveries. Another disadvantage is that right-hand turns, when allowed may conflict with bus flow; thus efforts should be made to either totally eliminate or at least restrict right-turning movements that would impede BRT service.

The primary example of a concurrent flow bus lane in California is in San Francisco under the operation of the San Francisco Municipal Railway (Muni) on various streets within the city including (Kiesling, M. and M. Ridgway, 2006):

- Sacramento and Clay Streets, which employ peak-hour curbside lanes that prohibit parking during peak periods.
- Mission Street operates curbside lanes between 7am and 7pm that dedicate a traffic lane to bus-only use, though convert to mixed flow use between 7pm and 7am.
- Third Street between Townsend and Market Streets operates a bus lane throughout the day; taxis are also allowed to travel in the lanes with buses

Normal flow interior bus lanes may be provided adjacent to parking lanes on both one-way and two-way streets. Examples of these lanes are located in the CBD of Ottawa, Canada and along Washington Street in Boston where they serve the Silver Line BRT.

No examples were identified for concurrent flow inside bus lanes in California. The concurrent flow inside bus lanes remove buses from most curbside conflicts from illegally parked vehicles and they do not impact left turn access. Right turns may be allowed from the bus lane or provided in the curb lane by prohibiting curbside parking at intersection approaches. Effective enforcement is essential because the lanes are not self-enforcing such as contra-flow lanes are. The disadvantage of concurrent flow interior bus lanes is that if parking is allowed such as in the off-peak period, there may be conflicts with parking and/or idling vehicles.

Contra-flow bus lanes enable buses to operate opposite to the normal traffic flow on one-way streets. They may, however, be used for a single block on two-way streets to enable buses to reverse direction and operate normally at all times. From the perspective of bus rapid transit systems implementation, contra-flow lanes have definite disadvantages, as follows:

- Tend to disperse buses onto two different streets thereby reducing notions of BRT identity
- Passing stopped or disabled BRT vehicles is difficult unless dual bus lanes are provided
- Buses run counter to the conventional traffic signal progression; however, this can be at least partially offset.

Examples of contra-flow bus lanes in California consist of the following:

- In San Francisco under the operation of the San Francisco Municipal Railway (Muni) on Sansome Street
- In Los Angeles under the operation of the Los Angeles County Metropolitan Transportation Authority on Spring Street.

Median bus lanes are located in the center of a roadway for exclusive bus use. They may operate in one-way or two-way directions depending on the street travel environment. Median bus lanes have continuous access, thus making enforcement difficult, but providing routes around disabled buses, for example, returning into mixed flow traffic. Currently in the planning stage is the Van Ness Avenue median bus lane BRT system in San Francisco; also is AC Transit's East Bay BRT system along E. 14th – Telegraph Avenue – International Boulevard BRT system, which will have a median component along part of its corridor alignment.

Bus-only streets or malls may be warranted where high bus volumes traverse narrow streets or as part of downtown revitalization programs. Bus streets or malls may include the last block of an arterial street, a dead-end street at the end of several bus routes, a "bus loop" to change directions at major bus terminals, downtown bus malls, and bus circulation through automobile-free bus zones.

Bus streets identify transit routes and are easy to enforce. They increase walking space for pedestrians and waiting space at bus stops. Bus streets should incorporate curb loading zones for off-peak service vehicles where the necessary service cannot be provided from intersecting streets or off-street; where other options are unavailable or impractical, pickups and deliveries may be allowed from the bus streets when bus traffic is low such as during night hours.

A succinct summary of the strengths and weaknesses associated with the various arterial BRT running ways is provided in Table 2.1 (Levinson, H.S., et al., 2003).

TABLE 2.1 Arterial-Related Running Ways: Strengths and Weaknesses

Arterial Bus Priority Treatments	**Strengths**	**Weaknesses**
Operations in mixed traffic flow	• Quick implementation • Minimum cost	• Buses subject to traffic delays • Little if any sense of identity
Concurrent flow curb bus lanes	• Ease of installation • Low cost	• Difficult to enforce • Least effective in reducing

Arterial Bus Priority Treatments	**Strengths**	**Weaknesses**
	• Minimize street space devoted to BRT	BRT travel time • Added delay for buses due to conflicts between right-turning traffic and pedestrians
Contra flow curb bus lanes	• Enables two-way bus operation on one-way streets • May increase number of curb faces available for passenger stops • Completely separate BRT from general traffic flow • Self enforcing	• May disperse BRT onto several streets and reduce passenger convenience • Limits passing opportunities around stopped or disabled buses unless multiple lanes are provided • Can create conflict with opposing left turns • May create safety problems for pedestrians
Concurrent flow interior bus lanes	• Remove BRT from curbside frictions • Allow curb parking to be retained • Provide far-side bus "bulbs" at stops for passenger convenience	• Require curb-to-curb street widths of 60 to 70 feet • Curb parking maneuvers could delay buses
Median arterial busways	• Physically separates BRT running ways from general traffic • Provides a strong sense of BRT identity • Eliminates conflicts between buses and right-turning automobiles • Can enable busways to be grade separated at major intersections	• Require prohibiting left turns from the parallel roadways or providing special lanes and signal phases for these turns • Require wide streets, generally more than 80 feet from curb to curb • Costs can be high
Bus-only streets	• Remove BRT from general traffic • Increase walking space for pedestrians and waiting space at stops/stations • Improves BRT identity • Improves the ambience of surrounding areas	• Require nearby parallel streets for displaced traffic, provisions for goods delivery and service access from cross streets or off-street facilities • Generally limited to a few city blocks

Source: (Levinson, H.S., et al., 2003)

2.2 Creating a Lane for Arterial Bus Rapid Transit Use: Issues and Impacts

When a transit agency considers implementing bus priority treatments on an arterial bus corridor, numerous options to choose from exist based on the previously discussed attributes: bus lane placement, direction of flow, mix of traffic, and traffic controls. Increasing levels of bus priority treatments on arterials that segregate buses from other vehicles include bus lanes (normal curbside/median or contra-flow), grade-separated lanes or exclusive transitways on separate rights-of-way. Increasing levels of separation from other vehicle traffic add increasing levels of travel time savings and reliability improvement for the operation of BRT services though at a higher cost. Thus there are crucial tradeoffs to consider when making bus priority treatment decisions.

When buses are separated from other vehicles by means of a bus-only lane, the following options are available with which to establish such a lane: adding a lane or taking a lane; and a lane may be taken away from mixed-flow travel use or from existing on-street parking use. There are numerous tradeoffs associated with each of these alternatives as shown in Table 2.2.

A recently completed study (Savage, K.J., 2009) examined the benefit/cost analysis of a bus-only lane and focused on converting a mixed-flow travel lane to exclusive bus rapid transit use because it is not always possible to implement BRT lanes through the provision of additional capacity. The authors of that study conducted a review (both a literature and online document review in addition to interviews) of more than three dozen BRT systems around the world with an emphasis on U.S. systems. The review was performed to identify locations where it was possible that an existing mixed-flow travel lane had been converted to a designated BRT lane. Results of this review indicate that "it is rare that implementation involves converting mixed-flow travel lanes for exclusive BRT or HOV use." (Savage, K.J., 2009). The authors, however, identified three U.S. BRT systems where lane conversion for BRT use was implemented and which are discussed in the following section.

TABLE 2.2 Establishing a Bus Lane: Potential Tradeoffs

Establishing a Bus Lane	Advantages	Disadvantages
Add a lane	• Reduces running time and thus travel time • Reduces travel time variability • Potential reduction in transit agency operating cost	• Availability of right-of-way for expansion • Potential right-of-way purchase • Lane construction • Maintenance of new lane
Take a lane from mixed-flow travel use	• Reduces running time and thus travel time • Reduces travel time variability • Potential reduction in transit agency operating cost	• Lane restriping capital cost • Increases delay/travel time • Contributing to travel diversion on side streets, which may/may not have excess capacity
Take a lane from existing on-street parking use	• Reduces running time and thus travel time • Reduces travel time variability • Potential reduction in transit agency operating cost	• Lane restriping capital cost • Potentially restricted access for customers / commercial deliveries to businesses unless additional parking supply is available

2.2.1 Examples of Lane Conversion for BRT Use

There are two operational BRT systems in the U.S. that are examples where an existing mixed-flow travel lane(s) has been converted for exclusive BRT use, namely, the Euclid Ave. BRT Corridor operated by the Greater Cleveland Regional Transportation Authority (GCRTA) and the EmX BRT Franklin Ave. Corridor in Eugene, Oregon run by the Lane County Transit District (LTD). Another BRT system, not yet operational, is AC Transit's E. 14th Blvd – Telegraph Av. – International Blvd. Corridor, and has plans for converting a mixed-flow travel lane to BRT use.

2.2.1.1 The Euclid Avenue BRT Corridor in Cleveland, Ohio

For 4.5 miles, a lane in each direction was taken away to build the Euclid Avenue BRT within the median of the corridor. During the planning stages there was a lot of resistance both from the public and institutional stakeholders about going from two lanes per direction down to one lane per direction. However, Cleveland was fortunate enough to have a robust number of parallel roadways to Euclid with more than enough roadway capacity and GCRTA also felt that it was more of a perception problem than an actual technical problem of insufficient space. During the Environmental Impact stage of the planning process, this part of the corridor was modeled and a worst case scenario was used – no cars allowed on Euclid Av. The modeling results came back with no problem at all in terms of roadway capacity on the parallel routes on to which cars diverted from Euclid Av and in terms of intersection delay. As a result of this modeling exercise, the major stakeholders were convinced that taking a lane from non-bus use on Euclid Avenue could work out; such stakeholders included the City of Cleveland (the GCRTA is not part of the city and is a separate entity from it); the Ohio Department of Transportation as Euclid Avenue is on a State route; and the community redevelopment corporation along the corridor. The Euclid Avenue Corridor and the GCRTA were fortunate in this way to have alternate parallel routes from which to absorb the traffic diverted from Euclid Avenue.

Because the Federal Transit Administration provided funding to GCRTA, it is bound by FTA's regulations that require GCRTA to conduct a before and after evaluation of the corridor both in terms of non-BRT and BRT impacts. The "before" component of the evaluation is complete; GCRTA is in the "after" process right now. The Euclid Corridor recently had its 1st anniversary of being in revenue service. Thus far non-bus traffic LOS is consistent with what modeling predicted; non-bus traffic is essentially not adversely impacted by the conversion of a traffic lane to BRT use. The measure of LOS used is intersection delay, which really does "control the street", as GCRTA specifically stated. There has been a lot of LOS B and C, with a few Ds, especially in the CBD portion of the corridor. LOS is actually better than predicted or improved in the middle of the corridor.

Ridership has increased; customer satisfaction surveys have shown "good" results and also "good" results from business development quarters as well.

2.2.1.2 The Franklin Avenue EmX BRT Corridor in Eugene, Oregon

The EmX on Franklin Avenue is four miles in length; approximately 2.6 miles is a dedicated bus-only lane and the remaining 1.4 miles is in mixed traffic flow. The 2.6 mile dedicated bus-only lane is divided approximately into a single bus-only lane that branches out into two parts at each BRT stop for two-thirds of this part of the corridor; the remaining one-third consists of one lane in each direction.

There are a number of sections of the route where general traffic lanes were converted to transit use. In total, the project included the following actions:

- Eliminated turn lanes
- Took travel lanes
- Removed 72 on-street parking spots

There was generally very little concern over the impact on traffic in terms of level of service arising from converting a travel lane to exclusive BRT use; similarly, there was little, if any, concern over the need for traffic diversion on any parallel roadways in those locations where lane conversion occurred. There was, however, concern over the conversion of parking lane space for BRT use due to the potential loss of parking revenue and parking ticket revenue.

The Lane Transit District (LTD) invested in modeling simulation studies on an intersection-by-intersection basis that demonstrated the impacts on traffic conditions that would result from implementing a BRT system. Lane Transit also worked very closely with the local businesses in order to develop a relationship that would allow them to avoid issues with the business community because of the removal of curbside parking spots. LTD developed a large public education campaign in order to prepare the public for the complex traffic arrangements that would result from the EmX's implementation. In terms of impacts on traffic volumes and level of service, there has not been a noticeable difference compared with before the EmX was implemented and no concerns at the current time as a result of these changes and improvements have been expressed; however, it is hard to gauge considering the present economic conditions with high gasoline prices and transit use at all-time highs.

For example, on East 11th Avenue, the existing curb lane was already a de facto bus lane, as the buses blocked the travel lane during the boarding operation and subsequently drivers in non-buses avoided using the lane. The City of Eugene was convinced of this through LTD's modeling to illustrate the situation. To provide sufficient space for the EmX lane, some left turn lanes were removed and replaced with a "jug-handle" configuration to accommodate left turns; moreover, some right turn lanes were removed and combined with through lanes.

2.2.1.3 AC Transit E. 14th – Telegraph Ave. – International Blvd. BRT Corridor in the East Bay Region of the San Francisco Bay Area

The area that the route passes through is entirely urban with buildings fronting on the roadway; subsequently, there was no opportunity of widening the road for bus rapid transit use. The public wanted to conserve parking so AC Transit considered converting a mixed flow traffic lane instead of converting parking to accommodate the BRT system. Thus plans call for converting two mixed-flow traffic lanes to one mixed-flow traffic lane and one two-way bus lane. Plans call for a bus-only lane to run for 17 miles within three municipal jurisdictions with dedicated lanes along 85 % of the route and mixed-traffic for the remaining 15%. Based on suggestions from local elected officials, AC Transit selected to convert a general purpose traffic lane to a bus-only lane rather than taking a parking lane due to the more serious issue over loss of parking than taking away a mixed-flow traffic lane. Moreover, it was felt that arterials running parallel to the expected route could accommodate an increased capacity resulting from the traffic overflow from the BRT route. A small diversion to other routes is possible, but not likely due to the capacity on the parallel arterials and the traffic analysis conducted by AC Transit did not reveal this to be an issue. AC Transit is currently developing a method to look at the potential diversion to local and/or neighborhood streets to determine the effects of converting a general purpose lane to a bus-only lane.

Most of the corridor runs through low-income neighborhoods where parking was underutilized; however, part of the corridor also runs through a thriving commercial development area where parking is highly utilized. The decision to convert a general purpose lane and to use the median rather than parking lanes was highly motivated by the characteristics of the smaller part of the corridor in commercial areas near station locations where parking is an important issue.

2.2.2 Actions to Address Impacts of Lane Conversion

When deciding whether or not to convert an existing mixed-flow travel lane to exclusive BRT, it is useful to consider the potential impacts of supportive actions on conditions in the travel corridor, as well as parallel and intersecting facilities. Corridor stakeholders may then utilize several strategies to minimize potentially negative impacts of a proposed lane conversion and improve the operating environment for the BRT system, as well as traffic in general. Supporting actions that can be used to mitigate potential negative impacts of a lane conversion fall into the following three categories (Savage, K.J., 2009):

- Implement intelligent transportation systems strategies in the corridor for all travel lanes and on parallel and intersecting routes. Advanced signal synchronization and transit signal priority for BRT vehicles can improve the traffic conditions in the BRT lane, as well as the overall flow and capacity of the facility. It is possible that traffic conditions could actually improve in the remaining mixed-flow traffic lanes if buses are removed from the traffic mix and appropriate ITS improvements are implemented. In addition to making ITS improvements within the BRT corridor, appropriate corridor stakeholders such as the relevant transit agency and local and/or regional departments of transportation may make ITS improvements on parallel and intersecting facilities to accommodate traffic that may be diverted to other facilities and to improve the traffic flow in a larger area.

- Implement Smart Growth land use policies and plans. Smart Growth strategies that call for increased density of development, mixed-use development, infill development, and improved conditions for pedestrians can all help to create a better environment for successful transit operations.
- Implement a comprehensive Travel Demand Management (TDM) program. The TDM program would include strategies/policies related to parking management, employer incentive programs, and increased transit services in the BRT corridor, as well as on parallel and intersecting facilities. It is also important to ensure that the BRT lanes link key locations and provide convenient access to them through multiple access modes (e.g., provision of a park-and ride lot at the end of a BRT corridor and/or feeder bus service to key nodes/stations on the BRT corridor). Together, these actions would help to improve the operating environment for transit and increase the demand for transit use relative to driving alone.

2.3 Use of Intelligent Transportation System Strategies

Intelligent transportation systems strategies play a fundamental role in the context of bus rapid transit system implementation. Such strategies include the following:

- Transit Signal Priority
- Collision Warning/Avoidance
- Vehicle Guidance Systems: Lane Assist & Precision Docking
- Passenger Information Systems: Stop/Station and In-Vehicle
- Automatic Vehicle Location

Transit Signal Priority

Transit Signal Priority (TSP) is an operational strategy that facilitates the movement of transit vehicles (usually those in-service) through traffic-signal controlled intersections. TSP modifies the normal signal operation process to better accommodate transit vehicles by altering the signal timing to give a priority or advantage to transit operations. TSP strategies may be passive, active, or adaptive. Passive priority operates continuously, regardless of the presence of the transit vehicle at the intersection, based on knowledge of transit route and ridership patterns, and does not require a transit detection / priority request generation system. One such passive priority strategy is establishing signal progression for transit in which the signals are coordinated for the flow of transit vehicles and not other traffic. Examples of active strategies include green extension (extends the green time for the TSP movement when a TSP-equipped vehicle is approaching) and early green (shortens the green time of preceding phases to expedite the return to green (i.e., red truncation) for the movement where a TSP equipped vehicle has been detected. TSP with adaptive signal control systems provides priority while simultaneously trying to optimize traffic performance criteria. Adaptive signal control systems continuously monitor traffic conditions and adjust control strategies in which it is possible to take into account person delay, transit delay, vehicle delay, and/or a combination of these criteria.

Collision Warning/Avoidance

Collision warning systems alert BRT vehicle drivers about the presence of obstacles or the impending impact with pedestrians or other obstacles. This includes forward, rear, or side impact collision warning systems or integrated 360-degree systems (a system that covers all sides of the BRT vehicle). These technologies employ primarily the use of radar to scan the environment surrounding the vehicle. Upon detecting an obstacle, the system automatically warns the BRT operator. A similar but more advanced system being developed is called collision avoidance. This system works similar to collision warning systems but, upon detecting an obstacle, automatic systems take control and decelerate the engine or apply the brakes if a driver does not properly respond to avoid colliding with the detected obstacle. However, as of 2008, these systems were still in research or early implementation stages and are not widely available for installation on BRT vehicles.

Vehicle Guidance Systems: Lane Assist and Precision Docking

Vehicle Guidance Systems technologies are those that help the driver maintain lateral control of the bus such as Lane Assist and Precision Docking. Lane Assist systems enable buses to stay centered in their traveling lane. Typical technologies include roadway magnetic marker sensors, vision/optical sensing systems with an electronically-controlled steering actuator. Precision docking systems involves the low-speed positioning of buses relative to the curb or loading platform at bus stops and/or stations under the direct bus driver supervision. The lateral position of the bus is precisely controlled with 1 to 2 cm. tolerances. Technologies that may be utilized include roadway magnetic marker sensors or visual/optical sensing systems with an electronically-controlled steering actuator.

Passenger Information: Stop/Station and In-Vehicle

At a minimum, BRT stops, stations, and terminals should provide route numbers, static schedule information, and route maps. Passenger information may come from video monitors or variable message signs, depending on the application and need for security. Monitors can be used when a large amount of information is being displayed and when there is a need for color and graphics to explain various options (e.g., in terminals). Variable message signs are more appropriate when information about a few buses is needed and security is an issue (e.g., at remote bus stops). Passengers may also get information from mobile and other wireless devices.

A traditional on-board information system consists of printed timetables and driver announcements. Improvements in technology have allowed stop announcements to be delivered by automated voice recordings or some type of message display. These systems can also announce transfer opportunities and local attractions. Some systems carry advertising messages to help cover the costs involved.

Automatic Vehicle Location

Automatic Vehicle Location (AVL) systems automatically determine and track the real-time geospatial location of a bus. Several different technologies may be used to perform AVL, such as GPS, ground-based radio, dead-reckoning, and combinations of these. AVL systems allow real-time monitoring of a bus's movements, control of its headways, closer schedule adherence (including more effective timed transfers), and the ability to direct maintenance crews in the event of a vehicle breakdown. It also gives transit agencies the opportunity to provide real time bus schedule information to customers at stops by various means such as Smart Phones. AVL systems also allow two-way communications between bus drivers and central supervisors.

2.4 Arterial Level of Service

An important consideration for BRT implementation of a bus priority treatment on an arterial is the impact this action would have on the level of congestion of adjacent mixed-flow traffic lanes. Congestion may be measured in multiple ways and is commonly expressed as a level of service (LOS) category ranging between A (best) to F (worst). LOS is defined in the Highway Capacity Manual as a "quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience."[1] LOS has been most commonly and traditionally used to analyze the efficiency or productivity of the highway system on a vehicle-centered basis; however, the concept has also been expanded and applied to transit, and pedestrian and bicyclist movements (Kittelson & Associates, Inc., 2003). LOS is customarily determined by a quantitative measure and is expressed differently for uninterrupted flow facilities such as freeways than for interrupted facilities such as arterials or urban streets with signalized intersections.

Speed and delay are the two primary measures of performance used to express LOS on arterials in the context of interrupted flow. Tables 2.3 and 2.4 show level of service criteria for an arterial/urban street, and for signalized intersections, in terms of average speed and delay, respectively.

TABLE 2.3 Arterial Level of Service Criteria by Class

[1] The definition of LOS as stated in the Caltrans Highway Design Manual is the following: A rating using qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers

Arterial Street Class	I	II	III	IV
Range of free-flow speed	55-45 mph	45-35 mph	35-30 mph	35-25 mph
Typical free-flow speed	50 mph	40 mph	35 mph	30 mph
LOS	**Average Travel Speed (mph)**			
A	> 42	> 35	> 30	> 25
B	34 – 42	28 – 35	24 – 30	19 – 25
C	27 – 34	22 – 28	18 – 24	13 – 19
D	21 – 27	17 – 22	14 – 18	9 – 13
E	16 – 21	13 – 17	10 – 14	7 – 9
F	<= 16	<= 13	<= 10	<= 7

Source: (Highway Capacity Manual, 2000)

TABLE 2.4 Level of Service Criteria for Signalized Intersections

LOS	Control Delay per Vehicle (seconds/vehicle)	Definition
A	<= 10	Very slight delay
B	10 – 20	Slight delay
C	20 –35	Moderate delay
D	35 –55	Heavier, frequently tolerable delay
E	55 – 80	High delay; frequent signal cycle failures
F	> 80	Very high delays and congestion

Sources: (Highway Capacity Manual, 2000) and (Savage, K.J., 2009)

For fixed-route transit service, there are numerous LOS measures (Kittelson & Associates, Inc., 2003) including:

- Service frequency
    - Vehicles/hour
    - Average headway (minutes)
- Bus passenger load
    - Square feet per passenger
    - Number of passengers per seat
- Hours of service

- Service area coverage

As previously mentioned, traditionally LOS has been until recently primarily a vehicle-based measure expressed in terms of vehicle delay, vehicle speed, and vehicle throughput without accounting for the capacity or occupancy of each vehicle. Hence in terms of converting a mixed-flow traffic lane to exclusive BRT use, its relative value would be underestimated. However transportation agencies have recognized especially in urban areas that person-based measures instead would more accurately quantify level of service measures and reflect more truly the actual operating condition of the corridor under study, whether it is expressed in delay, hours traveled, or throughput. On an exclusive BRT facility, person throughput or capacity can be determined based on the following input:

- Number of passengers a vehicle can carry (passenger capacity of BRT vehicles)
- Number of vehicles per hour using the BRT facility (headway, frequency of service – vehicle capacity of BRT facilities)
- Passenger demand characteristics (e.g., maximum load points)
- Vehicle size (standard/articulated vehicle division)

2.5 Benefits and Costs Associated with BRT Lane Conversion

One of the most critical evaluation factors in considering conversion of a mixed-flow traffic lane for exclusive BRT use is the potential benefits and costs that will accrue to all corridor users. Perceived costs for drivers may be more than offset by improvements for transit users, especially if there is a substantial mode shift from private automobiles to transit. Increasing transit capacity and transit utilization in the corridor will result in an increased person throughput for the entire corridor. In addition, intelligent transportation systems improvement on the facility, and on parallel and intersecting facilities, may offset the traffic impacts of converting a mixed-flow travel lane for exclusive BRT use and actually improve travel conditions for all vehicles. It is critical that all of these factors are taken into account in the evaluation of a proposed lane conversion to determine the net benefit of the proposed action and the cost-effectiveness of the potential investment.

The purpose of a cost/benefit analysis is to determine the alternative that would produce the largest net benefit, by comparing the monetary value of costs and benefits for each alternative and thus evaluate various transportation improvement projects. Numerous models exist that can be used to perform cost/benefit analysis, ranging from sketch planning tools and spreadsheet-based models used as screening-level tools (e.g., SPASM[2]) to more robust, stand-alone software programs (STEAM[3]) designed for use with the output of other models such as a four-step travel demand model. To completely perform a quantitative analysis, it is necessary to convert all costs and benefits into monetary units. Generally, costs are easier to quantify than benefits because they are more tangible; however, some costs are difficult to measure or quantify such as environmental costs. Costs and benefits can occur over extended periods of time and so cost-benefit analysis needs to take this into account. This is conventionally done by converting yearly benefit and cost information to a multi-year net benefit analysis; moreover, a discount rate is applied to the benefits and costs incurred in each year of the project's life cycle. It is important to categorize the benefits and costs in a standard fashion; and one way of doing this is as follows: direct and indirect benefits and direct and indirect costs. The following list summarizes example benefits and costs associated with converting a lane for BRT use organized into direct and indirect groupings. The two most widely used measures used to compare benefits and costs in cost-benefit analysis are net present value and benefit/cost ratio (Savage, K.J, 2009).

Benefits

- Direct benefits
    - Travel time savings for transit users
    - Vehicle operating cost, parking cost, and insurance savings for people who switch from private auto to transit

[2] ECONorthwest and Parsons Brinckerhoff Quade & Douglas, Inc., "Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners", TCRP Report 78, National Academy Press, Washington, D.C., 2002.
[3] ECONorthwest and Parsons Brinckerhoff Quade & Douglas, Inc., "Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners", TCRP Report 78, National Academy Press, Washington, D.C., 2002.

    - Improved access to jobs and amenities for certain population groups, especially transit-dependent travelers
    - Improved bus operating efficiency
    - Lower costs for transit per passenger due to improved operating efficiencies and higher ridership for transit
    - Benefits from reduced environmental damage
- Indirect benefits
    - Ridership increases by shifting trips to transit
    - Potential reduction in accident costs
    - Benefits from reduced emissions
    - Benefits from increased economic activity and/or agglomeration of businesses
    - Benefits from property development owing to transit investment
    - Growth in employment in transit service area
    - Benefits to government from increased taxes generated by new development

Costs

- Direct costs
    - Capital costs of materials and equipment
    - Delay for travelers in mixed-flow travel lanes
    - Infrastructure construction costs, including roadway improvements, bus shelters, and information technology
    - Capital costs for new buses
    - Operations and maintenance costs
    - Overhead expenses of business, commercial and government fleets using mixed-flow travel lanes resulting from traffic delays in mixed-flow lanes
    - Enforcement costs to government to prohibit use of dedicated lanes by general-purpose traffic
- Indirect costs
    - Costs of traffic delays during construction

- Costs of noise pollution
- Costs of emissions if congestion on remaining lanes of highway increases
- Costs of travel delay to others if congestion on remaining lanes of highway increases

2.6 Examination of California Bus Rapid Transit Systems

California has several implemented BRT systems as well as a few that are currently in the planning stage. Each system has its unique operating environment and implementation constraints. This section provides a review of some of these systems.

2.6.1 Dedicated Busway with Additional Right-of-Way -- LACMTA Orange Line

2.6.1.1 Introduction

The Orange Line is operated by the Los Angeles County Metropolitan Transportation Authority (LACMTA). It travels 14 miles and began revenue service in October 2005. The Orange Line runs in a dedicated transit way (Figure 2.1) for 13 of its 14 miles and travels one mile in mixed flow traffic; moreover the stations are approximately one mile apart, which are characteristics that are similar for a light rail system, thus, it is branded by LACMTA as part of its light rail system.

LACMTA purchased the former Southern Pacific Railroad Burbank Branch right of way in 1991. Because of legislative restrictions that prohibited the use of the corridor for any form of rail transit other than a "deep bore subway located at least 25 feet below ground" and that prohibited LACMTA from using its county sales tax funding to build subways anywhere in the county, the only option left for development of the transit corridor was to build a busway with construction beginning in September 2002.

In June 2009 construction began on a four-mile extension along the Burbank Branch railroad right-of-way, from the Orange Line's Canoga station northward to the Metrolink (Los Angeles County's commuter rail system) station in Chatsworth. The new construction is expected to be completed in 2012.

Figure 2.1 Orange Line Bus Operates on a Dedicated Bus Lane

2.6.1.2 Ridership

After opening, ridership grew rapidly exceeding expectations and forecasts, and the Orange Line currently operates at capacity during part of the day. The line had 25,428 average daily boardings in October 2008. In many peak periods, coaches depart the North Hollywood station[4] completely full with little standing room for riders wanting to board for points west.

Ridership has continued to increase with LACMTA reporting 548,111 boardings for June 2006, 652,875 for June 2007, and 679,578 for June 2008. This is an increase of 24% in two years, while boardings on its older, established light rail lines had modest increases over the same period. Studies of its use suggest that most riders are long haul and in fact travel east to or travel west from the Red Line subway service. This "extension" effect of Red Line service is more "traffic productive" than the more typical boarding and alighting of passengers along the bus line. Creating better service, with higher frequency or longer coaches on the Orange Line, will further stimulate ridership on the subway.

2.6.1.3 Traffic impact

Since the Orange Line operates in a dedicated busway for 13 of its 14 mile length, its impact on and interaction with traffic happen at intersections. During the first few months

[4] The North Hollywood station is a major transfer point between the eastern terminus of the Orange Line and the San Fernando Valley terminus of the Red Line (LACMTA's subway).

of operations, there were several collisions, approximately one per week. The Orange Line busway does not employ railroad crossing-style arms or lights (or grade separations) to prevent motorists from crossing that roadway while a bus approaches; instead, it relies on traffic lights and warning signs. Thus, it is more important for people to observe traffic signals and stop at red lights, as red-light runners have caused most of the accidents.

2.6.2 Dedicated Bus Lane without Additional Right-of-Way – AC Transit's International Boulevard

2.6.2.1 Introduction

As part of its East Bay Bus Rapid Transit (BRT) project, AC Transit proposed to construct bus-only lanes (Figure 2.2) along an 18-mile long stretch from downtown Berkeley and UC Berkeley in the north to the Bay Fair BART station in the south. In its Major Investment Study that was completed in 2002, six different technology and alignment alternatives were evaluated, and the BRT alternative was recommended as the preferred vehicle and operations technology for the corridor, with the understanding that LRT should be considered as a long-term goal. The recommended BRT system would include the following features:

- Special transit lanes dedicated to BRT along most of the corridor;
- Traffic signal priority and coordination throughout the corridor;
- Frequent BRT service with a background local service (5 to 7.5 minutes between BRT buses);
- Wider BRT station spacing than existing bus service (1/3 to 1/2 mile between BRT stations);
- Well-developed BRT stations including shelters, boarding platforms, benches, security features, fare machines, real-time bus arrival information and other amenities;
- Proof-of-payment ticket validation; and
- Low-floor, multi-door, level-boarding, low-emission BRT buses.

Figure 2.2 AC Transit's Bus Lanes in the Median (Current and Proposed)

2.6.2.2 Expected Traffic Impact

To construct the transit only lanes (for BRT for now, and potentially for LRT in the future), two options were considered, one was to convert the parking lane into a transit only lane, and the other was to convert a travel lane to a transit only lane. Since the proposed bus route goes through a busy commercial district, the idea of converting parking lanes became less favorable and the conversion of two of the four existing traffic lanes into special transit lanes is required to retain as much on-street parking as possible. While there would be adverse impacts to auto travel on these streets, a traffic study showed that the impact could be mitigated with the exception of only a few locations, and the overall person throughput capacity would remain largely unchanged because the lower auto capacity would be offset by increased transit service (See also Section 3.1.3).

2.6.3 Bus in Mixed Flow Traffic

2.6.3.1 Introduction

Due to the difficulty usually associated with acquiring additional right-of-way for or converting a current traffic/parking lane into a dedicated bus lane, many BRT implementations opt for operating in mixed traffic flow. The following are examples of such operations;

– Los Angeles County Metropolitan Transportation Authority's Metro Rapid Lines with the first two lines implemented in 2001 on Wilshire and Ventura Boulevards;

- AC Transit's San Pablo Rapid traveling on State Route 123 (San Pablo Avenue) between San Pablo and Oakland;
- Santa Clara Valley Transportation Authority (VTA)'s Rapid Line 522 along the El Camino/Santa Clara Street/Alum Rock Avenue corridor (State Route 82), which provides service along the east-west length of Santa Clara County between the Eastridge Shopping Center in San Jose and the Palo Alto Transit Center;

2.6.3.1.1 LACMTA Metro Rapid Lines

The Metro Rapid Bus Program was initiated in March 1999 by LACMTA as a demonstration program and currently operates 26 routes across a network of 450 miles, complementing light and heavy rail transit throughout Los Angeles County. The initial demonstration program aims to offer rail-type frequent and high quality transit services connecting the terminus of the Red Line to major destinations in the outlining areas. Two lines were selected for the demonstration:

- Line 720 Wilshire/Whittier, a very high passenger demand urban corridor connecting through the Los Angeles Central Business District;
- Line 750 Ventura, a high passenger demand suburban corridor serving the Metro Rail Red Line.

Key features of the metro rapid program include;

- Transit Signal Priority (TSP) implementation, which required the collaboration of the Los Angeles Department of Transportation, which operates the ATCS (Advanced Traffic Control System) in the area served by the two demonstration lines.
- Headways of 3-10 minutes during peak commuting times
- Bus stops about a ¾ mile apart
- Low-floor buses used to speed-up dwell times
- Color-coded buses and stops make it easy to identify Metro Rapid stops and buses
- Enhanced stations that provide information, lighting, canopies and "Next Bus" displays
- Headway-based schedules rather than time-point-based schedules

Figure 2.3 Los Angeles Metro Rapid Bus and Station

2.6.3.1.2 AC Transit San Pablo Rapid

AC Transit's San Pablo Rapid line serves a 16-mile route between Contra Costa College in San Pablo and Jack London Square in downtown Oakland. The rapid line service includes the implementation of several BRT attributes, including:

- TSP that utilizes the Opticom detection system;
- Limited number of stops that are approximately 2/3-mile apart to reduce overall travel time;
- New low floor, multiple door buses to expedite boarding and alighting;
- Rapid Bus logo and branding on all buses and shelters, to maximize visibility of this service;
- Bus Arrival information at all Rapid Bus stops to inform passengers of expected bus arrival time.

Figure 2.4 San Pablo Rapid Logo

2.6.3.1.3 Santa Clara VTA's Rapid Line 522

VTA's Rapid 522 serves a 26-mile corridor between Eastridge in San Jose and the Palo Alto Transit Center. It replaces Limited Stop Line 300 and supplements Line 22. The line currently operates in mixed traffic lanes, with exclusive bus lane in consideration for future enhancement. In its current implementation, it has the following features:

- TSP: The TSP system along El Camino Real was developed and installed by the California Department of Transportation (Caltrans) in collaboration with VTA.
- Bus stops are spaced approximately one-half to one-mile apart;
- Headway-Based Schedules that will allow Rapid 522 buses to travel as fast as traffic and signals allow;
- Queue-Jump Lanes that allow buses to bypass traffic at congested intersections, by making use of an exclusive right-turn lane and a "receiving" lane across the intersection. Initial queue-jump lanes are located at the Page Mill Road and Arastradero intersections in Palo Alto.
- All Low-Floor Buses for quick and easy passenger boarding and exiting.

Figure 2.5 VTA 522 Rapid Bus

2.6.3.2 Traffic Impact

With the bus operating in a mixed traffic lane with other vehicles, the interaction with other vehicles are the greatest and it limits the improvement of transit service. Transit agencies often will seek the opportunity to construct a dedicated bus lane. For instance, LACMTA currently has a project that studies the feasibility of improved bus service along the Wilshire Boulevard corridor. A number of general improvements are considered, one of them is the conversion of existing curb lanes to peak period bus lanes in each direction. And as mentioned previously, VTA is also considering exclusive bus lanes for future improvement.

CHAPTER 3
ASSESSMENT TOOLS FOR ESTIMATING BRT IMPACT

There have been many implementations of Bus rapid transit (BRT) projects nationwide and there are different levels of impacts on ridership and traffic conditions on the road, depending on various factors, such as the implementation strategies of the BRT system, as well as the characteristics of the corridor where it is implemented. There is not, however, a toolbox that would estimate the impacts of a planned BRT system, given some sketch planning level information regarding the system and its surrounding environment.

This project aimed at generating a process and toolbox that would assist agencies in their sketch planning level decision-making process. More specifically, the process and toolbox will be used for evaluation of the following three aspects – the change in ridership due to the implementation of a BRT system, the amount of ridership increase that are coming from previous auto drivers, and the potential congestion level changes in terms of LOS degradation on adjacent mixed-flow traffic lanes. The first two aspects are studied with ridership models and parameters gathered through the literature research. The third aspect is studied with Synchro, a macroscopic traffic simulation and signal timing software.

In this chapter, we summarize our findings during the process and toolbox building effort, which consists of two major components: a ridership estimation model and a traffic impact analysis model.

There are mainly three different approaches to estimate ridership: travel demand modeling based approach, direct modeling that links ridership directly with the characteristics of the transit service provided, and the elasticity method that use current ridership as the basis and estimates future change based on the change of service features. Both the travel demand based approach and direct modeling approach need significant efforts for data collection in order to give accurate results. In the contrast, the elasticity method does not require detailed data and can give a quick estimation. Therefore, at the sketch planning level, the elasticity method becomes a reasonable choice.

After mixed traffic lanes are replaced to build dedicated BRT lanes, a number of drivers will shift to the BRT bus. However, the traffic capacity is also due to the removal of mixed-traffic lanes. Therefore, a traffic impact model has to be developed to investigate the trade-off between the reduction of demands and reduction of capacity. There are two major approaches to studying traffic impacts: microscopic simulation and macroscopic simulation. In order to build a microscopic simulation model, data collection needs to be done at a low level of detail (e.g., the length of left turn pockets, the lane width, etc), which is time-consuming. Therefore, the microscopic simulation model may not be suitable for the planning stage. On the other hand, a macroscopic traffic model is easier to build since only high-level road geometry and traffic demand information is needed. Hence, we decided to use a macroscopic model to build our toolbox. Due to its wide use, SYNCHRO was selected to develop our macroscopic traffic tool.

3.1 Ridership Impact

The cumulative effects of implementing BRT can lead to changes in travel behavior, improved operating efficiency of buses, and improved general corridor efficiency. Combined, these contribute to higher ridership by shifting trips to public transit and non-motorized modes. This is considered a “Secondary” or “Co-benefit” of BRT, since the principal benefits of the BRT investment are the impacts on bus service. The secondary, or co-benefit, result from the changes which happen due to the improvements in bus service.

BRT will result in changes in ridership, which may be measured in the following ways:

1. Ridership on new BRT routes
2. Total ridership after BRT implementation
3. Change in ridership in the corridor
4. Use by travelers with access to other modes (“choice riders”)

3.1.1 Ridership Estimation Methods

There are three different approaches that are often used to estimate the ridership change with BRT implementation, which are described in the following subsections.

3.1.1.1 Travel Demand Models

Using the traditional four-step demand estimation process (trip generation, trip distribution, mode split, traffic assignment) when major investments are anticipated, e.g., when BRT will operate on a new right-of-way. Household travel surveys are customarily needed to provide the basic information for modeling and analyzing. The modeling process is appropriate on a system (or corridor) scale especially for long time horizons where future growth is anticipated. Providing realistic estimates of current and future employment is essential (Kittelson & Associates, Inc. et al, 2007).

This approach requires very extensive data collection and model calibration and forecasting efforts. It is especially necessary when the proposed BRT serves a corridor that doesn't have current transit service and thus the ridership of the proposed line needs to be estimated based on the social economic characteristics of the surrounding area.

3.1.1.2 Elasticity Methods

Ridership elasticity is defined as the change in ridership corresponding to a 1% change in fare, travel time, or service frequency. Application of elasticities is generally appropriate where BRT service is overlaid on existing bus routes and there are relatively small-scale invest
ments.

Based on the formulation used for computation, there are three ways of applying elasticities: shrinkage factor, midpoint arc elasticity, log arc elasticity (Kittelson & Associates, Inc. et al, 2007). The equations that are used for those applications are as follows:

Shrinkage factor:

$$R_2 = R_1\left(1 + \frac{E(X_2 - X_1)}{X_1}\right) \quad (3\text{-}1)$$

Midpoint arc elasticity:

$$R_2 = R_1\left(\frac{(E-1)X_1 - (E+1)X_2}{(E-1)X_2 - (E+1)X_1}\right) \quad (3\text{-}2)$$

Log arc elasticity

$$R_2 = e^{E(\ln X_2 - \ln X_1) + \ln R_1} \quad (3\text{-}3)$$

where E is the elasticity for the attribute

R_1 is the base ridership

R_2 is the estimation for future ridership

X_1 is the base value of the attribute (for instance, travel time, fare, or service frequency)

X_2 is the future value of the attribute

The shrinkage factor method is the simplest to use, but gives a reasonable approximation only for small changes; the midpoint arc and log arc methods provide similar results while the midpoint arc is commonly used since it is easier to calculate than the log arc method.

3.1.1.3 Direct Ridership Modeling

Direct models estimate ridership as a function of station environments and transit service features rather than using mode-choice results from large-scale models. This method has emerged as an alternative to the traditional four-step travel-demand modeling of corridor and station-level analyses (Cervero, R., J. Murakami, and M.A. Miller, 2010).

3.1.2 Discussion

A comparison of the modeling approaches discussed in Section 3.1.2 is presented in Table 3.1. As shown in the table, the four-step based demand modeling approach can provide a comprehensive evaluation of the corridor traffic condition. It produces both ridership estimates for the new (or improved) transit service, as well as a forecast for the traffic condition with the proposed project. The drawback is the amount of effort for data collection, model building, model calibration, and model application that is associated with the approach – detailed data are needed as input to the process, which include the social-economic characteristics of the planning area, inventory of the traffic and transit networks, and current transit and traffic conditions, etc. Typically, at an early planning stage (or sketch planning stage), no such data is available, and no such effort would be warranted, thus, this approach is typically used only at a later stage in the process, when a particular project is being seriously considered and a feasibility study needs to be carried out.

The direct modeling approach avoids going through all four steps of the transportation planning models, and targets "directly" at estimating station-based ridership as a function of the service features of the station. It avoids a major portion of the data collection and model calibration work associated with the four-step process, but still requires data to support the regression of the ridership forecast model as a function of different combinations of various station features. The direct model only forecasts ridership, and traffic impact needs to be studied separately.

On the other end of the ridership model spectrum is the elasticity method. This approach uses current ridership on an existing transit line as the base, and estimates the change in ridership as a function of change in service characteristics (such as travel time, service frequency, fare, etc). The parameters that are associated with the service characteristics are suggested based on national experiences and thus doesn't require further calibration. The drawback is that first it requires that transit service currently exists along the corridor under consideration for BRT so that there is a base ridership figure; and second, this method typically provides only a rough ridership estimate since the parameters are not calibrated specifically for the region and thus do not reflect its characteristics.

For the purpose of this project, since we are considering a tool at the sketch planning level, and the case study site is the Van Ness Avenue corridor, the elasticity method becomes a reasonable choice. The following lists the detailed reasons for the selection:

1. At sketch planning stage, detailed data usually are not available, and efforts to collect such data, and then to build and calibrate corresponding models are typically not supported. This makes the four-step model, and to some extent, the direct model, not a suitable choice;

2. For direct modeling approach, ridership data, as well as station characteristics data, are needed from transit lines that are in a similar environment as where the BRT project will be implemented. This is to ensure that the population surrounding the transit lines would exhibit a similar behavior when it comes to utilize transit service for their trips and that the models calibrated from the collected data could be reliably transferred to the project under consideration;

3. Since the case study project for the Van Ness Avenue corridor BRT system is an improvement of transit service for two existing bus lines, the elasticity method would provide a reasonably good ridership estimate;

4. The elasticity method is an appropriate choice for implementation in a web-based toolbox. The flowchart of the implementation is shown in Figure 3.1.

Table 3.1 Comparison of Ridership Forecasting Models

Model	Four-step Based Demand Modeling	Direct Ridership Model	Elasticity Model
How it works	Follow the four-step modeling process to estimate: 1. the amount of trips generated based on socio-economic characteristics of the modeling zones; 2. how the trips will distribute to determine the OD matrices ; 3. how the trips between each OD choose mode of travel 4. how the demand for each mode choose the path/transit service.	1. Uses the ridership data from similar transit lines (similar service, similar surrounding area), transit service characteristics, transit station characteristics, as well as socio-economic characteristics of the surrounding area to "directly" estimate/calibrate ridership as a function of the above mentioned variables, then 2. use the estimated model to forecast the ridership on the new transit service that's being proposed.	The elasticity refers to the ridership change in response to the change in transit service characteristics, such as travel time, service frequency, etc. The TCRP Report 118 provides examples of the elasticity model.
Input	Socio-economic characteristics for each analysis zone in the area; The complete road and transit network and their characteristics; A fully calibrated planning model system;	Ridership data from similar transit lines (similar service, similar surrounding area), transit service characteristics, transit station characteristics, as well as socio-economic characteristics of the surrounding area	Changes in transit service characteristics, such as headway, travel time, etc.
Output	For transit: ridership For auto: link volumes	Transit ridership	Transit ridership
Note	This modeling approach is a comprehensive way to capture the ridership changes. It can also reflect the traffic condition change in response to the changes in transit service (such as route diversion when there are parallel streets, auto traffic LOS, etc). It requires the existence of a well calibrated regional planning model so that the impact of changes in transit service could be forecasted reliably.	The calibration stage requires extensive data collection effort. It does not forecast the impact on traffic (i.e., the diversion of traffic, or the impact on traffic conditions).	Data requirement is minimum -- the elasticity factors are given based on previous experience, thus no calibration is needed for the site. For instance, elasticity factor of -0.4 is given for travel time change. Same as the direct model, it does not forecast impact on traffic. As suggested by TCRP #118, application of the elasticity model is appropriate when there is relatively small-scale investment and the suggested BRT service is overlaid on existing bus routes.

Figure 3.1 Ridership Forecast Using Elasticity Method

3.2 Traffic impacts assessment

After one or more mixed traffic lanes are replaced to build dedicated BRT lanes, some private car drivers will shift to the BRT bus. The ridership analysis provides a model that can estimate the amount of drivers who change mode. At the same time, the traffic capacity is also decreased after the replacement of mixed-traffic lanes. Therefore, a traffic tool is needed to estimate the trade-off between the reduction of traffic demand and reduction of traffic capacity. We build a macroscopic traffic analysis tool to evaluate the impact of converting a highway lane for exclusive bus usage. "Before" and "After" models were built. The former evaluated the current situation and the latter represented the scenario where a highway lane is converted to a bus lane. The major MOEs – ***the travel time and total delays***, were obtained for both models.

Microscopic simulation (such as VISSIM) requires a lot of data preparation and modeling efforts. At the sketch planning stage (which is what the toolbox design is for), such a detailed and elaborate study could be too much work for the agency. On the other hand, a macroscopic traffic model is easier to build and requires fewer data inputs. Due to its wide use, SYNCHRO was selected to develop our macroscopic traffic tool. SYNCHRO is a tool that can optimize the signal timing and offset. In addition, SYNCHRO can be used to evaluate corridor performance under existing signal timing plans. It is a widely used software package, and would be readily available at most agencies.

We used SYNCHRO to build our macroscopic traffic tool for the Van Ness Avenue corridor. Before-Models and After-Models were built to consider different traffic and road scenarios. Note that this tool can be easily adopted for other sites if the road geometry and traffic demand are known.

3.2.1 Use Synchro to Conduct the Macroscopic Analysis for Interrupted Traffic Flows

Microscopic models predict the following behavior of cars (their change in speed and position) as a function of the behavior of the leading vehicle. Moreover, if the inputs into the microscopic simulation are not of good quality, then the result would be GIGO (garbage in garbage out). On the contrary, macroscopic traffic flow theory relates traffic flow, running speed, and density. Macroscopic properties like flow and density are the product of individual (microscopic) decisions.

Synchro is a software package for modeling and optimizing traffic signal timings. Synchro implements the Intersection Capacity Utilization (ICU) 2003 method for determining intersection capacity. This method compares the current volume to the intersections ultimate capacity. Synchro includes a term for queue interaction blocking delay. A new Total Delay will include the traditional control delay plus the new blocking delay. Delay calculations are an integral part of the optimization objective in Synchro so this will be directly considered. In addition to calculating capacity, Synchro can also optimize cycle lengths and splits, eliminating the need to try multiple timing plans in search of the optimum. Synchro optimizes the split, cycle length, and offsets. Synchro optimizes to reduce delays and stops.

In order to implement the macroscopic traffic model in Synchro, following inputs are needed to build the network model, including the network's geometry (locations of intersections, distances between intersections, the number of lanes), the saturation flows, the link travel speed, the constant and known turning rates for each intersection, and the constant and known demands. The traffic model consists of nodes (intersections) and links (connecting streets).

3.2.2 Use Synchro to Analyze the Impacts of Mixed-Traffic Lane Replacements

The following steps can be followed to use the Synchro-based tool to analyze the impacts of the mixed-traffic lane replacements.

Step 1 is to collect the related data, including the network's geometry, saturation flows, the link travel speed, the constant and known demands at each intersection, etc. The existing timing data of each intersection is also needed. Note that the existing timing data should be consistent with the traffic demands collected.

Step 2 is to build the Synchro model to analyze the traffic impacts before mixed-traffic lanes are replaced. Step 2 is for the Before-Model. Based on the traffic demand and existing timing data, a Synchro model was built. Then, the related MOEs (e.g., the travel time and delays) were provided as output.

Step 3 is to build the Synchro model to analyze the traffic impacts after mixed-traffic lanes are replaced. The ridership analysis provides the reduction of traffic demands due to the mode shift. Step 3 is for the After-Model. Then, mixed-traffic lanes are removed from the Synchro model in Step 2, and the traffic demand revised at each intersection. Then, Synchro is used to optimize the signal timing and offset based on current traffic and network conditions. Then, the related MOEs (e.g., the travel time and delays) are provided as output. Note that Step 3 can be repeated if there are more scenarios of demand reductions and lane replacements.

Step 4 is to compare the MOEs of Before-Models and After-Models. The travel times and delays are examined for different models.

Finally, it is worth to mention that such steps are general to any site. The only thing specific is Step 1, where traffic data and existing signal timing data need to be collected.

CHAPTER 4

SAN FRANCISCO VAN NESS BLVD BRT SYSTEM: A CASE STUDY

The Van Ness Avenue corridor is two miles long extending from Mission Street in the south to Lombard in the north. From east to west, the study area includes the one-way pairs of streets: Larkin and Hyde. Polk is the local commercial street and the high-capacity one-way arterials of Franklin and Gough are to the west. Even though Franklin and Gough also carry large north/south traffic volumes, Van Ness Avenue is the most direct regional route through this portion of San Francisco and is designated to serve this role. The Van Ness corridor study area is shown below in Figure 4.1

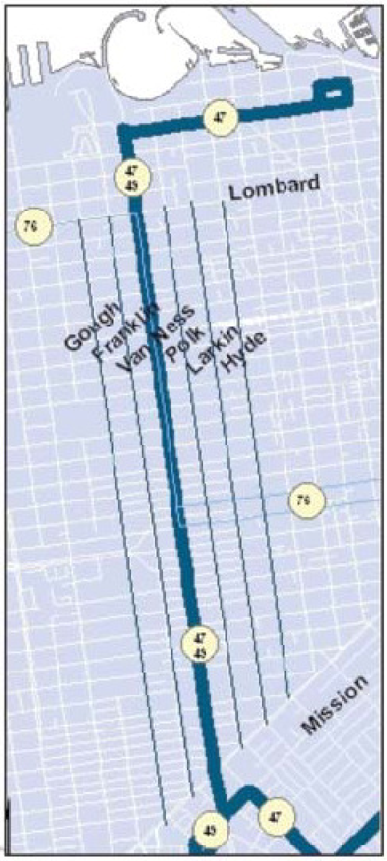

Figure 4.1: Van Ness Avenue Study Area (Source: Van Ness Avenue BRT Feasibility Study)

In order to maintain and enhance major bus service improvements along the Van Ness Avenue corridor – possibly using dedicated bus lanes and other BRT features – the San Francisco Municipal Transportation Authority in partnership with the Municipal Transportation Agency conducted a Feasibility Study in 2006 to examine alternative bus rapid transit treatments along Van Ness through technical analysis and community outreach. The Feasibility Study was officially adopted in December 2006 and is available online at the web site http://www.sfcta.org/content/view/425/252. Currently the project schedule consists of the following major milestones as shown in Table 4.1

Table 4.1 Van Ness BRT Project Schedule

DATE	MILESTONE
December 2006	Van Ness BRT Feasibility Study Approved
Sep-Oct 2007	Environmental Impact Report/Study Scoping Period
2008 – 2011	Draft Environmental Studies and Conceptual Engineering
2011 – 2012	Final Environmental Studies and Preliminary Engineering
2012 – 2013	Final Design and PS&E
2013 – 2015	Construction
2015	Revenue Service

4.1 Ridership Analysis

Different ridership analysis methods, along with their advantages and disadvantages, are discussed in Chapter 3. And due to the purpose of this project, the research team decided to use the elasticity model for ridership estimation (this is also discussed in Chapter 3).

As discussed in Section 4.1, Van Ness Avenue is used as a case study site. The ridership impact will be studied under various testing scenarios (as shown in Table 4.2) with different ITS technologies being implemented. The impacts of these technologies (typically on transit travel time) are summarized from the literature review and are discussed in Section 4.1.2 to facilitate the analysis of ridership estimate.

Table 4.2 Scenarios for Ridership Estimation

Scenario	Description
1	Conversion of two curb lanes into exclusive bus lanes with other service upgrades.
2	Implementation of a single bus lane in the middle, thus, only one traffic lane needs to be taken out instead of two traffic lanes.
3	Scenario 1 with transit signal priority (TSP) implemented along the corridor.
4	Scenario 3, adding precision docking technology to save travel time.

4.1.1 Data Items Needed for the Estimation

To apply the midpoint arc method, we need two categories of input data. First is the base ridership number, based on which the future ridership will be determined; and second are the types of improvements to be made to the current service.

4.1.1.1 Current Ridership

Two major bus lines, line 47 and line 49, operate along Van Ness Avenue. Based on the Van Ness corridor Feasibility Study Report, the 2010 ridership forecast for PM peak hours are shown in the following table.

Table 4.3 Van Ness Avenue Line 47 and Line 49 Ridership (passenger/trip)

Bus Line	EB/NB	WB/SB
47	54	30
49	45	24

4.1.1.2 Optional BRT features

For Scenario 1 in Table 4.2, based on the Van Ness corridor Feasibility Study Report, transit travel time improves from 19 minutes to 14 minutes for the study corridor, and there will be no change in service frequency (7~8 minutes headway).

For Scenario 2, single lane BRT needs to maintain a headway that is over 12 minutes to be a feasible choice (since that headway means the single lane BRT does not incur significantly increased travel time as compared with double lane implementation).

Assume that transit headway is 12 minutes. Under this headway, the travel time with single lane BRT would be approximately 10% higher than double lane BRT, and thus the travel time with single lane BRT is set at 15 minutes for the calculation.

For Scenario 3, based on the literature, travel time savings of anywhere between 5% and 20% have been reported for transit signal priority (TSP) implementation. The average figure, 12%, is used to approximate the travel time at 12.3 minutes.

For Scenario 4, implementation of precision docking usually makes the boarding process go more smoothly. A 5% saving in transit time saving was reported, and this brings the travel time down to 11.7 minutes.

The following table (Table 4.4) is a summary of the service characteristics for the four scenarios.

Table 4.4 Service Characteristics for the Testing Scenarios

Scenario	Transit Travel Time	Transit Service Headway
1	14 minutes	7~8 minutes
2	15 minutes	12 minutes
3	12.3 minutes	7~8 minutes
4	11.7 minutes	7~8 minutes

4.1.1.3 Other Improvements

As discussed in Chapter 3, the implementation of a BRT system attracts 15% ~ 25% more riders than that obtained from the elasticity method calculation and various components of the BRT system all contribute to the extra ridership increase. In Scenario 1, the transit line will have an exclusive running way, plus stations and vehicles will be improved. Other scenarios will have additional improvement(s) as explained in Table 4.2.

4.1.2 Ridership Calculation

Ridership calculation for Scenario 1 is shown in detailed steps in the first part of this section for illustration purposes. The results for Scenario 1, along with those for other scenarios, are summarized in Table 4.9.

4.1.2.1 Ridership estimation for Scenario 1

First, applying the travel time elasticity of -0.4 in the midpoint arc method, the ridership estimates can be calculated as following:

For Line 47, EB/NB

$$\text{Future ridership}=\frac{(-0.4-1)*19*54-(-0.4+1)*14*54}{(-0.4-1)*14-(-0.4+1)*19}=61$$

For Line 47, WB/SB

$$\text{Future ridership}=\frac{(-0.4-1)*19*30-(-0.4+1)*14*30}{(-0.4-1)*14-(-0.4+1)*19}=34$$

For Line 49, EB/NB

$$\text{Future ridership}=\frac{(-0.4-1)*19*45-(-0.4+1)*14*45}{(-0.4-1)*14-(-0.4+1)*19}=51$$

For Line 49, WB/SB

$$\text{Future ridership}=\frac{(-0.4-1)*19*24-(-0.4+1)*14*24}{(-0.4-1)*14-(-0.4+1)*19}=27$$

In summary, the future ridership is shown in Table 4.5.

Table 4.5 Van Ness Blvd Line 47 and Line 49 Ridership Due to Improved Travel Time (passengers/trip)

Bus Line	EB/NB	WB/SB
47	61	34
49	51	27

We then examine the amount of ridership change due to BRT system implementation. The following table shows the components in the Van Ness BRT system and their contribution to ridership increases.

Table 4.6 Contribution from BRT System Components to Additional Ridership Increase

Components	Max	Van Ness Site
Running ways	20%	20%
Stations	15%	15%
Vehicles	15%	15%
Service patterns	15%	0%
ITS applications	10%	0%
Branding	10%	0%
BRT component synergy (when the above is 60 or more)	15%	0%
Total	100%	50%

Assuming that an additional 20% ridership increase will be realized with implementation of all the components listed in Table 4.5, then for the Van Ness Avenue site, 50% of that additional 20% is 10%. The final ridership numbers are shown in Table 4.7.

Table 4.7 Van Ness Blvd Line 47 and Line 49 Ridership Estimate (passengers/trip)

Bus Line	EB/NB	WB/SB
47	66	37
49	55	29

Table 4.8 shows the ridership results reported in the SFMTA Feasibility Study Report. As can be observed, the ridership figures are very close, with the elasticity methods reporting an approximately 7~11% higher estimate.

Table 4.8 Van Ness Blvd Line 47 and Line 49 Ridership Estimate in the SFMTA Report (passenger/trip)

Bus Line	EB/NB	WB/SB
47	61	33
49	51	27

Headways for Line 47 and Line 49 are 7 minutes and 8 minutes, respectively. Based on the ridership reported in Tables 4.4 and Table 4.7, the total hourly ridership change during PM peak in the two directions of travel is:

For EB/NB:

(66-54)*(60/7)+(55-45)*(60/8)=178 passenger/hour

For WB/SB:

(37-30)*(60/7)+(29-24)*(60/8)=98 passenger/hour

These changes in ridership will be used in traffic analysis to estimate the number of drivers that switched to transit.

4.1.2.2 Ridership estimation for all scenarios

Similar calculations are carried out for all the scenarios based on the impacts of various technologies on transit travel time (as shown in Table 4.2). Table 4.9 summarizes the forecasts of hourly ridership change for PM peak period.

Table 4.9 Hourly Ridership Change Forecasts (passengers/hour)

Scenario	EB/NB	WB/SB
1	178	98
2	7	4
3	269	147
4	288	157

4.2 Application of the Macroscopic Traffic Analysis Tool in SF BRT

In this subsection, we will describe the data collection and model building, and then provide the analysis of results for the Van Ness Avenue corridor site.

4.2.1 Data Collection and Model Building in Synchro

We considered 13 signalized intersections along Van Ness Avenue from Post St. to Mission St. These intersections are as follows from North to South: Post St, Geary Blvd, O'Farrel St, Ellis St, Eddy St, Turk St, Golden Gate Ave, McAllister St, Grove St, Hayes St, Fell St, Market St, and Mission St. The Van Ness arterial and side streets are modeled and the distance between two successive intersections is obtained using Google Map. The number of lanes is obtained using Google Street View. A screen snapshot can be seen in Figure 4.2.

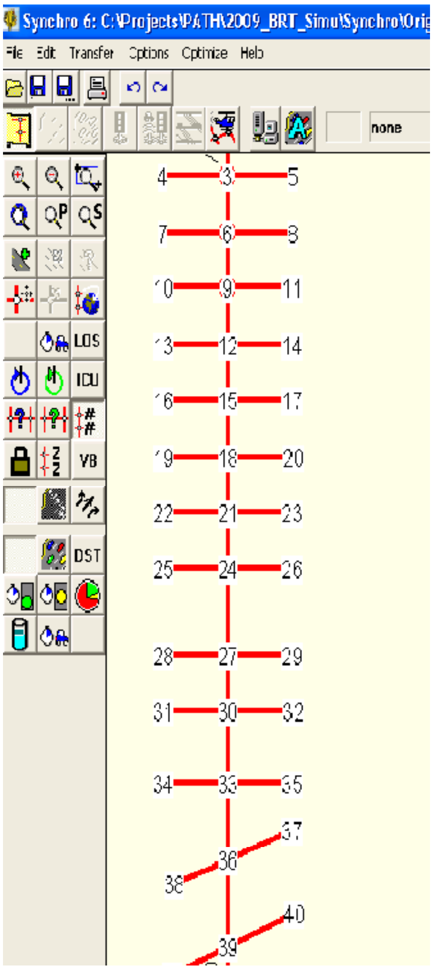

Figure 4.2: A Screen Capture of the Network Model in Synchro

Traffic demand is obtained from the SF MTA Feasibility Study Report. Demand for most signalized intersections were surveyed in 2005 except the following intersections: Demand for Turk St were in 1994; and demand for Post St were in 2002. There was no demand for Eddy St. We assume that the demand on Van Ness Avenue at Turk St are the same as the demand at nearby Ellis St.

The auto traffic demand reduction due to BRT implementation is determined by the percentage of new riders that were previously auto drivers. The percentage used in the SFMTA Feasibility Study Report is 60%. The range reported in the literature is generally between 30% and 85%. Thus, for the purpose of this case study, we report results using

30%, 60%, and 85%. Based on Table 4.9, these percentages represent the auto demand reduction shown in Table 4.10.

Table 4.10 Hourly Auto Demand Reduction (vehicles/hour)

Scenario	30% conversion		60% conversion		85% conversion	
	EB/NB	WB/SB	EB/NB	WB/SB	EB/NB	WB/SB
1	53	29	107	59	151	83
2	2	1	4	2	6	3
3	81	44	162	88	229	125
4	86	47	173	94	245	134

We obtained traffic signal timing tables from District 4 for all 13 signalized intersections. Timing tables include phase sequences, phase length, yellow time, all red time, etc. Offset data is also obtained for the signal coordination. We have to note that the timing table was made in different years. For a large number of intersections, timing was made in 2007. However, timing was made in 2003 to 2006 for some intersections. Therefore, the traffic demand and timing tables may not perfectly match each other.

4.2.2 Results for Before-Model and After-Model

The Before-Model considers the instance before a mixed-traffic lane is converted into a dedicated BRT lane. On Van Ness Avenue, there are three mixed-traffic lanes. As mentioned in section 4.3.1, the timing tab les we collected are not perfectly the demand data we collected. Therefore, we examine two instances for the Before-Model. In both instances, the demand data is from the SF MTA Feasibility Study Report. The timing data is different in two instances: the timing data collected from District 4 is used in the first instance, while in the second instance, the Synchro tool was used to generate the optimal timing.

As mentioned in section 4.2, we considered different scenarios, including replacing double mixed-traffic lanes, replacing a single mixed-traffic lane, applying Transit Signal Priority, precision docking, etc. For each scenario, different demand reductions can be achieved using the ridership analysis model. The detailed analysis of the demand reduction can be seen in section 4.2. The following table presents a summary for the scenarios we studied in this project.

Table 4.11 Scenario Settings and Descriptions for Traffic Impact Analysis

Model Name	Description
B-orig	Before-model with 3 lanes, original demands, and timing tables from District 4.
B-synchro	Before-model with 3 lanes, original demands, and timing tables determined by Synchro
A-DL-case1	After-model with 2 lanes, reduced demands, and timing determined by Synchro. The demand reductions are: 53 for NB and 29 for NB.
A-DL-case2	After-model with 2 lanes, reduced demands, and timing determined by Synchro. The demand reductions are: 107 for NB and 59 for NB.
A-DL-case3	After-model with 2 lanes, reduced demands, and timing determined by Synchro. The demand reductions are: 151 for NB and 83 for NB.
A-DL-TSP-case1	After-model with 2 lanes, reduced demands, and timing determined by Synchro. TSP is applied for both bounds. The demand reductions are: 81 for NB and 44 for NB.
A-DL-TSP-case2	After-model with 2 lanes, reduced demands, and timing determined by Synchro. TSP is applied for both bounds. The demand reductions are: 162 for NB and 88 for NB.
A-DL-TSP-case3	After-model with 2 lanes, reduced demands, and timing determined by Synchro. TSP is applied for both bounds. The demand reductions are: 229 for NB and 125 for NB.
A-DL-TSP-PD-case1	After-model with 2 lanes, reduced demands, and timing determined by Synchro. TSP and precision docking are applied for both bounds. The demand reductions are: 86 for NB and 47 for NB.
A-DL-TSP-PD-case2	After-model with 2 lanes, reduced demands, and timing determined by Synchro. TSP and precision docking are applied for both bounds. The demand reductions are: 173 for NB and 94 for NB.
A-DL-TSP-PD-case3	After-model with 2 lanes, reduced demands, and timing determined by Synchro. TSP and precision docking are applied for both bounds. The demand reductions are: 245 for NB and 134 for NB.
A-SL-NB	After-model with one lane on the northbound is replaced. BRT buses in two ways shares the same lane. The demand reductions are: 6 for NB and 3 for NB.
A-SL-SB	After-model with one lane on the southbound is replaced. BRT buses in two ways shares the same lane. The demand reductions are: 6 for NB and 3 for NB.

The speed limit is set at 30 mph for all these instances while the travel time, total signal delay along Van Ness Avenue, and LOS changes are used as MOEs. Table 4.12 presents the travel times and total delays for Before-models with 3 lanes and After-model with two lanes. Column 1 presents the model names; column 2, column 3, and column 4 provide the travel times, total delays, and LOS changes for Northbound Van Ness Avenue respectively; and column 5, column 6, and column 7 provide the travel times, total delays, and LOS for Southbound Van Ness Avenue respectively. The LOS of model B-synchro is used as the basis for the comparison.

Table 4.12: Traffic Impact Results Analysis

	North bound			**South bound**		
	Travel time (sec)	Total delay (sec)	LOS	Travel time (sec)	Total delay (sec)	LOS
B-orig	409.5	206.9	N/A	453.1	253.1	N/A
B-synchro	**352.9**	**150.3**	**N/A**	**403.9**	**203.9**	**N/A**
A-DL-case1	450.3	247.7	Decreased	392.7	192.7	Same
A-DL-case2	441.3	238.7	Decreased	383.3	183.0	Increased
A-DL-case3	437.7	234.9	Decreased	354.1	154.1	Increased
A-DL-TSP-case1	429.5	226.9	Decreased	434.3	234.3	Same
A-DL-TSP-case2	403.8	201.2	Decreased	415.6	215.6	Same
A-DL-TSP-case3	392.0	189.4	Same	397.4	197.4	Same
A-DL-TSP-PD-case1	412.6	210.0	Decreased	428.1	228.1	Same
A-DL-TSP-PD-case2	399.6	197.0	Decreased	411.3	211.3	Same
A-DL-TSP-PD-case3	386.8	184.2	Same	381.6	181.6	Increased
A-SL-NB	549.5	346.9	Decreased	339.6	139.6	Increased
A-SL-SB	338.8	136.2	Same	507.1	307.1	Decreased

First, we observe that timing tables do not fit the demand data we obtained. The new timing generated by Synchro is much better than the timing we collected. For example, the travel time in Northbound is 409.5 seconds if the timing we collected is used, while the travel time is 352.9 seconds if the timing determined by Synchro is used (see rows 3 and 4). Therefore, we will use the timing determined by Synchro as the basis to compare with after-models.

Second, we observe that after two mixed-traffic lanes are replaced by dedicated BRT lanes, the changes of travel times in Northbound and Southbound are not symmetric. For example, the travel time is 352.9 for Northbound and Southbound Van Ness Avenue before mixed-traffic lanes are replaced (see row 4). After two lanes are replaced, the travel times with models A-DL-case1, A-DL-case2, and A-DL-case3 are 450.3, 441.3, and 437.7 for the Northbound respectively. The travel times are increased for each after-model. For the Southbound, the travel time is 403.9 seconds before traffic lanes are replaced. After two lanes are replaced, the travel times with models A-DL-case1, A-DL-case2, and A-DL-case3 are 392.7, 383.3, and 354.1 for the Southbound respectively (see row 4). The travel times are decreased for the after-models. The results on the delay time are similar to the travel times.

Third, ITS techniques are very helpful to improve performance. For example, after TSP is applied, both the travel time and delay time are decreased compared with the corresponding model without using TSP (see rows 8, 9, and 10). After precision docking is further applied, the performance continued to improve (see rows 11, 12, and 13).

Fourth, if only one traffic lane is replaced for the dedicated BRT lane, the system performance is worse than the one with two lanes replaced (see rows 14 and 15). This is expected since little demand is shifted to the BRT lane with only one lane replaced. The use of ITS techniques with the single lane BRT system may increase the performance to some extent.

Fifth, the LOS of after-models is decreased if some demand is shifted. When more demand is shifted, the LOS of both directions may be unchanged, for example model A-DL-TSP-case3 (see row 10). Moreover, it is possible for LOS for one direction to improve if large amount of demand are shifted, for example, model A-DL-TSP-PD-case3 (where both TSP and precision docking are used).

Sixth, our studies show that the performance degradation is within an acceptable range for many after-models, especially ones with ITS techniques. Figures 4.3 to 4.6. show the percentage of the travel time and delays using the before-model (B-Synchro) as a comparative basis.

Finally, we will comment on our findings and the results presented in SFMTA's Feasibility Study Report. In the Feasibility Study Report of SF MTA, the travel time of Before-model is 11.2 minutes, while the travel time of After-model is 11.5 minutes for center-side BRT (see table 4-15 in their report). The travel time of after-model is 103% of the travel time of before-model. In our study based on Synchro, the travel times of the before-model (B-Synchro) are 352.9 and 403.9 seconds for Northbound and Southbound respectively. For the after-model (A-DL-case3), the travel times in the Northbound and Southbound directions are 437.3 and 354.1 respectively. On average, the travel time of the after-model A-DL-case3 is 106% of the travel time of the before-model. For A-DL-case1 and A-DL-case2, the corresponding percentages are 112% and 110%. Such percentages are consistent with ones by the Feasibility Study Report of SFMTA. It is worth mentioning that it is meaningless to directly compare the travel times by VISSIM and Synchro, since the VISSIM is a microscopic model, while the Synchro is a macroscopic model.

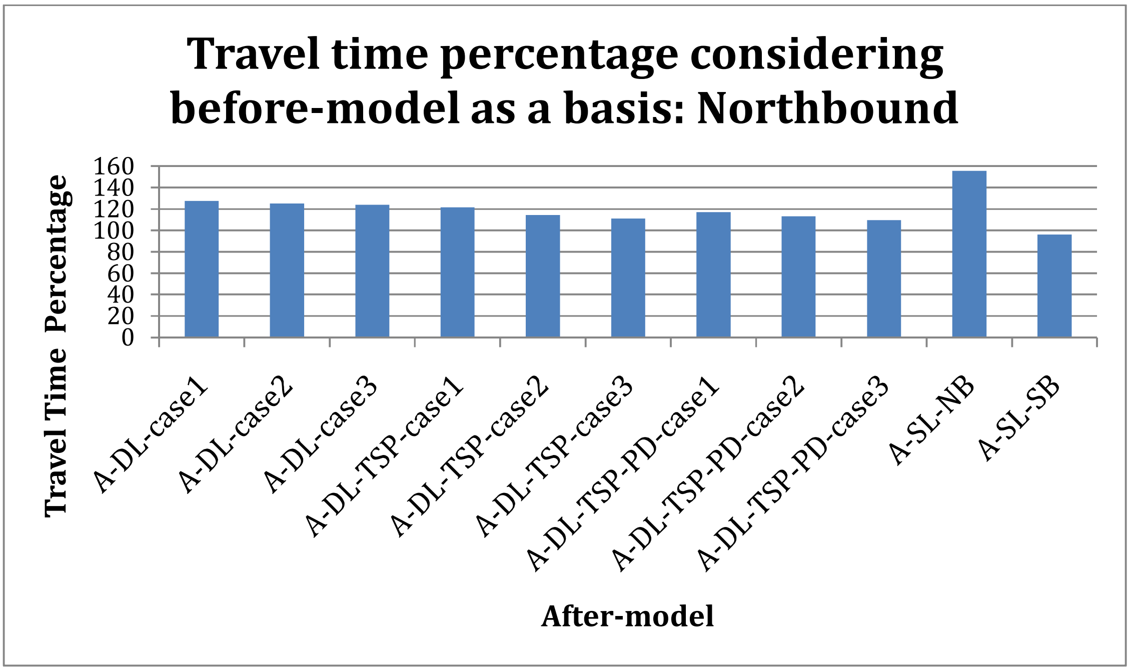

Figure 4.3: Travel Time Percentage Considering B-Synchro as a Basis: Northbound

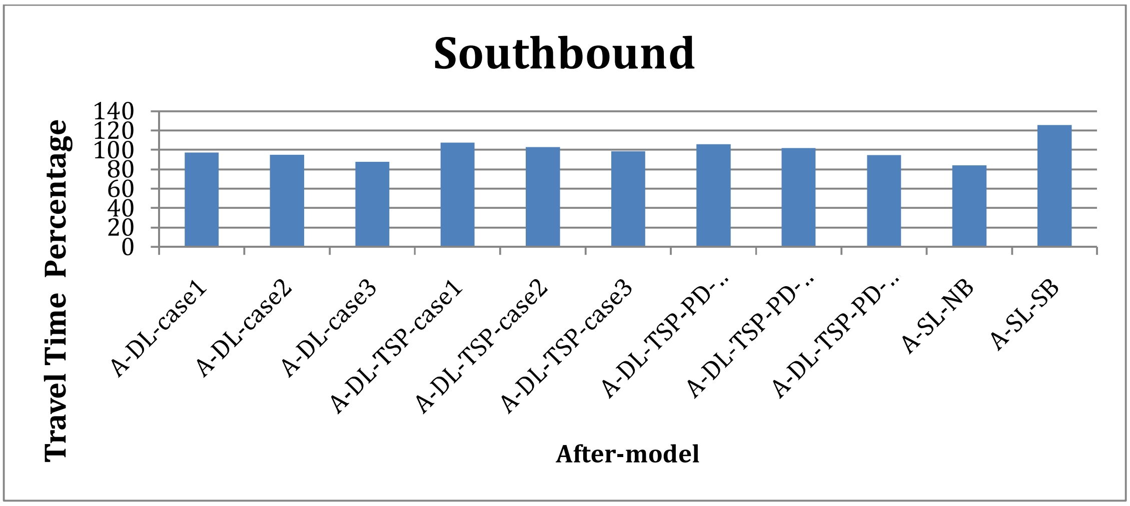

Figure 4.4: Travel Time Percentage Considering B-Synchro as a Basis: Southbound

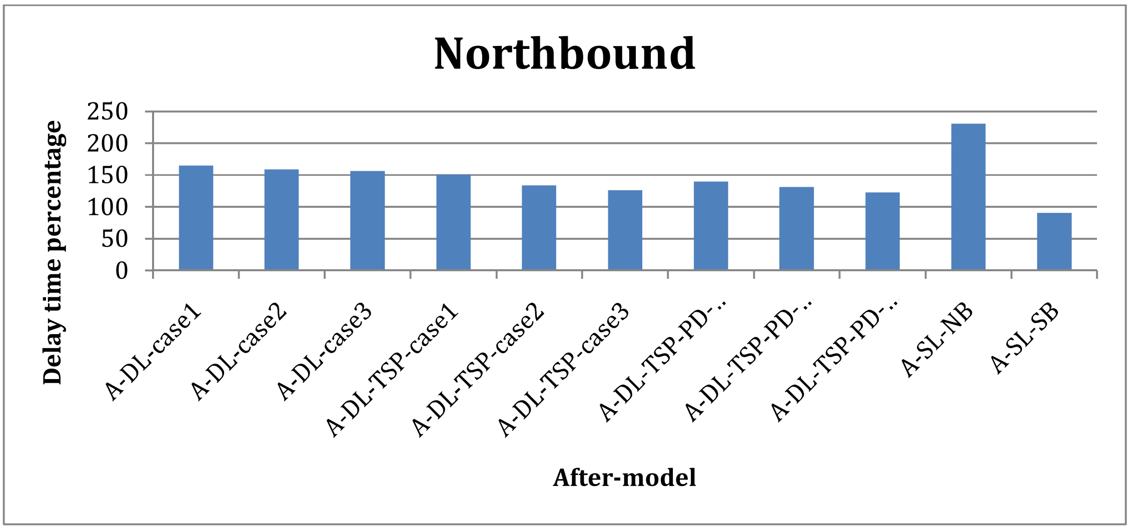

Figure 4.5: Delay Time Percentage Considering B-Synchro as a Basis: Northbound

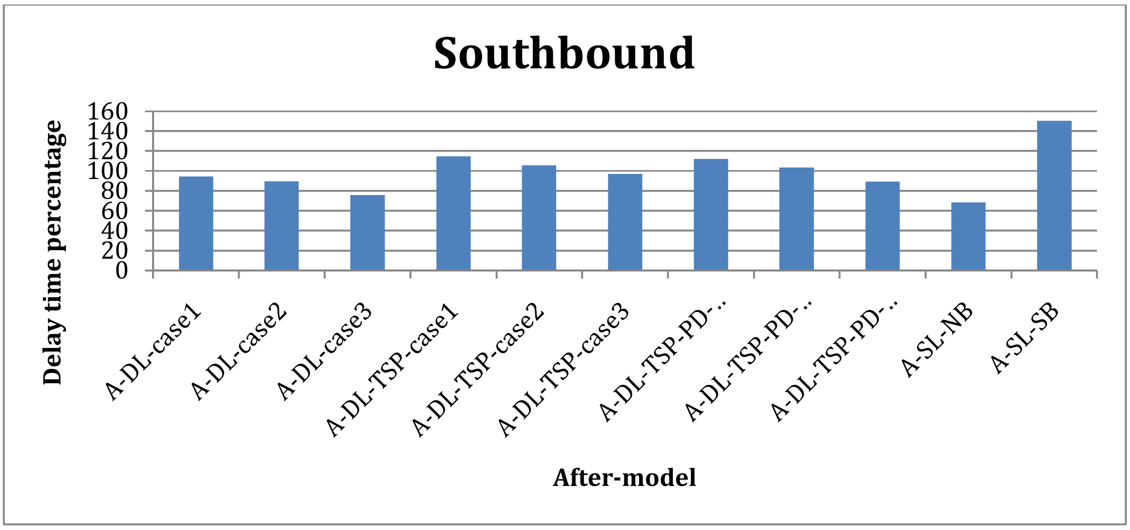

Figure 4.6: Delay Time Percentage Considering B-Synchro as a Basis: Southbound

4.3 Summary

This chapter uses Van Ness Avenue as a case study site for the methodologies discussed in Chapter 3. Analyses were performed in two areas: the impact on ridership; and traffic impact in terms of corridor travel time and degree of LOS degradation.

Ridership analysis was performed using the elasticity method. Four difference scenarios were tested, assuming the implementation of various ITS technologies (single lane BRT, TSP, precision docking). The result from Scenario 1, which is the scenario comparable with those in the Van Ness Avenue Feasibility Study Report, shows the ridership figures within 11% of those reported in the Feasibility Study Report. This demonstrates the feasibility of using the elasticity method for sketch planning level ridership estimates and supports the implementation of the method in the web-based toolbox.

With Synchro simulation, traffic impacts of the BRT system were studied with different lane replacements and various levels of ITS technology implementation. We observed that ITS technologies are very helpful in terms of decreased travel and delay times. In some cases, LOS could be maintained (for instance, with TSP and a higher conversion percentage from auto drivers to transit riders) or even improved (for instance, with TSP and precision docking, and a higher conversion percentage from auto to transit). The single bus lane alternative, however, seems to be a choice that is suitable for corridors that have very limited ROW and that cannot have a dedicated lane in each direction, since it may cause a significant increase in travel time and degradation in LOS. In general, our studies show that the performance degradation is typically within an acceptable range for many after-models, especially those with ITS techniques. Compared with corresponding results reported in SFMTA's report, where a 3% increase in travel time is reported in the scenario with BRT lane conversion, our results show a 10% increase in travel time. Moreover, it is worth pointing out that the modeling approach used for SFMTA's study (microscopic simulation) and the one used in our study (macroscopic simulation) model vehicle movement using completely different rules, and the results should not be expected to replicate each other.

4.4 Application of the Toolbox to Other Sites

Although we conducted case studies on San Francisco, the toolbox developed in this report can be applied to other sites. In order to apply the toolbox to other sites, the first thing is to determine the potential scenarios for lane replacements, for example, removing two center lanes, removing one lane, using ITS technology, etc.

The ridership model used (elasticity method) is a very general tool and can be easily applied elsewhere. The ranges for the parameters used in the model are estimated based on nationwide experiences. The user can use a default value (usually the middle point in the range) if there is no specific preference, or pick a value from the range based on local experience, or even specify a value that's outside the suggested range, again, based on previous local experience.

In order to apply the traffic analysis model to other sites, we first need to collect the road geometry data and build the network in Synchro. Based on the different scenarios from the ridership model, we have different demand configurations for each scenario. Such demand levels will be coded in the Synchro model, and the corresponding network will be changed, for example, removing two mixed-traffic lanes. For each scenario, we run the Synchro model and obtain the MOEs. Finally, the MOEs of different scenarios are compared and some suggestions can be recommended.

CHAPTER 5

DEVELOPMENT OF A WEB-BASED TOOLBOX FOR TRAFFIC IMPACT ANALYSIS OF TRAFFIC LANE CONVERSION

In this chapter, we document the development of a web-based toolbox that provides ridership estimates and performs a macroscopic traffic impact analysis.

As discussed in Chapter 1, although there have been quite a few BRT implementations in the state of California, there still isn't a good understanding of how a planned BRT system would impact transit service quality and traffic LOS, especially at an early planning stage of a project. Thus, it is highly desirable to have a toolbox that is easily accessible and that helps decision makers understand the above-mentioned impacts. At the sketch planning stage, there may not be many details available regarding the BRT system design and its surrounding environment, thus the toolbox would need to take very basic inputs of the system and be able to provide an approximate estimation of the benefits and impacts for the agencies to use as a starting point to decide whether to pursue further study and implementation of the proposed system.

5.1 Analysis methods implemented in the toolbox

5.1.1 Ridership model

As shown in Chapters 3 and 4, the elasticity method for ridership analysis requires relatively simple inputs that should be available even at the sketch planning stage of a project. It is thus suitable for implementation in the web-based toolbox. The flowchart of the ridership estimate module is shown in Figure 3.1. The toolbox asks the user for step by step inputs regarding characteristics of the planned BRT implementation and provides a final estimate of ridership.

5.1.2 Traffic impact model

The Synchro based macroscopic model provides a way to estimate the impacts of lane replacements, which is much easier to build than a microscopic simulation model. However, site-specific geometry and traffic control details are still needed as inputs. We can design and implement an even more high-level macroscopic tool to estimate the impacts of replacing mixed-traffic lanes so that little effort is required. This high-level tool is based on the BPR (The Bureau of Public Roads) function, which shows the relationship between travel time and traffic flows. However, its major application is freeway traffic rather than interrupted arterial flows.

The Bureau of Public Roads (BPR) developed a link (arc) congestion (or volume-delay, or link performance) function, which we will term

$$t = t_0\left(1+\alpha\left(\frac{v}{c}\right)^{\beta}\right)$$

where

t_0 t is average travel time for a vehicle on a link;

t_0 t_0 is free flow travel time on a link

v is traffic volume on the link

c is capacity of the link; and

α,β are parameters, typical values used are 0.15 and 4, respectively.

The flow chart for the traffic impact module of the toolbox is shown in Figure 5.1.

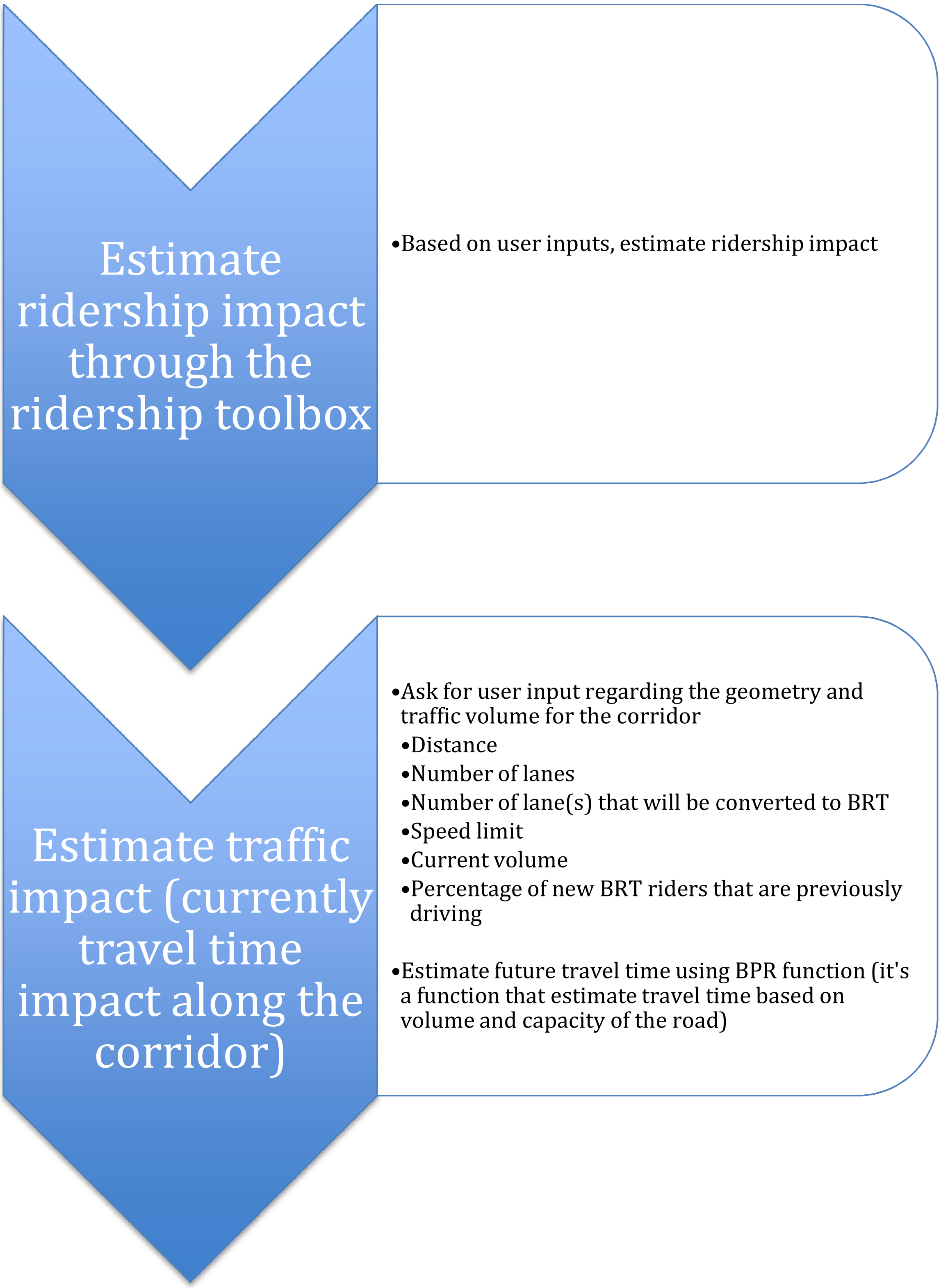

Figure 5.1 Traffic Impact Module Flow Chart

5.2 Toolbox description

For easy access, the toolbox is web based. Javascript was used to implement the interface and Apache is used as the web server. The web-based toolbox is located at the following website:

http://tlab.path.berkeley.edu:16060/tlab/brtbox.html.

The following describes the steps that are needed to carry out for the traffic impact analysis of the mixed-traffic lane replacements.

Step 1 is to estimate the reduction of car driver demand due to the mode shift. The following inputs are needed: baseline ridership in the unit of passengers/hour, travel minutes of the bus, transit fares, and service intervals for two situations: before the lane is converted and after the lane is converted. The figure below presents the interface. Note that related ridership models have been implemented in this high-level tool.

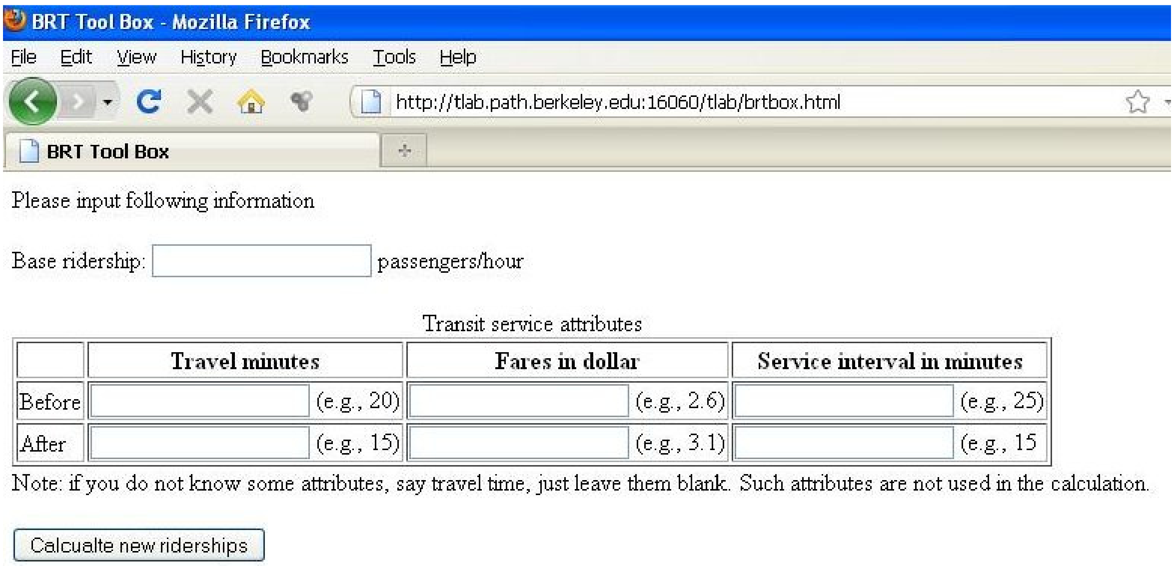

Figure 5.2 Screen Capture of the Web Accessible, High Level Tool (Step 1)

The results from three ridership models are then provided as output. For example, see the figure below.

Step 2 is to estimate the travel time using the BPR functions and demand reduction in the ridership models. The inputs include the distance of the arterial, number of existing lanes, the number of lanes that will be converted, speed limit, current traffic volumes, and percentage of new transit riders from previous drivers. The figure below presents the interface.

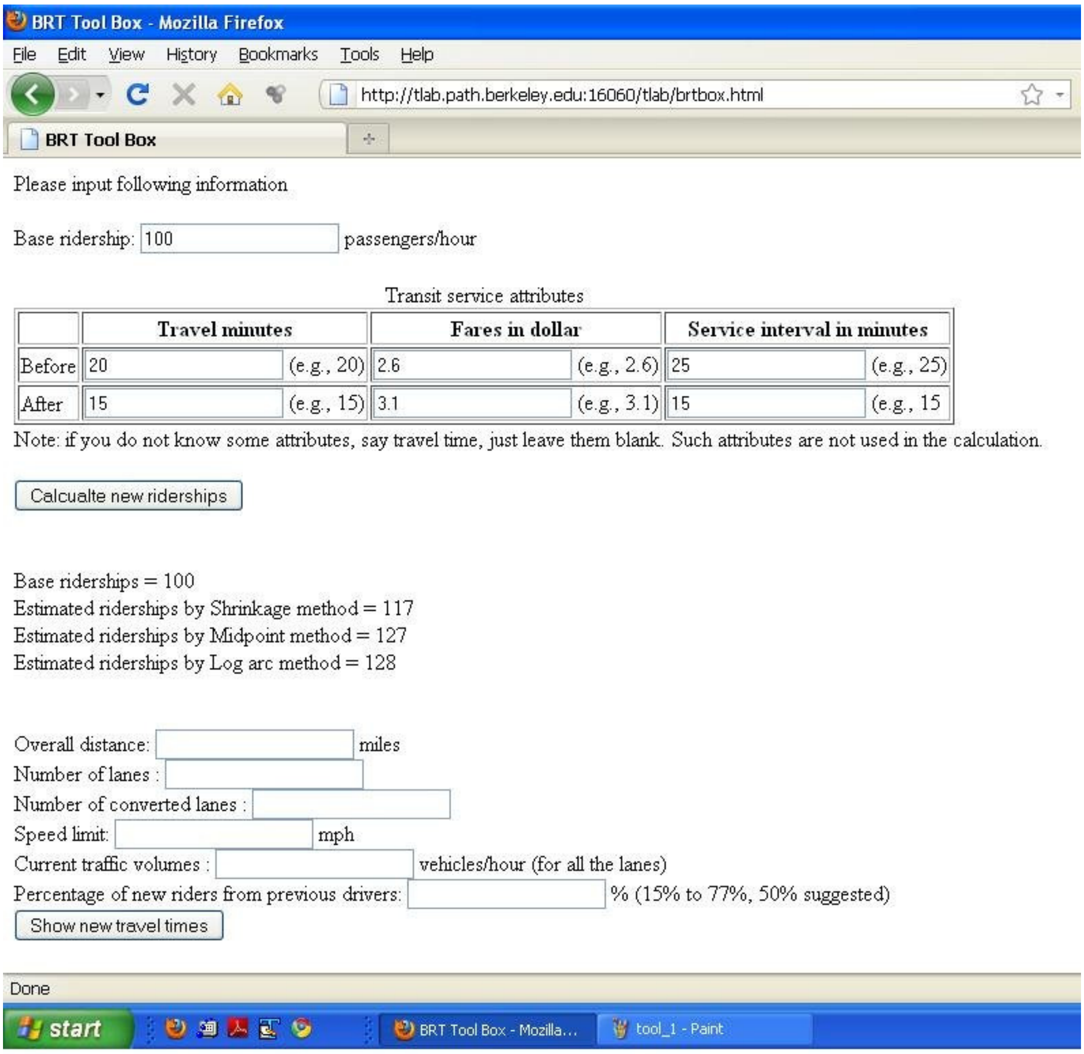

Figure 5.3 Screen Capture of the Web Accessible, High Level Tool (Step 2)

Step 3 is to compare the travel time in the Before-Model and After-Model. Note again such a tool is applicable only for the freeway traffic.

CHAPTER 6
CONCLUSIONS

There are a few different approaches to achieve dedicated BRT lanes along existing arterial highways. One commonly used approach is to convert current mixed traffic lane(s) into bus only lane(s). Such conversion certainly has its impact on traffic conditions. On the one hand, implementation of a BRT system with a dedicated lane would attract more transit users, many of them would be previous drivers and thus this would reduce the traffic volume; on the other hand, the conversion of a traffic lane means reduced capacity for autos along the corridor and this would cause traffic conditions to deteriorate. A systematic approach is needed to understand quantitatively such impacts.

This research team did a thorough review of the literature as well as BRT systems that are currently in operation or in late stages of planning in California. Lessons learned were used regarding the various approaches taken to create exclusive bus lanes and evaluation of the impacts of BRT implementations.

The project aimed at generating a process and toolbox for evaluation of the following three aspects – the change in ridership due to the implementation of a BRT system, the amount of ridership increase that are coming from previous auto drivers, and the potential congestion level changes in terms of LOS degradation on adjacent mixed-flow traffic lanes. The first two aspects were studied with ridership models and parameters gathered through the literature research. The third aspect was studied with Synchro, a macroscopic traffic simulation and signal timing software tool, and represented in the toolbox by an analytical volume-delay function (BPR function).

Van Ness Avenue in San Francisco was used as the case study site for the process mentioned above. It is observed that the ridership estimates are within 11% of the figures reported in SFMTA's Feasibility Study Report. As to traffic impact estimated using Synchro, it is observed that with ITS technologies implemented (TSP, precision docking, and potentially even more), the travel and delay time would see only a relatively small increase, with LOS maintained at the same level or even improved. It is worth mentioning that the simulation results are very dependent on the specific conditions of the implementation corridor and thus are not readily transferrable to other sites. Site-specific models need to be built if simulation analysis is needed for further understanding of site-specific corridor conditions.

The web-based toolbox developed in this project provides Caltrans with an easily accessible tool that takes simple and basic inputs from the user regarding a planned for BRT system, and then provides an estimate of future ridership. The toolbox would also take the basic inputs regarding the corridor's transportation facility (such as number of lanes, speed limit, etc) and estimate the traffic time along the corridor.

As to further development of the toolbox -- obviously, it would be highly desirable for the toolbox to be able to link to a microscopic simulation package (such as VISSIM) automatically, and with additional inputs from the user, to generate a microscopic simulation model that could be used to carry out a more detailed analysis of the traffic condition. The automated process would save tremendous amount of effort that is needed to build a microscopic simulation model and it would be an extremely helpful tool for the agency.

REFERENCES

AC Transit, Berkeley/Oakland/San Leandro Corridor MIS. 2002.

AC Transit, East Bay Bus Rapid Transit Project Draft Environmental impact Statement /Environmental Impact Report. May 2007.

Cervero, R., J. Murakami, and M.A. Miller, "Direct Ridership Model of Bus Rapid Transit in Los Angeles County, California", Transport Research Record: Journal of the Transportation Research Board 2145:1–7, 2010.

Diaz, R.B. and D. Hinebaugh, Characteristics of Bus Rapid Transit for Decision-Making (CBRT), Report Number FTA-FL-26-7109.2009.1, Federal Transit Administration, Washington D.C., 2009.

Miller, M.A., "Bus Lanes/Bus Rapid Transit Systems on Highways: Review of the Literature", California PATH Working Paper UCB-ITS-PWP-2009-1, California PATH Program, Institute of Transportation Studies, University of California, Berkeley, January 2009.

ECONorthwest and Parsons Brinckerhoff Quade & Douglas, Inc., *Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners*", Transit Cooperative Research Program, Report 78, Transportation Research Board, National Academy Press, Washington, D.C., 2002.

Diaz, Roderick B., et al., *Characteristics of Bus Rapid Transit for Decision-Making*, Federal Transit Administration, U. S. Department of Transportation, Washington, D.C., 2004.

Kiesling, M. and M. Ridgway, "Effective Bus-Only Lanes", *ITE Journal*, Institute of Transportation Engineers, July 2006.

Kittelson & Associates, Inc. et al., *Transit Capacity and Quality of Service Manual, 2nd Edition*, Transit Cooperative Research Program, Report 100, Transportation Research Board, National Academy Press, Washington, D.C., 2003.

Kittelson & Associates, Inc. et al, *Bus Rapid Transit Practitioner's Guide*, Transit Cooperative Research Program, Report 118, Transportation Research Board, Washington D.C., 2007.

Levinson, H., et al., *Bus Rapid Transit, Volume 2: Implementation Guidelines*, Transit Cooperative Research Program, Report 90, Transportation Research Board, Washington, D.C., 2003.

Los Angeles County MTA, Metro Rapid Demonstration Program Final Report. March 2002.

San Francisco County Transportation Authority. *Van Ness Corridor Feasibility Study report*. http://www.sfcta.org/content/view/425/252. 2006.

Savage, K. J., "Benefit/Cost Analysis of Converting a Lane for Bus Rapid Transit", Research Results Digest 336, National Cooperative Highway Research Program, June 2009.