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16. ABSTRACT

This report documents a research effort to understand the current practice and issues associated with Bus Rapid Transit (BRT) planning and deployment. It reviewed the design options incorporated into existing BRT deployments across California and the nation. The project team interviewed practitioners of Caltrans Districts and transit agencies to understand the BRT project approval decision-making process, the impacts of BRT implementation and the Measures of Effectiveness (MOEs) for transit and non-transit system performance. The studies revealed that though Caltrans and transit agencies do use a similar set of MOEs for the evaluation of BRT projects, the emphasis and parametric assumptions for the MOEs may be different and can influence the results of the evaluation. Other evaluation criteria and factors must be considered. This study concluded that a systematic approach needs to be developed and taken in the BRT planning process.

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Bus Rapid Transit (BRT) Toolbox: BRT Person Throughput-Vehicle Congestion Tradeoffs

**Jingquan Li, Jacob Tsao, Ching-yao Chan,
Kun Zhou, and Wei-Bin Zhang**

UCB-ITS-PRR-2015-02

**California PATH
University of California Berkeley**

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Executive Summary

This project studied the current practice and issues associated with BRT planning and deployment.

Under Task 1, literature review was conducted to assess the state-of-the-practice in the following areas: (1) BRT design options and existing BRT systems both within California and outside the state, (2) methods of comparing transit and non-transit improvements, and (3) guidelines developed by the transit industry on the decision-making process for BRT project approval. This literature review has identified relevant Measures of Effectiveness (MOEs) and associated measurements.

Task 2 surveyed expert BRT practitioners, focusing on the BRT project approval decision-making process, the impacts of BRT implementation and the MOEs for transit and non-transit system performance. The research team conducted direct interviews and surveys. Caltrans District 4, District 7, and District 11 were interviewed to understand the approaches the Districts currently use to analyze various BRT proposals prepared by local transit agencies, in particular with regard to the threshold on traffic impacts, the types of data and tools required for such analyses, and the limitations of the current analysis methods, data and software tools. The interviews revealed that the roles of Caltrans' districts are to review the BRT plan from the perspective of impacts to highway operation. In most of cases, no independent analyses were conducted by the Caltrans districts. Occasionally, traffic analyses using Synchro were performed for a limited number of intersections using data provided by local agencies. The thresholds for accepting BRT plans in these reviews were based on Level of Service (LOS). Typically, the 'after' performance should be either at a similar LOS before BRT was built or in between LOS C and D. Although the Caltrans director's policy on BRT was used as the guidance, the resources to support a thorough evaluation were not available. Tools for estimating mode shift, people-throughput and traffic diversion were not available. There is no specific policy on the thresholds for accepting BRT.

The outcome from the interviews in Task 2 raised comments from the Project Panel, recommending a new focus for this research in light of Senate Bill (SB) 743, which mandate the use of broader MOEs particularly person-throughput when planning a transportation system. It was agreed upon through discussions with our Caltrans project manager that PATH would change the original focus of Tasks 3 and 4 to investigate ways to incorporate MOEs that are consistent with SB 743.

Under the updated Task 3, the team conducted further interviews with three Caltrans districts as well as AC Transit to investigate the categories of MOEs that are currently used in planning and evaluating transportation projects, how the trade-offs between person-throughput and vehicle-throughput have been considered, and what the types of data are being used in the evaluation.

Under Task 4, the MOEs and data used by Caltrans districts with those used by transit agencies were synthesized. The similarities, differences and gaps among the MOEs used by these stakeholders and the needs for BRT pre-planning tools were identified. The studies revealed that though Caltrans and transit agencies do use a similar set of MOEs for their evaluation of BRT projects, the emphasis and parametric assumptions for the MOEs may be different. These differences can influence the results of the evaluation. This study concluded that a systematic approach needs to be developed and taken during the BRT planning process. A better way of evaluating person-throughput should be incorporated as an important part of this evaluation process. The study also recommends developing a data definition for BRT evaluation and tools that will facilitate the pre-planning decision process of BRT projects.

The studies conducted under this project have established the foundation for the next phase of the project to further investigate approaches to improve the current BRT planning practice and to develop tools and guidelines to assist Caltrans in the evaluation and approval process of future BRT projects.

1.0 Review the Literature on Existing BRT Systems and MOE Measurements

Public transportation is perhaps one of the few sustainable transportation solutions for urban or suburban areas. Most, if not all, cities have public transportation systems. However, relatively few provide rapid transit systems. Urban rail or light-rail system is the classical and conventional transit system used in most developed countries as well as in some cities of emerging economies (New Delhi, Beijing, Shanghai, etc.) while the Bus Rapid Transit (BRT) is a relatively new mass-transit concept that has been adopted by both developed countries and emerging economies (Levinson et al., 2002; Jarzab, et al., 2002; Miller et al., 2006; Kittelson & Associates et al., 2007; NBRTI, 2009).

To minimize travel time and its variability for BRT, traffic lanes together with spaces required for the passenger activities along a *street median* can be designated to form a dedicated transitway. In addition, transit signal priority and other technologies can be adopted to improve system performance. However, the current vehicular traffic of many cities is dominated by automobiles. Such cities include perhaps most US cities, with few exceptions like New York City and Chicago, and many cities in other developed nations or emerging economies. Dedicating two lanes in the street median and the additional spaces needed for bus stops often requires taking the same space away from use by automobiles. In prevailing geometric designs for dedicated BRT systems, passenger activities at a bus stop are accommodated with either two physically separate passenger platforms (one for each direction) or one dual-use platform. In either case, the width of the required space is approximately the width of two traffic lanes.

For wide acceptance of BRT implemented with such a dedicated transitway in developed nations, conversion of existing general purpose lanes to BRT lanes, without significant right-of-way acquisition, may be necessary. However, this kind of lane conversion could lead to heavy congestion during peak commute hours unless parallel streets or even corridors have sufficient capacity to accommodate the redirected traffic. In addition, the possible low bus-traffic volume on such a dedicated transitway before the demand for the bus services can be gradually built up could lead to the impression of space underutilization; such impression is sometimes referred to as the “empty-lane syndrome.” Resulting congestion potential and “empty lane syndrome” could lead to strong motorist resentment against implementation of BRT on a dedicated transitway.

This trade-off between the performance improvement of BRT due to space dedication and the performance degradation of mixed-flow lanes due to space deprivation has been a contentious issue and is the focus of this research project.

In emerging economies or urban or suburban areas of developed nations where bus transit is already popular, faster and more reliable bus service would be considered “rapid” and may suffice for public support. However, in the US, where the automobile is the primary mode of personal transportation and only (heavy) commuter-rail transit systems, e.g., the Bay Area Rapid Transit (BART) system of the San Francisco Bay Area, the New York City Subway, etc., have been considered as “rapid” by the general public, their expectation on the speed of a bus *rapid* transit system may be much higher. This higher speed expectation may only be achievable with a dedicated *median* busway and transit signal priority (and other features like off-board fare collection, express service with wide spacing between stations, etc.) and hence the efficient space dedication is critical.

Many BRTs with a dedicated transitway have been implemented in emerging economies, in a societal context where the vast majority of the population already relies on public transportation. Such BRT systems, if implemented appropriately, would improve transit services for the majority and proposals for building such systems tended to receive popular support. For wide-spread implementations of such BRT systems in the U.S. or other nations where urban and suburban transportation systems have been primarily developed for and used by automobile traffic, the benefit to the transit users must be sufficiently compelling for winning over car-drivers, and the negative impact on the automobile traffic must be minimized.

The goal of this task is to review the design options incorporated into existing BRT deployments across California and the nation. This review will include published papers and reports to identify relevant MOEs and associated measurements.

1.1 Review BRT Design Options and Existing BRT Systems Both within California and Outside the State

In this section, we will present a comprehensive review of design options and implemented BRT systems across the nation.

1.1.1 General design options

Many guidebooks and articles have described various BRT design options extensively. They include Bus Rapid Transit Planning Guide (ITDP, 2007). BRT guidebooks targeting US transit agencies include *TCRP Report 90, Volume I: Bus Rapid Transit: Case Studies in Bus Rapid Transit* (Levinson, 2003a), *TCRP Report 90, Vol II: Bus Rapid Transit: Implementation Guidelines* (Levinson, 2003b), *TCRP Report 118, Bus Rapid Transit Practitioner's Guide* (Kittelson and Associates, 2007) and *Characteristics of Bus Rapid Transit for Decision-Making* published by the National Bus Rapid Transit Institute (NBRTI, 2009), and two special editions of Journal of Public Transportation (2002 and 2006).

Characteristics of Bus Rapid Transit for Decision-Making published by the National Bus Rapid Transit Institute (NBRTI, 2009) groups design options into seven categories and a number of sub-categories as follows. It discusses the design options in detail; it also provides experiences of their implementation in the US as well as internationally.

1.1.2 Running-way design options and dedicated BRT lanes or transitways

1.1.2.1 Running-way design options

Table 1 outlines a preliminary decision matrix that correlates a given passenger demand with the type of system. Note the extremely high bus-passenger demand levels being considered for the developing nations; as far as the US is concerned, the transit demand levels of the vast majority of the commute corridors are 8000 per hour per direction or less. For example, it is stated about the AC Transit East Bay BRT (AC Transit, 2012a), "….. bus routes along the proposed BRT project alignment currently serve approximately 24,000 boardings a day – nearly 12 percent of AC Transit's total ridership."

Table 1: Typical Solutions for Different Demand Levels as Suggested in ITDP (2007)

Transit passengers per hour per direction	Type of BRT Solution
Less than 2000	Simple bus priority, normally without physical segregation, possible part-time bus lane
2000 to 8000	Segregated median busway used by direct services reducing the need to transfer
8000 to 15000	Segregated median busway used by trunk services requiring transfers but benefitting from faster boarding and operating speeds. Transit priority at intersections.
15000 to 45000	Segregated median busway, with overtaking at stops; possible use of express and stopping services. Use of grade separation at some intersections and some form of signal priority at others.
Over 45000	This level of demand is very rare on existing bus systems. It is possible, however, to design a BRT system that would serve up to 50,000 passengers per hour per direction. This can be achieved with full segregation, double busway, a high proportion of express services and multiple stops. This capacity could also be handled by spreading the load through two or more close corridors.

Source: "Table 4.1: Typical Solutions for Different Demand Levels" of *Bus Rapid Transit Planning Guide* (3rd Edition; ITDP, 2007)

Miller (2009) reviewed literature on bus lanes/BRT systems designed for implementation on conventional highways. In that study, conventional highways refer to arterials, freeways and busways. Bus service options are put in two categories: on-street and off-street facilities, as suggested on page 2-5 of (NBRTI, 2009; Chapter 2, page 5): "On-street bus facilities have widespread applicability because of their relatively low costs, ease of implementation, and opportunities for incremental deployment. For on-street facilities, numerous implementation options exist depending on the placement of the bus lane (curb or median), direction of flow (normal or contra-flow), mix of traffic (buses only (dedicated bus lanes), buses and taxis, buses and goods delivery vehicles, or mixed traffic flow with automobiles), and traffic controls (turn controls, parking, loading and unloading of commercial motor vehicles, and signalization). Off-street bus rapid transit running ways, however, require higher investments in land and construction, and which commonly take the form of special bus roadways that vary by type of construction (above grade, at grade, below grade), direction of flow (concurrent or contra-flow),

Table 2: Running Ways Classified by Extent of Access Control (Levinson, H.S., et al., 2003b)

Classification Scheme	Access Control	Facility Type
I	Uninterrupted flow – full control of access	• Bus tunnel • Grade-separated busway • Reserved freeway lanes
II	Partial control of access	• At-grade busway
III	Physically separated lanes within street rights-of-way	• Arterial median busway • Bus streets
IV	Exclusive / semi-exclusive lanes	• Concurrent and contra-flow bus lanes
V	Mixed traffic operations	

Source: Running Ways Classified by Extent of Access Control (Levinson, H.S., et al., 2003b)

Table 3: Running Ways Grouped by Facility Type Suggested in Levinson, H.S., et al., 2003b

Facility Type	Classificatio	Examples
Busways • Bus tunnel • Grade-separated running way • At-grade busway	 • I • I • II	 • Boston, Seattle • Ottawa, Pittsburgh • Miami, Hartford
Freeway lanes • Reserved concurrent flow lanes • Reserved contra flow lanes • Bus-only or priority ramps	 • I • I • I	 • Ottawa • New Jersey to Lincoln Tunnel • Los Angeles
Arterial streets • Median arterial busway • Curb bus lane • Dual curb lanes • Interior bus lane • Median bus lane • Contra flow bus lane • Bus-only street • Mixed traffic flow	 • III • IV • IV • IV • IV • IV • IV • V	 • Curitiba, Vancouver • Rouen, Vancouver • Madison Av., NYC • Boston • Cleveland • Los Angeles, Pittsburgh • Portland • Los Angeles

Source: Running Ways Grouped by Facility Type (Levinson, H.S., et al., 2003b)

and treatment of stations (on- or off-line).” Levinson et al., (2003b) provided a detailed discussion of running-way design options.

Table 2 classifies the options with respect to the extent of access control; Table 3 groups the options with respect to facility type.

1.1.2.2 Dedicated BRT lanes and transitways

BRT lane-conversion has not been treated as a critical important issue in guidelines provided for implementation in developing nations. This is likely because the vast majority of commuters rely on public transportation. Such a conversion benefits the vast majority of the commuters. Bus Rapid Transit Planning Guide (3rd Edition), which was published by Institute for Transportation & Development Policy (ITDP) originally for developing nations, provides little guidance on BRT lane-conversion trade-off, perhaps for good reasons.

Due to the facts that virtually the entire urban surface transportation systems of the US have been developed for automobiles and that the systems already experience significant congestion during peak commute hours, BRT lane-conversion trade-off is a critical issue for the US. Most urban commuters of developing nations already use public transportation, and space dedication for BRT, if necessary, faces much less public resistance or resentment, despite the fact that automobile users may have disproportionate representation in the legislative or even executive branches of the government. Needless to say, our assessment is relative. Regarding the resistance to dedicating space for BRT in developing nations, Bus Rapid Transit Planning Guide (3rd Edition; ITDP, 2007) states:

- "While automobiles may represent less than 15 percent of a developing city's transport mode share, the owners of such vehicles represent the most influential socio-political grouping." (page 44)
- "The professional staff within municipal agencies may also represent a barrier to public transportation improvement. Instead, municipal officials are part of the middle-class elite who have the purchasing power to acquire a private vehicle." (page 45)
- "The city [Bogotá , Colombia] decided to widen some roadways during Phase II in order to maintain the number of mixed-traffic lanes along the BRT corridor." (page 58)

In Section 5.3 Options for Narrow Roads (on page 158 of ITDP, 2007), it is stated, "In general, there are at least ten different solutions to designing BRT systems through an area with extremely narrow road widths:

1. Median busway and single mixed-traffic lane (e.g., Rouen, France)
2. Transit malls and transit –only corridors
3. Split routes (two one-way services on parallel roads)
4. Use of median space
5. Road widening
6. Grade separation
7. Fixed guideway
8. Single-lane operation
9. Staggered stations / elongated stations
10. Mixed-traffic operations

These are suggested mainly for small portions of a corridor, e.g., central business districts (CBDs) and historical centers. In a nation where automobiles dominate vehicular traffic and on a corridor where a dedicated BRT busway is needed to alleviate traffic congestion, the entire corridor can be regarded as narrow. In summary, guidebooks published for developing nations are not a good source of guidance for BRT lane-conversion trade-off studies.

BRT guidebooks targeting US transit agencies include *TCRP Report 90, Volume I: Bus Rapid Transit: Case Studies in Bus Rapid Transit* (Levinson, 2003a), *TCRP Report 90, Vol II: Bus Rapid Transit: Implementation Guidelines* (Levinson, 2003b), *TCRP Report 118, Bus Rapid Transit Practitioner's Guide* (Kittelson and Associates, 2007) and *Characteristics of Bus Rapid Transit for Decision-Making* published by the National Bus Rapid Transit Institute (NBRTI, 2009).

As experiences and lessons learned in designing and implementing BRT systems accumulate, the necessity of dedicating space for BRT success and the difficulty in acquiring right-of-way becomes clearer. Later guidebooks contain more discussion on this necessity and the corresponding difficulty.

Characteristics of Bus Rapid Transit for Decision-Making (CBRT) published by the National Bus Rapid Transit Institute (NBRTI, 2009) recognizes running ways as the most critical element in determining the speed and reliability of BRT services. In a nation like the US where the roadway space has been used predominantly by automobiles and has already experienced significant congestion during peak commute hours, space dedication can be easily understood as the most critical issue for a successful BRT implementation. *Characteristics of Bus Rapid Transit for Decision-Making*, in describing the role of running way in BRT on page 2-3 (NBRTI, 2009; Chapter 2, page 3), states, "The running way defines where BRT vehicles travel. It is analogous to tracks in a rail transit system. How running ways are incorporated into a BRT system is the major defining factor for the entire BRT system. Running ways are the most critical element in determining the speed and reliability of BRT services. Running ways can be the most significant cost item in the entire BRT system. Finally, as the BRT element most visible to the general public, including both existing and potential customers, running ways can have a significant impact on the image and identity of the system."

Several options for on-street bus lanes are proposed on page 2-5 of (NBRTI, 2009; Chapter 2, page 5):

- "Curbside—Exclusive lane is adjacent to the curb. In this case, delivery vehicles are typically permitted, at least during off-peak hours. Lanes shared with right-turning traffic are, typically, not very effective unless treated as queue jump lanes, as previously described.
- Outside of parking lane—The bus lane is to the left of a permanent parking lane. In this case, the curb flares into the parking lane at stations to become a "bus bulb."
- Center (or Median-Running)—The bus lane is in the center of the roadway. In this case, it is necessary to create a loading platform between the bus lane and the general purpose lanes at stations. Alternatively, if the vehicle has left-side doors, a central platform shared by both directions of movement can be used. Commonly, medium arterial busways are physically separated from adjacent travel lanes.
- Contraflow—The bus lane runs opposite the direction of general traffic. This design is like a two-way street that operates in one direction only for general traffic. Contraflow lanes on the

left side of the road require fencing because they operate contrary to the expectation of pedestrians."

Single-lane operations were very briefly mentioned but in the context of at-grade transitways for a short section and for a low-frequency service, possibly with some space to accommodate a waiting bus. Note that at-grade transitways are defined to be "roads for the exclusive use of transit vehicles can be created where there is available right-of-way, such as a railroad corridor that is no longer in use and where there is sufficient transit demand to warrant the investment that will support frequent bus service."

Despite this recognition of running ways as the most critical element in determining the speed and reliability of BRT services, CBRT offers no guidance on or discussion about how to allocate space for BRT so as to minimize the negative impact of loss of space for mixed traffic.

TCRP Report 90, Vol II: Bus Rapid Transit: Implementation Guidelines (Levinson, 2003b) suggested the following guidelines for designing running ways and selecting their locations.

- Running ways should serve and penetrate major travel markets.
- Running ways should serve the three basic route components of CBD distribution, line haul, and neighborhood collection in a coherent manner.
- Running ways will generally be radial, connecting city centers with outlying residential and commercial areas.
- BRT is best achieved by providing exclusive grade-separated right-of-way.
- Effective downtown passenger distribution facilities are essential.
- BRT running ways should follow streets and roadways that are relatively free flowing wherever possible.
- Special running ways (e.g., busways, bus lanes, and queue bypasses) should be provided when there is (1) extensive street congestion; (2) a sufficient number of buses; (3) suitable street geometry; and (4) community willingness to support public transport, reallocate road space as needed, provide necessary funding, and enforce regulations.
- Preferential treatments for BRT may be provided (1) around specific bottlenecks or (2) along an entire route.
- Running ways should maximize the person flow along a roadway with minimum net total person delay over time.
- Buses should be able to enter and leave running ways safely and conveniently.
- Running ways should provide a strong sense of identity for BRT.
- Adequate signing, markings, and traffic signal controls are essential.
- Bus lanes and queue bypasses may be provided along both one-way and two-way streets.
- Running way designs should be consistent with established national, state, and local standards.
- Running way designs may allow, when feasible, possible future conversion to rail transit without disrupting BRT operations.

TCRP Report 118, Bus Rapid Transit Practitioner's Guide (Kittelson and Associates, 2007) discusses busways as a possible design option for the running-way component of a BRT system, in particular the scale of application, selected typical example, conditions of application, location and alignment, design and operation, estimated costs, likely impact ("travel time savings" for busway users), ridership, cost-ridership considerations, operating benefits (greater driver productivity, lower fuel consumption, and greater safety), land development benefits, implementability, and evaluation. Note that there is no discussion on efficient geometric design and minimum space requirement.

1.1.3 Existing BRT systems in the US

The National Bus Rapid Transit Institute (NBRTI) provides an excellent summary of all BRT projects. As of February 2015 (NBRTI, 2015), a total of 42 BRT systems are in operation, under construction, or planned in California. Two additional BRT systems including the South Bay BRT and Mid-City Rapid in San Diego region are under planning but was not included in the NBRTI database. The reader is referred to the NBRTI website for details. Table 4 provides a high-level summary of the current status of BRT implementation in the US and in California. Majority of these BRT systems adopted transit signal priority for achieving travel time reduction and reliability.

Table 4: BRT Projects: US Tally and CA Projects

Status	US Total	CA Total
Operating	631	27
Planning	33	16
Conceptual	12	0
Implementing	10	0
Early Planning	6	0
Total	124	42

The four NBRTI summary tables do not track provision of dedicated lanes for BRT, perhaps because few of the BRT systems (having been implemented, being implemented or being planned or explored) are implemented on dedicated lanes. In this report, a BRT system in operation with dedicated lanes will be interpreted as a system with BRT dedicated lanes throughout the system or on the majority of the system.

Only four of the currently operating ones are implemented on dedicated lanes: Cleveland Healthline; Oregon EM X connecting Eugene and Spring Field; LA Orange Line and Pittsburgh East, West and South Busways. The latter two are operating on busways essentially separated from all other traffic. The Pittsburgh busway system contains three physically-segregated busways connecting the downtown area to the eastern, western and southern suburbs. The LA Orange Line was constructed primarily on the right-of-way of an abandoned railroad. Lessons learned from these two implementations are not directly relevant to the trade-off study of this project. The Cleveland Healthline and Oregon EM X implementations do involve BRT lane conversion and are directly relevant, but the traffic conditions before their implementation were not particularly congested and there has been no reported study about the impact of the BRT on the general vehicular traffic.

1.1.4 Before-and-after changes (for operational BRT systems)

Many lessons have been learned and documented about the improvements made to bus operations with BRT. But, there has been little literature on performance degradation on general-purpose lanes, not to mention trade-off.

As pointed out earlier, *TCRP Report 118, Bus Rapid Transit Practitioner's Guide* (Kittelson and Associates, 2007) discusses busways as a possible design option for the running-way component of a BRT system, in particular the scale of application, selected typical example, conditions of application, location and alignment, design and operation, estimated costs, likely impact ("travel time savings" for busway users), ridership, cost-ridership considerations, operating benefits (greater driver productivity, lower fuel consumption, and greater safety), land development benefits, implementability, and evaluation. Note that there is no mention in the likely-impact discussion of the effect on the mixed-flow traffic traveling on general-purpose lanes. The same is true for other guidebooks, articles or reports. This is probably understandable because these guidebooks have been developed to promote BRT, not to present it as a solution to urban transportation problems. This and other guidebooks are also not a good source of information about BRT lane-conversion trade-offs.

1.2 Review the Literature in the Areas of Methods of Comparing Transit and Non-Transit Improvements

In this section, we will review published papers and reports to investigate how MOEs are measured, such as person throughput, vehicle throughput, and traffic congestion. In addition, we will examine if there are published guidelines for approving or disapproving a BRT project based on tradeoffs between and/or among MOEs.

The Federal Transit Administration has set up requirements, selection criteria, application procedures and even reporting templates for applicants for FTA (discretionary major investment) grants to follow in the competitive process. Build alternatives must be developed and studied together with the no-build alternative. The detailed design of each build-alternative typically involves a trade-offs analysis. Comparing these different alternatives inevitably involves other trade-offs as well. However, since few BRT implementations or plans involve extensive BRT lane-conversion, little has been established in terms of credible and well accepted methodology to conduct a trade-off study for BRT lane-conversion.

1.2.1 BRT lane-conversion trade-off study for requesting federal funding and state support

National Cooperative Highway Research Program (NCHRP) Project 20-65, Task 21, "Cost/Benefit Analysis of Converting a Lane for Bus Rapid Transit" was funded to identify best practices of analysis for converting an existing lane to BRT, including data collection, organization and analysis. That research included a comprehensive literature review of BRT projects in operation in the United States and several other countries, an identification of potential locations where BRT implementation involved taking or converting an existing mixed-flow traffic lane for exclusive BRT use, and interviews with representatives of these projects. It also conducted research on Level of Service (LOS) and other evaluation criteria used for the evaluation of BRT proposals, benefit/cost approaches, and evaluation criteria for the Federal Small Starts program—a major source of federal funding for BRT implementation. That research was the Phase I of a larger effort; research results can be found in Savage (2009).

Phase II of this research was conducted as National Cooperative Highway Research Program (NCHRP) Project 20-65, Task 22, "*Cost/Benefit Analysis of Converting a Lane for Bus Rapid Transit-Phase II Evaluation and Methodology*." It was originally intended to develop a benefit-cost assessment tool to be used in analyzing conversion of an existing lane to BRT, including the evaluation requirements and methodology. However, the objective was modified to provide transportation agencies with only a methodology and a guide for evaluating the potential benefits and costs of converting a mixed-flow lane to exclusive BRT use. No tools were developed as originally intended. Developing such tools is the main objective of this current BRT Toolbox research project. As pointed out in the research report (Ang-Olson and Mahendra, 2011), the benefits and costs of converting a lane to a BRT lane would depend heavily on how a project affects traffic speed, delay, and vehicle miles traveled, both in the mixed flow lanes and the BRT lane. The benefits would also depend on the extent to which improved transit service results in mode shift to transit. The research made a set of assumptions and provided analytical methods for the benefit-cost calculations.

The first overall assumption made in that research is that an urban BRT line is created on a three-lane arterial (in each direction) by taking one lane, leaving two general purpose lanes in the corridor. As discussed earlier in this white paper, BRT lane-conversion is not simply a matter of converting one general-purpose lane to a dedicated BRT lane; space is required for passenger platforms and left-turning should not be significantly impeded. There are many design options and the associated geometric designs. How a BRT lane fits in the existing right-of-way, including space required for left-turn lanes, and how the space required for bus stops is converted from its current use plays a critically important role in any BRT lane-conversion trade-off study. The research did not report the geometric designs considerations and trade-offs. Another assumption made is that all bus traffic utilizes the BRT lanes. This assumption may not be realistic because a BRT line tends to offer express service. That research also made some generic assumptions about the corridor, e.g., uniform traffic along the corridor. Such generic assumptions are necessary because any realistic trade-off study must take into consideration the site-specifics.

1.2.2 Published research papers on BRT lane-conversion trade-off study

Four peer-reviewed papers that were found in the literature were briefly reviewed. The first one is directly related to this BRT Tool Box project, although the corridor in question is in Beijing, China. So is the second one, although it has a limited scope of Central Business Districts (CBDs) and was conducted in Ottawa, Canada. The third one is about dedicating a BRT lane on a freeway or expressway type of limited-access infrastructure in China. The fourth one is about BRT dedication in India. All four had no discussion on geometric designs and did not discuss site-specifics in sufficient detail.

Chen, X. et al. (2007) studied the impact of two types of BRT lane configurations - curbside and median BRT lanes – and the impact of transit signal priority (TSP) on traffic flow. The study was conducted for a major arterial called the North-South Central Axis of Beijing through microsimulation using VISSIM. Although the issue being dealt with in this paper is directly related to our BRT Toolbox project, the paper did not reveal the geometric designs of the median BRT lanes and did not provide site-specifics in sufficient detail.

Siddique and Khan (2006) focused on BRT scenarios developed for the CBD of Ottawa, Canada and sought to determine the state beyond which throughput of transit buses in exclusive bus lanes of the city's BRT corridors could not be increased without making facility design changes. They used NETSIM as microsimulator for the traffic study.

Zhu et al. (2012) investigated two scenarios for deploying exclusive bus lanes—a curbside bus lane scenario and a median bus lane scenario—along a busy expressway in Beijing using VISSIM as a microsimulator. It was found that for both the mainline and the whole network, the operational efficiencies of buses, general traffic, and all mixed traffic are improved with the deployment of exclusive bus lanes. Further, the median bus lane scenario slightly outperforms the curbside bus lane scenario in this case.

Patankar1, et al. (2007) proposed a methodology that can be used to selectively target corridor for BRT modeling in India. Through microsimulation with AIMSUN, they studied traffic performance measures, such as traffic flow, speed, travel time, delay time, stop time, and fuel consumption. Although they claimed that a dedicated lane-based public transport system showed promising results, the paper did not reveal the geometric designs and did not provide a summary about site-specifics. The only diagram provided in the paper is a before-and-after comparison of the configuration of an intersection, where the only differences revealed are (a) the separation of three types of traffic, namely buses, motorized vehicles and non-motorized vehicles into different lanes and (b) placing the dedicated bus lane next to the median. Since a significant portion of the vehicular traffic modeled in the study is non-motorized, its applicability in the US is limited, although it is applicable for many other developing nations.

Some other papers dealing with this subject exist. However, they tend to deal with possible BRT lane implementation at a very specific site whose study does not directly inform our BRT Toolbox project beyond what the four papers just briefly reviewed. For example, Papageorgiou, G., et al. (2009) conducted a simulation study for comparing several options for improving traffic flow on a congested four-lane road in Cyprus, two lanes in each direction.

These papers all reported the impact of BRT lane-conversion on the bus lanes and the general-purpose lanes and hence, made judgments about the degrees of desirability associated with all the alternatives considered with their scope of study, and concluded the studies with their recommendations. However, the trade-off study was conducted implicitly in these studies. None of these studies hinted about the "indifference region" of BRT performance improvement vs. general-traffic degradation under various BRT lane-conversion scenarios and what level of trade-off' would be considered acceptable. Nevertheless, these BRT projects had gone through rounds of evaluation and iterative design processes and were examined from many perspectives by many stakeholders. For example, for a city or region whose residents or council members strongly believe in transit-oriented development (TOD), the required balance between transit-performance improvement and general-traffic degradation may be much in favor of BRT implementation.

1.2.3 Reports published by transit agencies with assistance of private consultants

Most, if not all, BRT projects rely on FTA for a significant portion of the construction cost. To seek FTA grant funding and to maximize the likelihood of FTA approval, transit agencies typically conduct a detailed cost and benefit analysis and report the results as part of their applications. Such studies are typically performed with the assistance of private consultants. Perhaps the most thorough study of this kind is the one already conducted by AC Transit for the East Bay Bus Rapid Transit (EBBRT) Project. The EBBRT project is in the stage of final design, and construction is scheduled to begin in 2014 and to be completed in 2016.

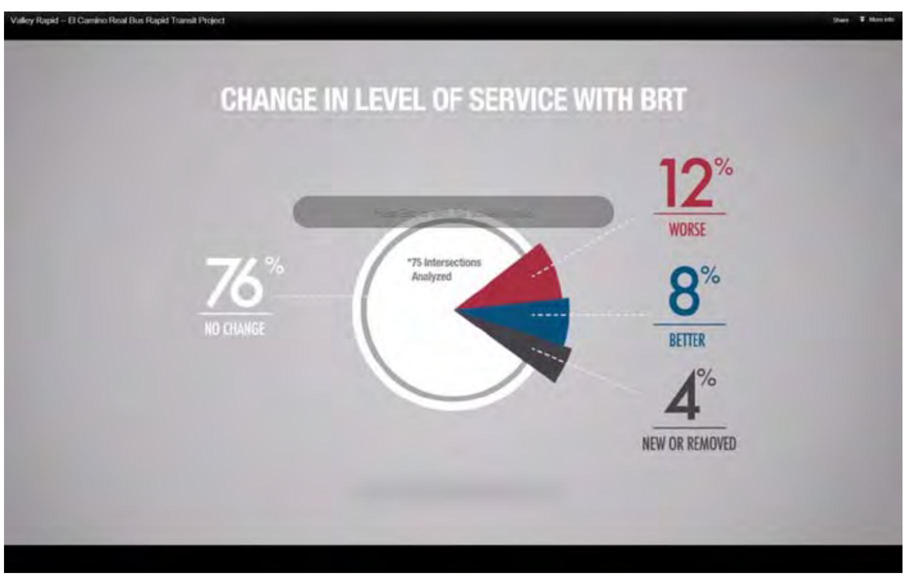
AC Transit published numerous reports during its planning process for the EBBRT Project and has posted them online for open access by the general public. The most important document is perhaps the AC Transit East Bay Bus Rapid Transit Project in Alameda County, California - Final Environmental Impact Statement/Final Environmental Impact Report (FEIS/FEIR) (AC Transit, 2012a). It consists of two big volumes.

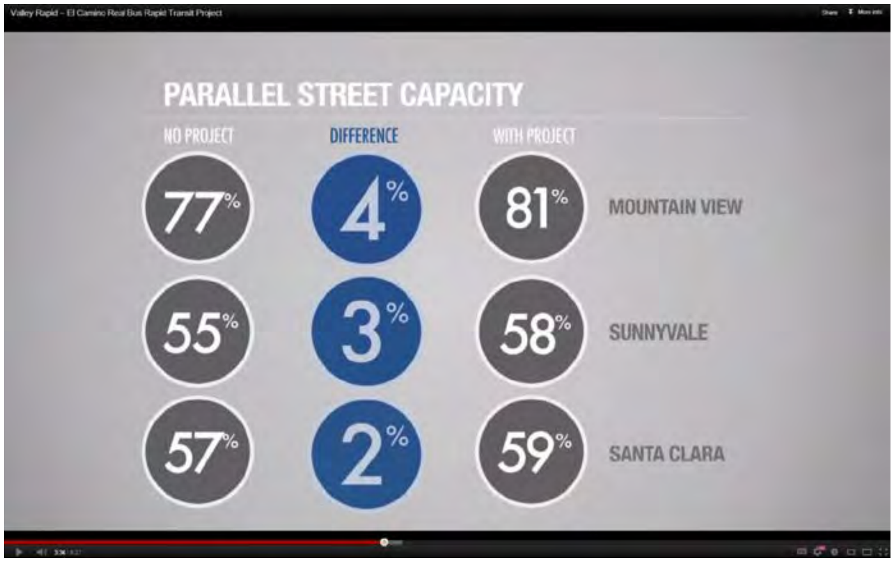
Numerous supporting reports have been published and posted online (AC Transit, 2012c). For example, the Traffic Analysis Report has been published and posted at (AC Transit, 2012d). This report and its Appendix A through Appendix AU contain a large amount of analysis results and span 4137 pages. The level of detail the Report covers can be revealed somewhat by the Appendix A, which summarizes the lane configuration for each of the 129 intersections selected as study intersections for the project. In addition to the Traffic Analysis Report, many other reports pertaining to impact of BRT lane-conversion have been published. For example, a report entitled *Neighborhood Traffic Diversion and Change in Local Circulation Patterns Analyses* was published in December 2011 (AC Transit, 2011). Removal of one general-purpose lane in each direction and anticipated growth in population and employment in the next 25 years would increase traffic congestion at some intersections. Such congestion may cause motorists to seek alternate routes and avoid such intersections. The key diversion movement to avoid the delay at such intersections, as anticipated by the project team, would be a right-turn onto a local street prior to reaching the congested area. An analysis was conducted to show the potential diversion of right-turning traffic upstream from congested intersections on the BRT route, and the results were documented (AC Transit, 2011). Note that the results of this analysis constituted an integral part of the overall performance evaluation, particularly the trade-off study between the transit-performance improvements vs. general-traffic performance degradation. More importantly, such analyses should be conducted for any BRT lane-conversion project and their results should be fully considered in the performance trade-off.

The diversion study was conducted in a larger effort. The BRT implementation may lead to change in travel mode and/or travel route. Since travelers who change their routes might do so for just a few blocks or for their entire trip. EBBRT project team developed an analysis process that captures and assesses modal shifts, short-distance traffic diversion, long-distance traffic diversion, and changes in operating conditions at intersections and along major roadways. The team used the Alameda County Transportation Commission (ACTC) travel demand model to provide estimates of roadway volumes throughout the study area for the AM peak hour, PM peak hour, and entire day from years 2015 and 2035. The demand model uses population and employment estimates, and a simplified representation of the highway and transit systems to derive estimates of roadway traffic and transit volumes. For further details on the application of the ACTC travel demand model for this project, the reader is referred to AC Transit (2012e). The methodology used for the traffic analysis for this study is a macroscopic intersection analysis based on the process presented in Chapter 10, Chapter 16, and Chapter 17 of the *2000 Highway Capacity Manual*. These and many other reports provide input to the very complex issue of trade-offs and point to the necessity to conduct similar studies for performance trade-offs associated with any BRT lane-conversion study.

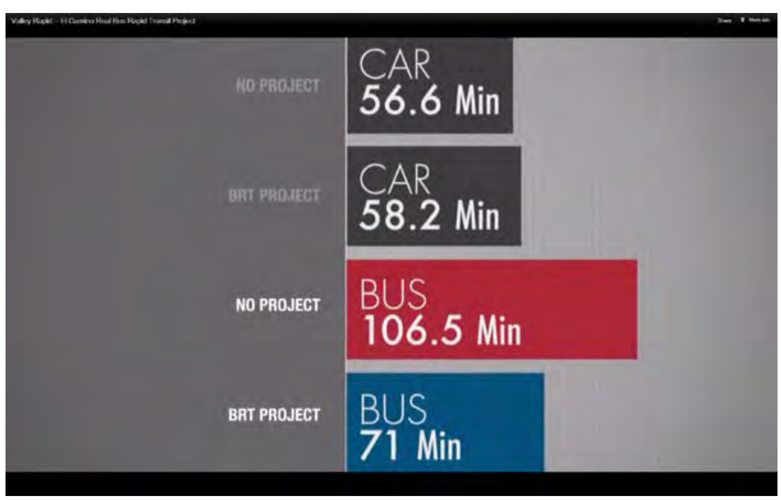
Despite the very detailed results, the lane configurations for the 129 intersections provided in Appendix A under each of the build-alternatives do not reveal the geometric designs of the lane configuration, not to mention the sections corresponding to pairs of adjacent intersections. Some such configurations are revealed in promotion video clips, and some still pictures have been shown earlier in this document; some others are posted by AC Transit at its website and have been briefly discussed earlier. It is clear from the video clips and the official artist renderings that all the BRT lanes are on straight tangent alignment with respect to the orientation of the roadway, just like all the designs of all currently implemented or planned BRT systems. The documents published by AC Transit on traffic analysis are already quite long, and, given the currently standard tangent BRT lane design, it is not reasonable to expect more details beyond what the current documents have already provided.

The Santa Clara Valley Transportation Authority (SCVTA), in its promotional video (VTA, 2012), discusses traffic impact of the proposed El Camino Real Corridor BRT on bus travel and on other modes. The following still pictures captured from the video reveal somewhat VTA's strategy in framing BRT lane-conversion trade-off. These contrasts may reveal what VTA considers as a good trade-off for BRT lane-conversion.




PARALLEL STREET CAPACITY
NO PROJECT
DIFFERENCE
WITH PROJECT
77%
4%
81%
MOUNTAIN VIEW
55%
3%
58%
SUNNYVALE
57%
2%
59%
SANTA CLARA


120 Min
100 Min
80 Min
60 Min
40 Min
20 Min
CAR - NO PROJECT
CAR - WITH BRT
BUS - NO PROJECT
BUS - WITH BRT
Expected Car & Bus Travel Times (Minutes) - 2035
University Ave (Palo Alto) - HP Pavilion (San Jose)


NO PROJECT
CAR
56.6 Min
BRT PROJECT
CAR
58.2 Min
NO PROJECT
BUS
106.5 Min
BRT PROJECT
BUS
71 Min

1.3 Review Published Guidelines from Transit Industry on the Decision-Making Process for BRT Project Approval

In this part, we will review all available published guidelines from the transit industry on the decision-making process for BRT project approval.

1.3.1 FTA guidelines for funding request

Most, if not all, BRT projects rely on the federal government for a significant portion of the project funding, and the Federal Transit Administration (FTA) has set forth a set of analysis requirements for possible approval of such a funding request. There are two types of FTA grant programs: Formula Grant Programs and Discretionary Grant Programs. The amount of funding a grantee of a formula grant program receives is determined by a formula established in law or by administrative order while the Congress or FTA determines the amount of funding an individual discretionary grantee receives based on competition. In 2010, four core programs (5307 Urbanized Area Formula Grants/ 5309 Fixed Guideway Modernization Formula Grants/ 5309 New Starts-Small Starts Discretionary Grants/ 5309 Bus and Bus Facility Discretionary Grants) total 87.7% of FTA grant funding.

On July 6, 2012, President Obama signed Moving Ahead for Progress in the 21st Century (MAP-21), reauthorizing surface transportation programs through fiscal year 2014. Each reauthorization amends the Federal Transit Laws codified in US Code Title 49 (Transportation) Chapter 53 (Public Transportation) - Federal Transit Act. MAP-21 took effect on October 1, 2012.

The previous Section 5307 Urbanized Area (Formula) Grant Program has been expanded with new Section 5336 and Section 5340 for Growing States and High Density (Formula) Grant Programs (MAP-21 Sections 20007, 20026). These programs provide grants to Urbanized Areas (UZA) for public transportation capital, planning, job access and reverse commute projects, as well as operating expenses in certain circumstances. These funds constitute a core investment in the enhancement and revitalization of public transportation systems in the nation's urbanized areas, which depend on public transportation to improve mobility and reduce congestion.

The previous Section 5309 Bus and Bus Facilities (Discretionary) Grant Program has been replaced by Section 5339 (MAP-21 Section 20029) Bus and Bus Facilities (Discretionary) Grant Program. This program provides capital funding to replace, rehabilitate and purchase buses and related equipment and to construct bus-related facilities.

In MAP-21, the grant programs that are most relevant for BRT projects are (a) Section 5309 Fixed Guideway Capital Investment (Discretionary) Grants Program ("New Starts") (MAP-21 Section 20008), replacing the previous Section 5309 New Starts/Small Starts (Discretionary) Program and (b) Section 5337 State of Good Repair (Formula) Grants, replacing the previous 5309 – Fixed Guideway Modernization Formula Program). They are summarized below.

Section 5309 Fixed Guideway Capital Investment (Discretionary) Grants Program "New Starts") (MAP-21 Section 20008). It provides grants for new and expanded rail, bus rapid transit, and ferry systems that reflect local priorities to improve transportation options in key corridors. This program defines a new category of eligible projects, known as core capacity projects, which expand capacity by at least 10% in existing fixed guideway transit corridors that are already at or above capacity today, or are expected to be at or above capacity within five years. The program also includes provisions for streamlining aspects of the New Starts process to increase efficiency and reduce the time required to meet critical milestones. The funding levels for 2013 and 2014 will be $1,907,000,000 for each of the two years. Eligible Projects include

- New fixed guideways or extensions to fixed guideways (projects that operate on a separate right-of-way exclusively for public transportation, or that include a rail or a trolley system).
- Bus rapid transit projects operating in mixed traffic that represent a substantial investment in the corridor.
- Projects that improve capacity on an existing fixed-guideway system.

Funding requirements include:

- This discretionary program requires project sponsors to undergo a multi-step, multi-year process to be eligible for funding.
- Maximum federal share is 80%.

Section 5337 State of Good Repair Grants (replacing the previous Section 5309 Fixed Guideway Modernization (Formula) Grant Program). This formula-based program is a new FTA's first stand-alone initiative written into law that is dedicated to repairing and upgrading the nation's rail transit systems along with high-intensity motor bus systems that use high-occupancy vehicle lanes, including bus rapid transit (BRT). These funds reflect a commitment to ensuring that public transit operates safely, efficiently, reliably, and sustainably so that communities can offer balanced transportation choices that help to improve mobility, reduce congestion, and encourage economic development. Eligible Recipients include state and local government authorities in urbanized areas with fixed guideway public transportation facilities operating for at least 7 years. The funding levels for 2013 and 2014 are $2,136,300,000 and $2,165,900,000, respectively. Federal share is 80% with a required 20% match. Although the program comprises two separate formula programs, namely High Intensity Fixed Guideway and High Intensity Motorbus, the former comprises 97.15% of FY 2013 and FY 2014 apportionments.

Details about FTA grant programs can be found at FTA (2013a). However, the current details posted pertain to FTA Grant Programs authorized under the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), signed into law on August 10, 2005 by President George W. Bush. Details about changes authorized in MAP-21 can be found at an FTA website (FTA, 2013b) and in FTA **Federal Register,** Vol. 77, No. 200 (National Archives and Records Administration, 2012). FTA (FTA, 2013b) also contains FY2013 Apportionments, Allocations, Program Information and Interim Guidance under MAP-21.

A key requirement that all transportation projects must meet is the National Environmental Policy Act (NEPA) of 1969. The purpose of NEPA was to "declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality." Council on Environmental Quality (CEQ) was established in the Executive Office of the President and created federal regulations, whose purpose "is to tell federal agencies what they must do to comply with the procedures and achieve the goals of the Act." Current CEQ regulations for implementing NEPA are stated in Title 40 of Code of Federal Regulations Parts 1500-1508, often abbreviated as 40 CFR Parts 1500-1508 and can be found at CEQ (CEQ, 2013a). The Council on Environmental Quality established NEPAnet as the web site to serve as a central repository for NEPA information (CEQ, 2013b).

The directly relevant federal regulation for BRT project is 23 CFR 771 (GPO, 2013). "This regulation prescribes the policies and procedures of the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) for implementing the National Environmental Policy Act of 1969 as amended (NEPA), and supplements the NEPA regulation of the Council on Environmental Quality (CEQ), 40 CFR parts 1500 through 1508 (CEQ regulation). Together these regulations set forth all FHWA, FTA, and Department of Transportation (DOT) requirements under NEPA for the processing of highway and public transportation projects." US DOT developed an Environmental Review Toolkit to assist its employees and grant applicants in understanding and abiding the nation's environmental laws and regulations (USDOT, 2013).

The FTA published FY 2013 New Starts and Small Starts Evaluation and Rating Process to describe the methodology that the Federal Transit Administration (FTA) uses to evaluate and rate candidate New Starts and Small Starts projects as of August 2011 (FTA, 2011a). This process requires that projects proposed for New Starts funding be justified based on a comprehensive review of the criteria and measure of performances summarized in the Table 5.

FTA assigns a summary project justification rating of *High, Medium-High, Medium, Medium-Low* or *Low* to each project based on consideration of the ratings applied to these project justification criteria and the specific measures.

To further assist grant applicants, the Federal Transit Administration (FTA) produced *Reporting Instructions for the Section 5309 New Starts Criteria* to inform sponsors of proposed New Starts projects of the information they must provide to FTA so that it may undertake the legislatively required evaluations and ratings of project merit (FTA, 2011b). As part of this effort, the FTA even prepared WORD and EXCEL document templates to facilitate the application process.

State government has jurisdiction over highways designated as State Routes and has the responsibility of ensuring good levels of service on such State Routes. Any planned infrastructure modifications that may result in significant impact on the traffic conditions and hence service levels on such State Routes must be reported to the State Government, and traffic analyses required by the State must be conducted and results reported to the State Government for possible approval or consent. The scope and levels of detail of such analyses required by the State of California are specified in Caltrans (2002). Various measures of effectiveness by facility type are listed in Appendix C.

The FTA's project evaluation criteria and process may be different from a state's counterparts. Such differences may cause delays to project implementations. Miller (2011) studied the differences between the FTA's criteria and process and California's. All the BRT guidebooks cited so far contain discussions on major performance measures and stakeholders that should be considered in the decision-making process for BRT planning and implementation. In the next section, we will discuss a critically important but often neglected stakeholder.

Table 5: New Starts and Small Starts Project Justification Criteria (Table II-1 of (FTA, 2011a))

Criterion	Measures/Categories
Mobility Improvements (New Starts only)	• Number of Transit Trips • User Benefits per Passenger Mile • Number of Transit Dependents Using the Project • Transit Dependent User Benefits per Passenger Mile • Transit Dependents Compared to Share of Transit Dependents in the Region
Environmental Benefits (New Starts only)	• EPA Air Quality Designation
Operating Efficiencies (New Starts only)	• Incremental difference in system-wide operating cost per passenger mile between the build and the baseline alternatives
Cost Effectiveness (New Starts and Small Starts)	• Incremental Cost per Hour of Transportation System User Benefit between the baseline and build alternatives
Transit Supportive Land Use (New Starts and Small Starts)	• Existing Land Use
Economic Development Effects (New Starts and Small Starts)	• Transit Supportive Plans and Policies • Performance and Impacts of Policies

Source: "Table II-1 New Starts and Small Starts Project Justification Criteria" of (FTA, 2011a).

1.3.2 Critically important but often neglected practical considerations

The Bus Rapid Transit – A Handbook for Partners (Caltrans, 2007) contains the following paragraph about the role of local agencies:

"LOCAL AGENCIES

BRT systems will traverse through many neighborhoods, cities, and unincorporated communities, with their own identities, values, and needs. BRT project team members must be flexible to satisfy these varying local requirements and still propose a BRT project that will be part of a larger coordinated transit network. Cities, CMAs, or similar organizations often want to see a prototype or limited pilot project to determine if BRT can produce adequate benefit before making major commitments. Forming project development teams that include the affected cities and county communities early will enhance the potential for agreement to system parameters. Members of BRT project teams should be prepared to address city council meetings and community groups to inform and educate citizens, help to resolve conflicts, and ultimately gain project support. The project development team should include local officials who could champion for the project."

Almost all major BRT projects rely on FTA as a significant source of construction funding, and therefore the guidelines published by FTA on requirements for funding requests have been well known in the industry. However, transit agencies do not "own" the roads, but cities do. BRT projects and possible lane-conversion elements must be approved by the city legislature, and this points out the importance of the legislators and their constituents. For example, the Council members of the City of Berkeley did not approve the lane-conversion along the Telegraph Avenue proposed by the AC Transit for the East Bay BRT Project, and the Berkeley portion of the original Berkeley-Oakland-San Leandro BRT Corridor is removed from the scope of detailed design and construction.

Ultimately, it is the approval (i.e., votes) of city council members that matters the most. The city council members are elected by and represent the citizens of the city or the corresponding districts. This in turns reflects the critical importance of the opinions of the citizens who may be negatively affected in a significant way. This is particularly important in cases where (a) a long stretch of a target BRT corridor does not have sufficient right-of-way to accommodate at least two general-purpose lanes, one left-turn lane (at major interactions) plus the one dedicated BRT lane per direction, particularly after conversion of parking lanes for moving traffic, and (b) such a stretch is lined with retail stores on both sides of the street, with a sidewalk (separating the roadway from the stores) that is not sufficiently wide to be narrowed. The importance results from the merchants' fear of loss of business due to possible traffic congestion and hence possible avoidance of the stretch by potential customers. This was the primary concern of some of the merchants whose retail stores are located on such a stretch on the Telegraph Avenue in Berkeley. In such areas, efficient space allocation is particularly important. The slanted median BRT lanes proposed recently can reduce right-of-way requirement and may be able to significantly reduce resistance from the merchants.

In a 2007 Berkeley City Council meeting, as reported on the front page of The Berkeley Daily Planet (September 21, 2007), a representative of the Friends of Bus Rapid Transit was the only public speaker indicating that he favored the BRT option with dedicated lanes. Eight or nine opponents spoke against the proposal. A member of the Telegraph Avenue Merchants Association, which opposes the BRT with dedicated lanes, told the council "There were tears when Cody's closed, referring to the book store that shut its doors on Telegraph a year earlier due to declining revenues. The merchant said that creating a dedicated bus lane would increase traffic on Telegraph, making it more convenient for people to shop at the Emeryville mall than at smaller Berkeley stores. The merchant urged the council to "have a discussion with the public." Other groups on record opposing BRT with dedicated lanes include the Claremont-Elmwood and Willard neighborhood associations. "There's clearly significant opposition to BRT," said a councilmember. "There are some very legitimate concerns on the potential impact of the bus lanes. The merchants are clearly concerned."

2.0 Solicit Information and Advice from Stakeholders for Guidelines for BRT Project Approval

The goal of this task is to survey expert BRT practitioners, within and outside California. The focus of the survey will be: the BRT project approval decision-making process, the impacts of BRT implementation and the MOEs for transit and non-transit system performance. The research team conducted direct interviews and surveys, and emphasized the use of surveys for the nationwide component of this investigation. The research team selected certain BRT projects and interviewed the corresponding BRT Coordinators to obtain how they measure relevant MOEs, such as person throughput, vehicle throughput, and traffic congestion.

The following questions are designed for conducting the survey.

- How do the Districts currently analyze various BRT proposals prepared by local transit agencies, in particular with regard to the threshold on traffic impact?
- What data are required for such analyses? How do the Districts currently secure the data?
- What tools are used for the analyses?
- What are the limitations of the current analysis methods, data and software tools?

The Caltrans District 4, Caltrans District 7, Caltrans District 11, York Region Rapid Transit at Ontario Province of Canada, and Cleveland Healthline BRT, Ohio were interviewed.

2.1 Interview District BRT Coordinators and Project Development Team Members

Interviews were conducted with Caltrans District BRT coordinators and project development team members to examine MOEs in the districts' decision making processes.

2.1.1 Interview with Caltrans District 4 (San Francisco Bay Area)

Over a two-year period from 1999 to 2001, the Alameda-Contra Costa Transit District (AC

Transit) conducted a Major Investment Study to examine the feasibility of providing a new or improved transit service in the Berkeley/Oakland/San Leandro corridor. The following summarizes the process for the BRT planning process and the experiences accumulated by District 4 during the decision-making for the BRT system.

- All analyses to date are done by the transit and local agencies that sponsor the BRT projects.
- District 4 does not have the resources and expertise to do an independent analysis and evaluation.
- Expertise can be acquired if the required resources are available.
- Caltrans reviews agency's analysis results. When conducting reviews, looking at key locations to see whether findings are reasonable or not.
- District 4 expressed concern about AC Transit's analysis result of not having a Level of Service of F at any intersection even when two general-traffic lanes are reduced to one.
- Decisions were made solely on impact to traffic (Level of Service – LOS).
- If there would be service degradation, a degraded level of service is acceptable as long as it is between LOS C and D or better.
- LOS degradation also depends on the level at no-built condition, i.e., maintaining a similar level of service as existing condition.
- Consideration of tradeoffs between person-throughput and LOS requires policy and guidelines

District 4 uses Synchro for traffic analysis. When necessary, they can get data for Synchro from local agencies. However, District 4 does not have tools to evaluate or analyze traffic diversion and modal shift. Forecast models typically being used are not refined enough to accurately reflect transit rider demand shift when a BRT is introduced thereby improving the transit travel time.

2.1.2 Interview with Caltrans District 7 (Los Angeles/Ventura Counties)

District 7 gained experience for BRT decision making from the Big Blue Bus of Santa Monica Route 1 project. The following findings are obtained from the interview:

- District 7 did not have the resources or data to conduct independent thorough analysis. District personnel conducted high level reviews with comments on the proposal by local agencies.
- Level of Service has been a critical consideration for Caltrans recommendation. Typically, LOS C or better is acceptable. Anything below LOS C would necessitate mitigation methods.

District 7 has Synchro for traffic analysis and suggested that tools for demand forecasting and mode shift will be helpful for decision making.

2.1.3 Interview with Caltrans District 11 (San Diego/Imperial Counties)

District 11 has gained experience from a number of BRT projects, including San Diego Mid-City Rapid Bus, San Diego South Bay BRT, San Diego Escondido Breeze BRT, and San Diego I-15 Corridor BRT. Currently, District 11 is working with local agencies on a project study that involves an overpass structure over a State route. Caltrans is evaluating whether such BRT deployment would impact the operations on the State route.

District 11 used the term “review” to define their role in the analysis, evaluation and validation process. Similar to other Caltrans districts, LOS has been used as a primary MOE for District 11’s position on BRT projects. Specifically, a BRT plans are acceptable to the District as long as LOS projections are not below C. If LOS forecasts are D, E or F, then mitigations are required.

District 11 has Synchro for traffic analysis. It may request that the local agency provides Synchro output files that contain all the details. District 11 may even run its own Synchro, but for a limited number of intersections.

2.1.4 Comparisons of three Caltrans Districts

The following table briefly summarizes the findings from three Caltrans Districts.

Table 6 Comparison of Inputs from Three Caltrans Districts

	D4	D7	D11
Roles on decisions for BRT Planning	Review only, no independent analysis	Review only, no independent analysis	Mainly review; may conduct analysis for a few intersections
Thresholds for accepting BRT plans	At a similar level before the BRT, between LOS C and D	LOS C or better	LOS C or better
Tools and data	Use Synchro for traffic analysis; need data from local agencies		
Constraints	Caltrans Director’s policy on BRT is available but need (1) resources to support the evaluation, (2) tools to estimate mode –shift, people throughput, and traffic diversion, (3) specific policy on thresholds for accepting BRT plans		

3.0 Investigate MOEs and Other Review Criteria in Caltrans Districts and Transit Agencies

The outcome from the interviews in Task 2 raised comments from the Project Panel, recommending a new focus for this research. In September 2013, Senate Bill (SB) 743 was signed by the Governor which affects the way transportation impacts are analyzed under the California Environmental Quality Act (CEQA). SB 743 requires transportation agencies (such as Caltrans) to no longer exclusively use Level of Service (LOS) when planning a transportation system. By July 1, 2014 the Governor's Office of Planning and Research (OPR) was required to develop an initial draft of alternative metrics, which may include

- vehicle miles traveled
- vehicle miles traveled per capita
- automobile trip generation rates
- automobile trips generated

It was agreed, based on discussions with our Caltrans Project Manager, that PATH would change the original focus of Tasks 3 and 4 to investigate ways to incorporate Measures of Effectiveness (MOE) that are consistent with SB 743.

The following set of questions was designed to conduct interviews with both Caltrans districts and transit agencies.

Question 1: What trade-offs between person-throughput and vehicle-throughput have been considered in BRT projects?
Question 2: What MOEs are used in planning and evaluating transportation projects?
Question 3: Have there been before and after studies conducted for BRT planning projects (at stages of BRT planning, before and after the BRT project, where data was collected and compared)?
Question 4: Can Caltrans get access to the raw data used in the analysis by transit agencies?

Two Caltrans districts, including Districts 4 and 11, and AC Transit in the San Francisco Bay Area were interviewed. Caltrans District 7 responded to the questions in writing. The discussions with the districts during the interviews extended to other topics as well.

3.1 Additional Interviews with Caltrans District

Under Subtask 3.1, PATH performed follow-up interviews with Caltrans district personnel to determine what sort of information was focused on when reviewing the projects and why. The goal of this sub-task was to identify MOEs and other review criteria. This section summarizes the interviews and inputs from these districts.

3.1.1 Additional interviews with Caltrans District 4

Caltrans District 4 was interviewed in May 2014. The interview and subsequent correspondence are captured and summarized below.

3.1.1.1 The trade-off between person-throughput and vehicle-throughput in BRT planning projects

The conversion of a dedicated lane from existing traffic lanes likely has negative impacts on the overall traffic flow. It is important from the planning study to demonstrate that the potential increase in person-throughput introduced by BRT can help offset this impact.

The trade-off between person-throughput and vehicle-throughput should be evaluated when reviewing a BRT project. Based on District 4's experience with the Van Ness (VN) BRT project, the project review was done in the environmental approval phase, based on the needs and purposes of the project. In the case of the VN BRT project, the needs were to improve transit trip times and reliability. There was no mention of performance regarding vehicle-throughput on the corridor. Whether the person-throughput or vehicle-throughput would be higher or lower with the implementation of the BRT project was not actually evaluated. Thus, one of the key steps for evaluating BRT fairly is to make sure the statement of need and purpose contains language regarding the need to increase person-throughput or decrease person-delay.

3.1.1.2 MOEs used in evaluating transportation projects

LOS is a commonly used MOE while others are important too. The selection of the MOEs will depend on the nature of the projects and the evaluation criteria. For BRT projects, the most informative MOEs are vehicle-throughput, person-throughput, vehicle-delay, and person-delay.

It is expected that reassigning a traffic lane to be a dedicated transit lane would have negative impacts on vehicular operations. Using LOS has been a primary way to evaluate whether the intersections can operate adequately. The performance of parallel routes, also measured by LOS, has been used as a guide to ensure that the forecasted redistribution of traffic is acceptable. However, intersection LOS has often been used without regard for the potential to overlook adverse impacts on an approach or a movement at an intersection.

In evaluating the traffic impacts, comparative analyses are typically carried out in the environmental studies, where the proposed system is evaluated against the no-build alternative and other alternatives to reveal the advantages of the proposed system versus the other options. The accuracy of models for forecasting traffic and for traffic analysis is an issue.

3.1.1.3 Before and after study

Typically, a traffic study is customarily performed to evaluate the environmental impact of the project to compare the proposed system versus the no-build alternative and/or other alternatives as a part of the approval process. A before versus after study is typically not part of this environmental process as required by law. Formal before and after studies are seldom performed for any highway improvement project. However, ad hoc and informal studies are frequently conducted to collect before and after data to approximately evaluate how some highway improvement projects have performed.

3.1.1.4 Data availability

Data needed to support evaluation could be obtained from demand forecast models. The "per capita information" would be part of the land use information in the forecast model. The same applies to automobile trip rate per capita data. Please note that some metrics, such as vehicle-miles and automobile trips, may be both forecast demand and operations analysis related.

3.1.2 Additional Interviews with Caltrans District 11

Caltrans District 11 was interviewed in September 2014. The interview and subsequent correspondences are captured and summarized below.

3.1.2.1 The trade-off between person-throughput and vehicle-throughput in BRT planning projects

Performance metrics of a project or a proposal dictate the approach for evaluation. For example, ridership is an important consideration for BRT. Recently, attention is being focused more on person-throughput. However, different performance metrics are interrelated. For example, congestion causes delay for bus operations and buses bunching, which in turn can worsen congestions. Overall good performance for both transit and traffic is important, but sometimes it involves trade-offs.

In the case of District 11, it is important to learn how the district is making decisions in the earlier planning stages. At the higher level, there is need for a policy decision, for example, to be integrated in the regional strategy. BRT carries more passengers and is deemed as a viable option to achieve higher person-throughput. However, when it comes to the implementation and execution levels, there will be issues. For example, if signal priority is given to BRT, thus creating delay for general purpose traffic, how are these effects accounted for? This sometimes presents a challenge.

Assumptions for the impact of a BRT project are often made in the early project stages, but they are not well thought out. Often, it is based on more qualitative rather than quantitative approaches. For example, it is assumed that the availability of BRT will cause certain levels of modal shift, yet the effects are not thoroughly understood. Traditional analysis is not appropriate for BRT-type projects, because it is more automobile-centric.

3.1.2.2 MOEs used in evaluating transportation projects

LOS is a traditional measure. However, for evaluation of larger projects, LOS is far from the only criterion of performance measures. Other performance measures include:

- Speed
- Vehicle Miles Traveled (VMT)
- Generation of green-house gases

- Intersection LOS and delay
- Estimation of ramp queue buildup
- Vehicle hour delay
- Travel time reliability

While these performance measures may all be required for evaluation of a large project, performance measures needs to be selectively used depending on the purpose of a project. One measure is not necessarily more important than the other, as the overall project considerations need to take into account all relevant performance measures. LOS is relevant for freeway operations and ramp, merging and diverging operations. On the other hand, intersection delay is a necessary criterion for corridor projects. It is necessary to compare different projects in the same context.

As far as the use of metrics is concerned, more emphasis on person-throughput and less emphasis on LOS should to be the approach. As with any modal alternative, Caltrans should be concerned with the total person-throughput. Throughput is dependent not just on modal demand but on the ability of the particular mode to deliver that demand. In most urban areas where BRT is to be considered, LOS is not relevant. LOS is not an appropriate measure and indeed doesn't have a technical foundation where saturated conditions are expected.

3.1.2.3 Before and after study

This question is partially covered in previous questions, about the needs for more early-stage evaluation. However, no specific discussions were carried out for this topic.

3.1.2.4 Data availability

Caltrans can access data used by transit agencies via Synchro software. Caltrans also has access to the data from consultants who conducted the analysis.

3.1.2.5 Additional Topics of Discussions:

<u>Needs for Refined Guidelines and Roadmaps</u>

New guidelines need to take into account the evaluation of multi-modal systems. It is necessary to look at the overall system performance. The current approach is to accommodate what is available now for analytics but not comprehensive enough for thorough assessment. Without the proper tools, the public transit sectors may be overestimating the value of a proposed BRT project. In some previous cases, Caltrans questions the analysis results from some transit projects. Questions arise as to what should be addressed in the evaluation or analytical processes, which need to be coordinated between Caltrans and transit agencies or other stakeholders. Most likely, the evaluation of individual projects will be performed on a case-by-case basis. The use of performance measures and approaches for analysis should be coordinated among agencies. Currently, Caltrans is in a reactive mode to such BRT project evaluation. Being proactive and doing evaluation in advance, if it can be done, would be valuable.

It is desirable to develop a roadmap that defines a process through which BRT policy decision-making is made. In this roadmap, impacts to traffic as well as benefits to the corridor can be evaluated in both qualitative and quantitative ways using consistent assumptions and constraints. Caltrans districts would like to participate in the policy decision process.

<u>Forecasting demand</u>

Demand modeling and forecasting modal split will remain problematic in the near future. The economics behind mode shift and modal demand predictions are far from robust. However, the regional planning process used by MPOs and RTPAs is developed generally to show transit benefits within an overall system. For a corridor level study, a number of sound tools are reliable for predicting transit ridership. They have been used for years in transit planning. Caltrans staff needs to become more familiar with the measures of effectiveness that these tools generate.

<u>Tools used for Evaluation</u>

San Diego region uses a "regional transit model" which is a component of the four-step model to forecast ridership based on a variety of inputs. These inputs generally come from socio-demographic, econometric and land use sources. Transit agencies then do detailed service studies looking at routing, scheduling and anticipated ridership based on headways, speeds, subsidy levels, etc.

For the purpose of this work, these tools and their capabilities should be documented. Caltrans staff tends not to be aware that there is a world beyond traffic studies and the highway capacity manual. There are also transit LOS tools much like what you would see for freeway LOS analysis, but the approaches and data differ. The key is that we need to see how these tools, whatever they are, can be used to compare the transit and auto modes. This is at the heart of the issue.

3.1.3 Caltrans District 7

Caltrans District 7 has responded in writing to answer the questions.

3.1.3.1 The trade-offs between person-throughput and vehicle-throughput in BRT planning projects

The focus of the review of the BRT project is based on selections of running ways or on-street or off-street bus service options. Three major objectives to mitigate congestion on the region's roadway system and enhance its performance should be pursued:

- Increase the people-moving capacity of the metropolitan highway system while reducing future demand on the system but increasing the BRT on the arterial and highway systems.
- Manage and optimize, to the greatest extent possible, the existing system.
- Accommodate future demand within the metropolitan highway system.
- Increase trip reliability.
- Reduce travel time.

- Implement strategic and affordable BRT capacity expansion projects.

The following principles are applied when evaluating BRT projects:
- Utilize the most cost-effective operational and management techniques to optimize system performance.
- In effect, this principle states that system and demand management strategies will be prioritized over new capacity for mobility improvement.
- Managed BRTs should be a higher priority for improvement than expanding freeway and highway lanes.
- Highway improvements should enhance and support transit use where existing or planned express transit service exists. The provision of transit advantage may include the conversion of right-side bus shoulder to left-side managed lanes.
- Flexible design may be needed to accommodate an improvement or project within the existing right-of-way. Overall safety must be maintained or improved.

3.1.3.2 MOEs used in evaluating transportation projects

The Measure of Effectiveness is the user-perceived attractiveness of one transit mode compared to another, excluding the influence of factors such as fare, walk time, wait time, in-vehicle travel time, and the need to transfer. The MOE is usually measured as a constant and expressed in minutes of equivalent in-vehicle travel time. Performance measures of a BRT system relate to its performance. There are two basic types of measures:
- *Quantitative* — a measure expressed in terms of counts, dollars, measurements, or other physical units
- *Qualitative* — a measure expressed in terms of people's attitudes, perceptions, or observations

The performance of BRT systems can be measured in terms of passengers earned, ridership growth, travel speeds, and travel time savings. The following quote personifies one view of the MOE:

- Travel Time: The most critical question here is "How much time does the BRT service save?" The relevant measure is travel time savings, measured for each phase of a bus trip and for the trip as a whole. Savings is derived as the difference between the trip times for BRT service (the "after" times) and the baseline (the control or "before" times), depending on the choice of the baseline. Total trip time is of interest as well, for example, to compare to the time it takes to drive the same route in an automobile. This would be equivalent to the sum of the separate times for the two phases. Another related measure is bus speed in miles per hour.
- Schedule Adherence: Related to travel time, schedule adherence is a comparison of the *actual* arrival times of a bus at scheduled stops to the *scheduled* times of arrival; a bus can be on time, late or early.
- Ridership: Ridership is an indirect function of all the BRT components.
- Impacts on Other Traffic

- A BRT demonstration project may have significant effects on other traffic on the BRT route, both positive and negative.
- Decreased traffic levels along its routes may result if the BRT system is able to entice enough automobile drivers to shift modes.
- A secondary benefit, though difficult to measure, would be improved air quality from fewer cars on the roads.
- Parking restrictions and increased enforcement of traffic and parking regulations along an exclusive bus lane may improve the traffic flow for automobiles as well as BRT vehicles. On the negative side, signal priority may increase the time vehicles on side streets have to wait at traffic signals.

3.1.3.3 Before and after study

Many BRT lines have been implemented in the LA region. Before and after studies have been carried out. Operating speeds reflect the type of running way, station spacing, and service pattern. The LOS is estimated based on a time savings. Travel time savings have been reported at 32-47% for busways on freeways, 33% for bus tunnels and 23-28% for general bus lane applications. Busways on essentially grade separated right-of-way generally save 2 to 3 minutes per mile. Bus lanes on arterial streets typically save 1 to 2 minutes per mile. Savings are greatest where buses experienced major congestion.

3.1.3.4 Data availability

District 7 would be able to obtain data collection for evaluation of a BRT (demonstration) including activities that occur during the evaluation implementation phase, which includes data collection and analysis relating to site characteristics and performance measures.

3.2 Interview with Transit Agencies

AC Transit was interviewed for their planning effort on their 14.38-mile Bus Rapid Transit system connecting Berkeley, Oakland, and San Leandro. This BRT system has 34 rail-like stations and 9.5 miles of center dedicated bus lanes (from downtown Oakland to San Leandro accounting for 81% of the corridor) to provide faster and more reliable service. A large segment of the dedicated BRT lanes is on International Blvd., which is a state highway, namely SR 185. Signal priority, off-board fare payment (limited on-board), level passenger boarding, safety and security features, pedestrian access improvements will all be implemented with the BRT system. This project involves $174 million capital investment

3.2.1 The trade-off between person-throughput and vehicle-throughput in BRT planning projects

AC Transit has requested federal funding for the BRT project through the Regional Transportation Improvement Program (RTIP) and has been followed in the project planning process. RTIP is a portion of the State Transportation Improvement Program (STIP) and is in full compliance with the Federal Transportation Improvement Program (FTIP). Additionally, an environmental impact evaluation needs to be conducted as per the Clean Air Act Amendments.

3.2.2 MOEs used in evaluating transportation projects

The typical performance measures recommended in RTIP cover mobility, productivity and congestion and system preservation, as summarized below:

- Under the mobility performance measures, total vehicle miles traveled (VMT) and total vehicle hours traveled are used for roadway vehicles and modal split (transit based people trips) are used for measure transit system.
- Under productivity/congestion relief, performance measures for roadway vehicles, people and the roadway itself are used for evaluation.
- For roadway vehicles, average AM and PM peak hour vehicle trips, average off peak (22 hours) vehicle trips, and average daily vehicle trips (ADT) are used.
- For roadway people in cars, PM period occupancy rate and average daily vehicle occupancy rate are used. Bus ridership is to be used to measure the peak hours and daily occupancy rate for the transit system.
- PM percentage of congested lane miles at LOS E or F is used to measure the congestion level.

Since the BRT system on International Blvd. will convert two center traffic lanes to dedicated BRT lanes, the evaluation is focused on the total roadway capacity, including the loss of the roadway capacity for conventional traffic due to lane conversion and the roadway capacity increase after introduction of the BRT. In AC Transit's study, the roadway capacity is evaluated based on a combination of roadway vehicle occupancy rate and total carrying capacity for BRT buses, factored together by service frequencies. This is essentially a people throughput oriented measure. It is important to note that the total transit carrying capacity is the most desirable condition.

In addition to the MOEs defined by the RTIP, the critical decisions on BRT such as route selection, right-of-way issues, lane arrangements, and station location also need to consider various criteria directly or indirectly raised by the stakeholders who are either the owners or the operators of the roadways, sidewalks, and/or traffic control systems. These criteria may involve parking, bike lanes, curb bulbs, pedestrian crossing/crosswalks, improvements and pedestrian signals, American with Disability Act (ADA) compliant ramps, median refuges and landscaping, etc. Consensus building with the general public has also played an important role in the decision of the BRT route and station selections. Local businesses and average citizens are given opportunities to provide their opinions through public hearings organized by the cities through which the BRT route travels. These inputs have influenced the position of the involved cities and are reflected in the final BRT plan. The negotiation with cities took a substantial amount of effort, time and resources. The AC Transit BRT planning project began in 2000. Because of the project complexity, Caltrans' review took several years to complete. The cities and AC Transit did not reach an agreement on final project terms among them until the spring of 2012.

3.2.3 Before and after study

The performance and impacts of the planned system is typically estimated against current operation and no-build scenarios. The AC Transit study followed the RTIP guidelines and therefore has used the above performance measures in its BRT project planning.

3.2.4 Data availability

The traffic data AC Transit uses are from Caltrans. Assumptions have been made on transit capacity and ridership, which are available to Caltrans in the Major Investment Study report.

3.2.5 Interview with transit agencies outside of California

The project team has also attempted to examine the MOE measurement by transit agencies outside of California. The Chief Engineer of York Region Rapid Transit at Ontario Province of Canada was interviewed. York Transit runs a dedicated BRT system with the major portion on two dedicated lanes, one of the very few such BRT systems in North America. The options York Transit faces are to either add two new dedicated lanes (median), or creating Rapid bus system that shares with other traffic. No conversion is needed. Because the BRT system does not use any road owned by the State, State DOT was not involved in the tradeoff analysis and decision.

4.0 Develop Guidelines for Caltrans for Evaluation and Approval of BRT Projects

Under advice from the project panel, the scope of this project is focusing on the synthesis of MOEs and data used by Caltrans districts with the ones used by transit agencies and the identification of the similarities, differences and gaps among the MOEs used by these stakeholders and the needs for BRT preplanning tools. The guidelines for evaluation and approval will be developed during the next phase of the project.

4.1 Interview Summary of Three Caltrans Districts

Task 3 documented interviews with three Caltrans districts 4, 7, and 11, as well as AC Transit. Besides considering the questions posed prior to the interviews, the discussions during the interviews extended to additional topics. The findings from these interviews are summarized in Table 7 through Table 12.

Table 7 Performance Measures Used for Project Review

D4	D11	D7	AC Transit
• LOS is the primary MOE. • The most informative MOEs are vehicle and person throughput, vehicle delay and person delay • Performance measures are dictated by project purpose and needs (e.g., in the Van Ness project, improvements of ridership and reliability were strongly considered)	• LOS is far from the only criterion of performance measures. Other performance measures include: speed, VMT, green-house gases, intersection LOS, estimation of ramp queue buildup, vehicle hour delay, travel time reliability • Ridership is a relevant criterion for BRT • LOS is important for freeway operations • Intersection delay is important for arterial operation • Performance measures are strongly influenced by the intended purpose of a project	• MOEs for BRT can be measured in terms of ridership growth, travel speeds, and travel time savings, and impact on other traffic • Reflect the user-perceived attractiveness of one transit mode such as fare, walk time, wait time, in-vehicle travel time, and the need to transfer; can be qualitative or quantitative	• MOE for mobility: o total vehicle-miles traveled o total vehicle-hours traveled are used for roadway vehicles o Modal split (transit based person trips) o PM percentage of congested lane-miles at LOS E or F • MOE for Productivity (roadway person-throughput) o PM period occupancy rate and average daily vehicle occupancy rate o peak hours and daily bus ridership • MOE for Productivity (roadway person-throughput) o average AM peak hour vehicle trips o average PM hour vehicle trips o average off peak (22 hours) vehicle trips o average daily vehicle trips (ADT)

Table 8 Trade-off Considerations

D4	D11	D7	AC Transit
• Negative impact caused by creation of dedicated lane must be compensated by increase in person-throughput • Vehicle-throughput and person-throughput should both be reviewed • Parallel route analysis used to check if traffic redistribution is acceptable.	• Caltrans perspective should place more emphasis on person-throughput for BRT and less on LOS • Transit oriented projects may cause delays in general purpose traffic, but not completely accounted for in the initial evaluation	• Increase of the people-moving capacity (person-throughput) of the metropolitan highway system vs. reduction of future demand on the highway system but increasing the BRT on arterial and highway system • Increase trip reliability vs. reduction of travel time • Implement strategic and affordable BRT capacity expansion projects	• Environmental impact evaluation needs to be conducted as per Clean Air Act Amendment

Table 9 Evaluation Process

D4	D11	D7	AC Transit
• Evaluation done at an early stage of environmental review • Technical reviews not necessarily done adequately in the evaluation process	• Assumption often made at the policy level • Typically qualitative decision rather than quantitative • Complications come later at the implementation level	• Utilize the most cost-effective operational and management techniques to optimize system performance and to manage demand for mobility improvement. • Managed BRTs as a higher priority for improvement than expanding freeway and highway lanes, including the conversion of right-side bus shoulder to left-side managed lanes • Flexible design may be needed to accommodate an improvement within the existing right-of-way. • Overall safety must be maintained or improved	• Consensus building with general public has also played an important role in the decision of the BRT route and station selections. • Local businesses and average citizens are given opportunity to provide opinion through public hearings organized by cities. • These inputs have influenced the position of the involved cities and reflected in the final BRT plan. The negotiation with cities took substantial amount of efforts, time and resources. • The AC Transit BRT planning project was started in 2000. Because of the project complexity, Caltrans review took several years to complete. The cities and AC Transit did not reach an agreement on the final project terms among until the spring of 2012.

Table 10 Tools for Evaluation

D4	D11	D7	AC Transit
• Accuracy of traffic forecast and analysis models is an issue • Evaluation of intersection traffic often not comprehensive enough	• Accuracy of forecast model is problematic • Mode shift and modal demand predictions are far from robust. • Transit agencies do detailed service studies looking at routing, scheduling and anticipated ridership based on headways, speeds, subsidy levels, etc. • For a corridor level study, a number of tools are reliable for predicting transit ridership. • Need for Caltrans staff to learn more about transit tools that are existent these tools generate.		

Table 11 Before and After Study

D4	D11	D7	AC Transit
• Typically not conducted for BRT projects		• Operating speeds reflect the type of running way, station spacing, and service pattern. • Bus ways on grade separated right-of-way generally save 2 to 3 minutes per mile • Bus lanes on arterial streets typically save 1 to 2 minutes per mile. • Savings are greatest where buses experienced major congestion	• The performance and impacts of the planned system is typically estimated against current operation and no-build scenarios. • Follow the RTIP guideline therefore have used the above performance measures in their BRT project planning

Table 12 Data, Evaluation Process, Evaluation Tools, Guidelines, and Roadmap

D4	D11	D7	AC Transit
• Mostly available from forecasting model	• Data used by transit agencies accessible via Synchro software and from some consultants as well	District 7 is able to obtain data for evaluating a BRT (demonstration) including activities that occur during the implementation phase include data collection and analysis relating to site characteristics and performance measures.	• The traffic data AC Transit uses are from Caltrans. Assumptions have been made on transit capacity and ridership, which are available to Caltrans in the major investment study report.
• Need to ensure project need and purpose cover critical metrics in the project statement (in early stages)	• Currently evaluation is done by accommodating available analytics, but it is not comprehensive enough • Caltrans needs to be more proactive, rather than reactive as it is now • Caltrans districts would like to participate in the policy decision process		
	• Desirable to develop a roadmap that defines a process through which the BRT policy decision is made. • In this roadmap, impacts to traffic as well as benefits to the corridor can be evaluated in both qualitative and quantitative manners using consistent assumptions and constraints.		

4.2 Comparison of MOEs and Data Used By Caltrans Districts with Those Used by Transit Agencies

The feedback obtained from this study indicate Caltrans and transit agencies consider a set of consistent MOEs for assessing mobility, productivity, congestion and system preservation when a BRT plan is reviewed. The following MOEs are best summarized using the performance measures recommended in the State Transportation Improvement Program (STIP), which includes the Regional Transportation Improvement Program (RTIP). These MOEs are in full compliance with the Federal Transportation Improvement Program (FTIP). STIP/RTIP includes common guidelines for each region to follow when major improvement projects such as BRT are planned.

- Under the mobility performance measures, total vehicle miles traveled (VMT) and total vehicle hours traveled (VHT) are used for roadway vehicles and modal split (transit-based person trips) is used to measure the transit system.
- Under productivity/congestion relief, performance measures for roadway vehicles, people and the roadway itself are used for evaluation.
- For roadway vehicles, average AM and PM peak hour vehicle trips, average off peak (22 hours) vehicle trips, and average daily vehicle trips (ADT) are used.
- For roadway people in cars, PM period occupancy rate and average daily vehicle occupancy rate are used. Bus ridership is to be used to measure the peak hours and daily occupancy rate for the transit system.
- PM percentage of congested lane-miles at LOS E or F is used to measure the congestion level.

In addition to the MOEs defined by the RTIP, the critical decisions on BRT; such as route selection, right-of-way issues, lane arrangements and station location; also need to consider various criteria directly or indirectly raised by the stakeholders who are either the owners or the operators of the roadways, sidewalks, or traffic control systems. These criteria may involve parking, bike lanes, bus bulb-outs or curb extensions, pedestrian crossing/crosswalks, improvements and pedestrian signals, ADA compliant ramps, median refuges and landscaping, etc. Generation of green-house gases is also an important MOE for transportation air quality conformity analysis conducted under environmental studies.

4.3 The Similarities and Gaps of MOEs, Data and Tolls for Assessing BRT

The PATH team reviewed the input from Caltrans districts as well as AC Transit and investigated the similarities, gaps and tools for assessing BRT and has concluded the following:

4.3.1 Similarities and gaps in MOEs

According to the interviews, Caltrans districts and AC Transit reference a similar set of MOEs, which are consistent with those that are recommended by STIP/RTIP and the Clean Air Act Amendments. However, it is recognized that not all MOEs are weighted equally by every agency in the evaluation of specific BRT projects.

As BRT planning is typically conducted by transit agencies who are owners of the BRT project, a full set of MOEs are required to be used during the phases of Major Investment Studies, Environmental Studies and detailed designs. Caltrans districts, on the other hand, are responsible for review and approval of the BRT segments or aspects that are relevant to State highway systems. While Caltrans districts have been traditionally reviewing the completeness of the MOEs used in the studies, their main focus has been on impacts to the State highway system. LOS has been an important MOE for measuring highway and intersection operations. However, Caltrans and transit agencies have recognized the shortcomings of LOS and are investigating ways to integrate person-throughput into performance measures and in the context of the specific projects.

Equally important to the selection of appropriate MOEs are the assumptions. Different parametric assumptions on the MOEs can result in very different results. For example, when lane conversion is planned for a dedicated BRT system, the assumption of BRT operating at full capacity will affect the estimation of the person-throughput at the corridor level. An argument may be made that ridership for a new BRT system would be low at the initial stages and can vary significantly between peak and non-peak hours and the peak of transit and surface traffic may not overlap. It is important to note that modal split has been based on mode choice models but data has not been available to support the ridership assumptions that are easily verifiable and agreed upon by all stakeholders.

Data to support these studies are typically collected by the transit agencies that are responsible for the BRT projects. The traffic data for State highways are mostly acquired from Caltrans. In addition to the lack of supporting data for ridership assumptions, the availability and quality of other types of data used in BRT evaluations may also present issues.

4.3.2 Criteria beyond traditional MOEs

The approval of BRT projects is a highly political process. The outreach to local communities can be a long and enduring process. In addition to the MOEs defined by the RTIP, the critical decisions on BRT such as route selection, right-of-way issues, lane arrangements, and station location also need to consider various criteria directly or indirectly raised by the stakeholders who are either the owners or the operators of the roadways, sidewalks, and/or traffic control systems. These criteria may involve parking, bike lanes, bus bulb-outs or curb extensions, pedestrian crossing/crosswalks, improvements and pedestrian signals, ADA compliant ramps, median refuges and landscaping, etc. Consensus building with the general public has also played an important role in the decision of the BRT route and station selections. Local businesses and average citizens are given opportunities to provide their opinions through public hearings organized by the cities through which the BRT route travels. These inputs have influenced the position of the involved cities and are reflected in the final BRT plan. The negotiation with cities requires a substantial amount of effort, time and resources. The AC Transit BRT planning project began in 2000. Because of project complexity, Caltrans' review took several years to complete. The involved cities and AC Transit did not reach an agreement on final project terms until the spring of 2012.

4.3.3 Gaps, needs and next steps

Through the interviews, the following gaps and needs have been identified.

1) **A systematic approach with guidelines and roadmaps:** While the planning and development of BRT systems follow the general guidelines for an infrastructure project, BRT has its own characteristics and the BRT projects require different levels of involvement by various stakeholders. It is important that the guidelines and roadmap for BRT planning and implementation are developed and transparent to all stakeholders so that Caltrans can be more proactive and involved rather than reacting to the request of project review.

   As a part of this systematic approach, stakeholders' participation of the planning process from the start of the project is critical. The objectives of the BRT projects are defined at the early stage by the agency that is in charge of the planning, design and deployment of these projects. These objectives will often drive the decisions to be made throughout the project by the involved stakeholders. It is desirable that all impacted agencies including Caltrans are involved in the project definition stage such that consensus making can be easier later on.

2) **A better way to incorporate person-throughput in MOEs:** Person-throughput has been emphasized in recent years. For a corridor, person-throughput is the overall roadway capacity based on a combination of roadway vehicle occupancy rate and total carrying capacity for BRT buses, factored together by service frequencies. Methods to estimate the occupancy of roadway vehicles and transit/BRT vehicles under various operating conditions are needed in order to be able to reasonably assess whether the impacts of converting dedicated lanes can be justified by the total person-throughput.

3) **Tools for assessing benefits and impacts:** During the interviews, Caltrans districts have all expressed the strong need for a set of high level tools that can be used to conduct an initial evaluation of BRT proposals, including the alternatives and do nothing approaches and a trade-offs assessment using different MOEs, to test various assumptions and hypotheses to support a sound and balanced decision making process. Approaches and tools for before and after evaluation for BRT projects are also desired by the stakeholders.

4) **Definition of data needs:** Although current BRT studies have used a standard set of planning and traffic data, the types and quality of data are not consistent. As a part of the BRT tool box, it is critical to define the needs and quality of the data.

In the next phase of the study, the project team plans to address the above gaps and needs and to explore possible ways to configure a set of tools for supporting BRT decisions at an early stage.

5. Summary

Under this project, the existing practice and issues associated with BRT planning and deployment have been studied. The study first reviewed literatures in order to establish a solid understanding of the BRT planning processes and MOEs used in these processes. The study then interviewed expert practitioners in three metropolitan Caltrans Districts (District 4, District 7, and District 11) to investigate the BRT project approval decision-making process, the impacts of BRT implementation, the MOEs for transit and non-transit system performance, and the approaches the Districts currently use to analyze various BRT proposals prepared by local transit agencies, in particular with regard to the threshold on traffic impacts, the types of data and tools required for such analyses, and the limitations of the current analysis methods, data and software tools.

The study revealed that Caltrans' districts have primarily filled the role as reviewers of the BRT plan from the perspective of impacts to highway operation. In most cases, no independent analysis was conducted by the districts. Occasionally, traffic analyses using Synchro was performed for a limited number of intersections. The thresholds for accepting BRT plans during these reviews have been based on Level of Service (LOS). Typically, the 'after' performance should be either at a similar level before the BRT was built or in between LOS C and D. Although the Caltrans director's policy on BRT was used as the guidance, the resources to support a thorough evaluation were not available. Tools for estimating the mode shift, person-throughput and traffic diversion were not available. There is no specific policy on the thresholds for accepting BRT.

In light of Senate Bill (SB) 743, the Project Panel recommended a new focus for this research to investigate how broadly defined MOEs using person-throughput can be applied to the BRT planning process. Subsequently, PATH has focused later tasks to further investigate the specific MOEs used by Caltrans and transit agencies in order to identify that set of MOEs that would be consistent with SB 743.

Through additional interviews, the MOEs and data used by Caltrans districts and those used by transit agencies were summarized and compared. The studies revealed that though Caltrans and transit agencies use a similar set of MOEs for the evaluation of BRT projects, but the emphasis and parametric assumptions for the MOEs may be different. These differences can influence the results of the evaluation. Furthermore, this study concluded that a systematic approach needs to be developed and taken during the BRT planning process. A better way of evaluating person-throughput should be incorporated as an important part of this evaluation process. The study recommends developing a data definition for BRT evaluation and tools that will facilitate the preplanning decision process of BRT projects.

The findings from this project established the foundation for further investigation of the approaches for improving the current BRT planning practice and for development of tools and guidelines to assist Caltrans in the evaluation and approval process of future BRT projects.

REFERENCES

AC Transit. 2010. *AC Transit East Bay Bus Rapid Transit Project: Transit Patronage and Forecasting Methodology Report*, Alameda-Contra Costa Transit District, Oakland, California, U.S.A., accessed online on March 25, 2013 at http://www.actransit.org/wp-content/uploads/ACT_EBBRT_TransitRidershipForecasting_0Main.pdf

AC Transit. 2011. *AC Transit East Bay Bus Rapid Transit Project: Neighborhood Traffic Diversion and Change in Local Circulation Patterns Analyses*, Alameda-Contra Costa Transit District, Oakland, California, U.S.A., accessed online on March 25, 2013 at http://www.actransit.org/wp-content/uploads/ACT_EBBRT_NeighborhoodDivReport_0Main.pdf

AC Transit. 2012a. *AC Transit East Bay Bus Rapid Transit Project in Alameda County –Final Environmental Impact Statement/Final Environmental Impact Report (FEIS/FEIR)*, Alameda-Contra Costa Transit District, Oakland, California, U.S.A., accessed online on Dec. 29, 2012 at http://www.actransit.org/final-environmental-impact-statementfinal-environmental-impact-report-feisfeir/.

AC Transit. 2012b. *AC Transit East Bay Bus Rapid Transit Project – Final Environmental Impact Statement/Report: Community Meetings February – March 2012*, Alameda-Contra Costa Transit District, Oakland, California, U.S.A., accessed online on Dec. 29, 2012 at http://www.actransit.org/wp-content/uploads/BRT-Exhibit-Boards.pdf.

AC Transit. 2012c. *AC Transit East Bay Bus Rapid Transit Project: Supporting Technical Reports to the FEIS/FEIR*, Alameda-Contra Costa Transit District, Oakland, California, U.S.A., accessed online on March 25, 2013 at http://www.actransit.org/supporting-technical-reports-to-the-feisfeir/.

AC Transit. 2012d. *AC Transit East Bay Bus Rapid Transit Project: Traffic Analysis Report*, Alameda-Contra Costa Transit District, Oakland, California, U.S.A., accessed online on March 25, 2013 at http://www.actransit.org/wp-content/uploads/ACT_EBBRT_TrafficReport_0Main.pdf.

AC Transit (2013). *AC Transit East Bay Bus Rapid Transit Project:Photosimulation*, Alameda-Contra Costa Transit District, Oakland, California, U.S.A., accessed online on March 25, 2013 at http://www.actransit.org/east-bay-brt-photosimulations/

Ang-Olson, J. and Mahendra, A. (2011), "Research Results Digest 352 - Cost/Benefit Analysis of Converting a Lane for Bus Rapid Transit—Phase II Evaluation and Methodology," Transportation Research Board, Washington, D.C., USA.

California Department of Transportation (Caltrans) (2002), *Guide For The Preparation Of Traffic Impact Studies*, Sacramento, California, U.S.A.
California Department of Transportation (Caltrans) (2007), *Bus Rapid Transit – A Handbook for*

Partners, Sacramento, CA; accessed at http://www.dot.ca.gov/hq/MassTrans/Docs-Pdfs/BRT/BRT-Handbook-030706.pdf on march 25, 2013; also published as MTI Report 06-02 by the Mineta Transportation Institute of San Jose State University, with George Gray, Norman Kelley and Tom Larwin as authors.

Callaghan, L. and Vincent, W. (2007), "Preliminary Evaluation of Metro Orange Line Bus Rapid Transit Project," *Transportation Research Record*, n 2034, p 37-44, 2007, *Transit Marketing, Bus, and Paratransit.*

Carey, G. 2006. "Bus Rapid Transit – The Eugene–Springfield, OR, USA, Experience," *ITE Journal*, Jul. 2006, pp. 20 – 23, Institute of Transportation Engineers, Washington, D.C.

Chen, X., Yu, L., Yu, L., and Guo, S. (2007), "Impacts of exclusive lanes and signal priority on bus rapid transit effectiveness," Proceedings of 2007 International Conference on Transportation Engineering, pp. 364-369.

Council on Environmental Quality (CEQ) (2013a), Council on Environmental Quality Regulations for Implementing NEPA, accessed on March 25, 2013 at http://ceq.hss.doe.gov/ceq_regulations/Council_on_Environmental_Quality_Regulations.pdf and http://ceq.hss.doe.gov/nepa/regs/ceq/toc_ceq.htm.

Council on Environmental Quality (CEQ) (2013b), NEPAnet, accessed on March 25, 2013 at http://ceq.hss.doe.gov/nepa/nepanet.htm .

Federal Transit Administration (FTA) (2011a), FY 2013 New Starts and Small Starts Evaluation and Rating Process, accessed on March 25, 2013 at http://www.fta.dot.gov/documents/FY13_Evaluation_Process.pdf.

Federal Transit Administration (FTA) (2011b), Reporting Instructions for the Section 5309 New Starts Criteria**, accessed on March 25, 2013 at** http://www.fta.dot.gov/printer_friendly/12304_2619.html.

Federal Transit Administration (FTA) (2013a), Federal Transit Administration Grant Programs, accessed on March 25, 2013 at http://www.fta.dot.gov/grants.html.

Federal Transit Administration (FTA) (2013b), Moving Ahead for Progress in the 21st Century - MAP-21, accessed on March 25, 2013 http://www.fta.dot.gov/map21/.

Institute for Transportation & Development Policy (ITDP) (2007), *Bus Rapid Transit Planning Guide*, 3rd Edition, New York, New York; accessed at http://www.itdp.org/microsites/bus-rapid-transit-planning-guide/brt-planning-guide-in-english/ on March 25, 2013.

Jarzab, J.T., Lightbody, J., and Maeda, E. 2002. "Characteristics of Bus Rapid Transit Projects: An Overview," *Journal of Public Transportation*, Vol. 5, No. 2, 2002, pp. 31- 46.

Journal of Public Transportation, Special Edition: BRT 2002, Volume 5, No. 2 2002; accessed at http://www.nctr.usf.edu/2002/10/journal-of-public-transportation-vol-5-no-2-2002/ on March 25, 2013.

Journal of Public Transportation, Special Edition: BRT 2006, Volume 9, No. 3, 2006; accessed at http://www.nctr.usf.edu/2006/06/journal-of-public-transportation-vol-9-no-3-special-edition-brt-2006/ on march 2013.

Kittelson & Associates (2007), *TCRP Report 118, Bus Rapid Transit Practitioner's Guide*, Transportation Research Board, Washington, D.C.

Lane Transit District. 2002. *Eugene-Springfield, Oregon East-West Pilot BRT*, Eugene, Oregon, USA; http://gulliver.trb.org/publications/tcrp/tcrp90v1_cs/Eugene.pdf, accessed on Dec. 29, 2012.

Levinson, H.S., Zimmerman, S., Clinger, J. and Rutherford, C.S. 2002. "Bus Rapid Transportation: An Overview," *Journal of Public Transportation*, Vol. 5, No. 2, 2002, 1 – 30.

Levinson, H.S., Zimmerman, S., Clinger, J., Rutherford, S., Smith, R.L., Cracknell, J., and Soberman, R. (2003a), *TCRP Report 90, Volume I: Bus Rapid Transit: Case Studies in Bus Rapid Transit*, Transportation Research Board, Washington, D.C.

Levinson, H., S. Zimmerman, J. Clinger, J. Gast, S. Rutherford, and E. Bruhn (2003b). *TCRP Report 90, Vol II: Bus Rapid Transit: Implementation Guidelines*, Transportation Research Board, Washington, D.C.

Li, Y.I., Li, J-Q., Miller, M.A., and Zhang, W.-B. (2011), "Assess the Trade-Offs between People Throughput and Level of Service Degradation in the Conversion of a Mixed Flow Lane to a Bus Only Lane on US 101," California PATH Research Report, UCB-ITS-PRR-2011-03, Institute of Transportation Studies, University of California, Berkeley, California, USA.

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

Miller, M.A.; Tan, C.-W.; Golub, A.; Hickman, M.; Lau, P.; Zhang, W.-B. 2006. *Development of Deployment Strategy for an Integrated BRT System,* PATH Research Report, UCB-ITS-PRR-2006-9, Institute of Transportation Studies, University of California, Berkeley, U.S.A. 2006.

Miller, M.A. (2011), "State and Federal Project Development Procedures for Bus Rapid Transit: Managing Differences and Reducing Implementation Delays," California PATH Research Report UCB-ITS-PRR-2011-08, Institute of Transportation Studies, University of California, Berkeley, California, USA.

National Archives and Records Administration (2012), Federal Register, Vol. 77, No. 200 (Part V – Department of Transportation), Tuesday, October 16, 2012.

National Bus Rapid Transit Institute (NBRTI) (2013), *BRT Database*, accessed at http://www.nbrti.org/database.html on March 25, 2013.

National Bus Rapid Transit Institute (NBRTI) (2009), *Characteristics of Bus Rapid Transit for Decision-Making*, Diaz, R.B. (Editor), Center for Urban Transportation Research, University of South Florida, February 2009, accessed at http://www.nbrti.org/CBRT.html on March 25, 2013.

Papageorgiou, G., Ioannou, P., Pitsillides, A., Aphamis, T., Maimaris, A (2009), "Development and Evaluation of Bus Priority Scenarios via Microscopic Simulation Models," Proceedings of the12th International Federation of Automatic Control (IFAC) Symposium on Control in Transportation Systems (2009) , pp. 434-441.

Patankar1, V.M., Kumar, R.,and Tiwari, G. (2007), "Impacts of Bus Rapid Transit Lanes on Traffic and Commuter Mobility," ***Journal of Urban Planning and Development***, Vol. 133, No. 2, June 1, 2007, pp. 99 – 106.

Rathwell, S. and King, M. (2011), "Considerations for Median BRT on Arterial Roads," *Institute of Transportation Engineers. ITE Journal,* Vol. 81, No. 1.

Savage, K.J. (2009), "Research Results Digest 332 - Benefit/Cost Analysis Of Converting A Lane For Bus Rapid Transit," Transportation Research Board, Washington, D.C., USA.

Siddique, A.J. and Khan, A.M., (2006), "Microscopic Simulation Approach to Capacity Analysis of Bus Rapid Transit Corridors," Journal of Public Transportation*,* Volume 9, No. 3, 2006*,* pp. 181-200.

The Berkeley Daily Planet (2007), "Council Slows BRT Decision Process," *by Judith Scherr, published on Friday September 21, 2007*; accessed on March 25, 2013 at http://www.berkeleydailyplanet.com/issue/2007-09-21/full_text.

Tsao, H.-S. J., Dessouky, Y., Ingham, K., Ongkowidjojo, R. and Tsao, J.R. (2010), *Developing Operating Rules and Simulating Performance for One-Dedicated-Lane Bus Rapid Transit/Light Rail Systems*, PATH Research Report UCB-ITS-PRR-2010-01, Institute of Transportation Studies, University of California at Berkeley, March, 2010.

Tsao, H.-S.J., and Pratama, A. (2013), "Efficient Space Dedication to Bus Rapid Transit or Light Rail Systems," to appear in *Journal of Public Transportation*, Vol. 16, No. 3.

Tsao, H.-S. J., Wei, W., and Pratama, A. 2009a. *Feasibility of One-Dedicated-Lane Bus Rapid Transit/Light-Rail Systems and Their Expansion to Two-Dedicated-Lane Systems: A Focus on Geometric Configuration and Performance Planning*, MTI Report No. 08-01, Mineta Transportation Institute, San Jose State University, San Jose, California, U.S.A.; accessed online on March 25, 2013
at http://www.transweb.sjsu.edu/MTIportal/research/publications/documents/BRT.pdf

Tsao, H.-S. J., Wei, W., and Pratama, A.2009b. "Operational Feasibility of One-dedicated-lane Bus Rapid Transit/Light-rail Systems," *Transportation Planning and Technology*, Vol. 32, No. 3, pp. 239-260. Also translated into Chinese and published in Urban Transport of China, Vol. 8, No. 2, March 2010, pp. 80-93.

Tsao, H.-S.J., Wei, W., Pratama, A., and Tsao, J.R. 2009c. "Launching Bus Rapid Transit with Only One Dedicated Lane for Two-Way Bus Traffic on Congested Corridors," presented at the *2nd Annual Conference of Indian Subcontinent Decision Science Institute* (ISDSI 2009) held on Jan. 3-5, 2009 in Mumbai, India and published in the Proceedings, pp. 113-125.

US Department of Transportation (USDOT) (2013), Environmental Review Toolkit, accessed on March 23, 2013 at http://environment.fhwa.dot.gov/projdev/pd2implement.asp.

US Government Printing Office (GPO) (2013), *Code Of Federal Regulations, Title 23, Part 771--Environmental Impact and Related Procedures*, accesed on March 25, 2013 at Http://Www.Ecfr.Gov/Cgi-Bin/Text Idx?C=Ecfr&Tpl=/Ecfrbrowse/Title23/23cfr771_Main_02.Tpl .

Valley Transportation Authority (VTA) (2007), Bus Rapid Transit Service Design Guidelines, San Jose, California, USA.

Wong, C. and Fisher, S. (2010), "Developing a Bus Rapid Transit Strategic Plan for San Jose and Silicon Valley, California," *Transportation Research Record: Journal of the Transportation Research Board, No. 2145,* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 30–39.

York Region Rapid Transit Corporation. 2012. *VivaNext*, accessed on Dec. 29, 2012 at http://www.vivanext.com/rapidways .

Zhu, L.,Yu, L., Chen, X.-M., and Guo, J.-F. (2012), "Simulated Analysis of Exclusive Bus Lanes on Expressways: Case Study in Beijing, China," *Journal of Public Transportation, Vol. 15, No. 4, 2012*