

Final Report

Bus Rapid Transit (BRT) Toolbox: Assessing Person Throughput to Measure Transportation Impacts for BRT Projects

Adam Koling, Wei-Bin Zhang, Kun Zhou and Huadong Meng
California PATH Program
University of California at Berkeley

January 22, 2018

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV. 10/98)

1. REPORT NUMBER CA17-2664	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
4. TITLE AND SUBTITLE Bus Rapid Transit (BRT) Toolbox: BRT Person Throughput-Vehicle Congestion Tradeoffs		5. REPORT DATE January 22, 2018
7. AUTHOR(S) Adam Koling, Wei-Bin Zhang, Kun Zhou and Huadong Meng		6. PERFORMING ORGANIZATION CODE
9. PERFORMING ORGANIZATION NAME AND ADDRESS California PATH Program, University of California at Berkeley 1357 46th St., Richmond, CA 94804		8. PERFORMING ORGANIZATION REPORT NO. UCB-ITS-PRR-2018-0X
12. SPONSORING AGENCY AND ADDRESS California Department of Transportation Division of Research and Innovation P.O. Box 942873, MS 83 Sacramento, CA 94273-0001		10. WORK UNIT NUMBER
15. SUPPLEMENTAL NOTES		11. CONTRACT OR GRANT NUMBER
16. ABSTRACT This report studied person throughput as an impact metric for proposed BRT routes under Caltrans jurisdiction, given the agency's specific interest in preserving or improving the performance of particular state-owned corridors. It also introduces a simple spreadsheet tool to estimate a BRT project's traffic impact and show how improved bus service can boost corridor performance. Representatives of Caltrans D4, D7, and D11 were interviewed after tentative development of the tool, expressed support of a transition towards person throughput, and offered feedback on how the tool might best suit most district employees' needs.		13. TYPE OF REPORT AND PERIOD COVERED
17. KEY WORDS Bus Rapid Transit, Transportation Planning, Measure of Effectiveness		14. SPONSORING AGENCY CODE
19. SECURITY CLASSIFICATION (of this report) Unclassified		18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161
20. NUMBER OF PAGES		21. PRICE

Reproduction of completed page authorized

Disclaimer Statement

This document is disseminated in the interest of information exchange. The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This publication does not constitute a standard, specification, or regulation. This report does not constitute an endorsement by the California Department of Transportation (Caltrans) of any product described herein.

For individuals with sensory disabilities, this document is available in braille, large print, audiocassette, or compact disk. To obtain a copy of this document in one of these alternate formats, please contact: the California Department of Transportation, Division of Research Innovation, and Systems Information, MS-83, P.O. Box 942873, Sacramento, CA 94273-0001.

Table of Contents

Acknowledgements.....	4
Executive Summary.....	5
1. Context.....	6
1.1 Bus Rapid Transit (BRT).....	6
1.2 Characteristics and Challenges of BRT	7
Environmental Review for Transportation Projects.....	8
1.3 Measures of Effectiveness (MOEs) and Level of Service (LOS).....	9
1.4 The Impetus for Senate Bill 743 (SB 743).....	10
1.5 Senate Bill 743: Transitioning to Alternative Measures of Effectiveness	11
2. Literature Review.....	13
2.1 Academic Research on BRT, Traffic, and Tradeoffs.....	13
2.2 Previous Caltrans and PATH Documents	14
2.3 Bay Area Examples.....	16
3. Development of a BRT Planning Tool.....	18
3.1 Methodology and Assumptions	18
3.2 Input and Output: Step-by-Step Instructions on Completing Spreadsheet Tool.....	18
3.4 Overview of 2014 Interviews with Caltrans Districts.....	20
3.5 Interviews with Caltrans Districts to Review Spreadsheet Tool.....	21
4. Conclusion and Recommendations.....	23
Works Cited.....	24
Appendices.....	26
Appendix A: Perspectives of Interviewed BRT Project Managers of Two Transit Agencies	27
a.1 Interview Findings: AC Transit.....	27
a.2 Interview Findings: SFCTA	27
a.3 Interview Synthesis	29
Appendix B: Caltrans Director’s Policy (2013).....	31
Appendix C: Caltrans Deputy Directive (2013)	32

Acknowledgements

This work was performed by the California PATH Program at the University of California at Berkeley in cooperation with the California Department of Transportation (Caltrans). The authors thank Bradley Mizuno, Gloria Gwynne, Fouad Ziaullah, Lai Saetern, and Prakash Sah of Caltrans' Division of Research and Innovation and System Information, and Scott Sauer of Caltrans Division of Mass Transportation/ Division of Transportation Planning for their support and advice during the project. The authors would also like to thank Michael Schwartz and Bob Masys of the San Francisco County Transportation Authority and Jim Cunradi of AC Transit and the members of the project Technical Advisory Committee members Antonette Clark, Jean Finney, Wingate Lew, Fredrick Schermer, Ina Gerhard, Connery Cepeda, Chris Schmidt, Al Cox, Jila Priebe, Scott Sauer, and Emily Abrahams which provided valuable inputs.

Executive Summary

This report contributes to ongoing research conducted by the California Partners for Advanced Transportation (PATH) on tradeoffs arising when portions of a roadway are reserved for bus rapid transit (BRT). Specifically, this project builds on the findings of a 2015 PATH report entitled *Bus Rapid Transit Toolbox: BRT Person Throughput-Vehicle Congestion Tradeoffs* that examined how the California Department of Transportation (Caltrans) decides whether to allow transit agencies to build and operate BRT—enhanced bus service with exclusive lanes, dedicated boarding platforms, and separation from other traffic—on sections of its state highway system. BRT can play a new and significant role in transportation systems. Less expensive and more flexible than rail while faster and more reliable than conventional buses, BRT has emerged in recent decades to relieve multiple sources of bus delay while reducing economic and political challenges associated with large-scale infrastructure “megaprojects.” Transit agencies across California operate or anticipate BRT corridors as components of their service networks, and many existing or planned BRT routes align partially or completely within Caltrans rights-of-way. Whether on limited-access highways or urban arterials, BRT can achieve increases in speed and reliability, and often bus mode share, by replacing one or more general purpose lanes with exclusive bus lanes.

Although Caltrans has formally recognized the benefits of BRT and allotted district-level responsibility for implementing this new mode, the extent to which district project approval criteria have internalized this Sacramento policy statement remains unclear. Initial interviews with transit agencies suggest that, despite statements from Caltrans leadership, certain regional review processes sometimes still prioritize automobile lanes even at the possible expense of BRT potential. Their traditional project impact evaluation metric has been Level of Service (LOS), or a similar type of vehicle delay assessment. For decades, LOS also figured into environmental review processes in compliance with the California Environmental Quality Act (CEQA). In 2013, however, the California legislature passed Senate Bill 743, mandated that CEQA review of transportation impacts of proposed development be modified by eliminating consideration of delay- and capacity- based metrics such as level of service (LOS) and instead focusing analysis on another metric of impact under CEQA. Following SB 743, the Governor’s Office of Planning and Research (OPR) considered a range of alternatives, suggested vehicle miles traveled (VMT) by default, but empowered individual agencies to select their own. Caltrans has developed a ‘Local Development Intergovernmental Review Program Interim Guidance’, directing that “LD - IGR coordinators and functional reviewers will transition away from using delay based analysis, such as LOS or similar measures of vehicular capacity or traffic congestion, to determine the impacts of land use and infrastructure plans and projects. Instead, they will identify opportunities for reduced VMT generation, advise Lead Agencies on maintaining safe operations, and provide recommendations on developing location - efficient (e.g., centrally located, infill) and travel - efficient (e.g., inclusion of TDM measures) land use.”

(California Department of Transportation, 2017) It is expected that Caltrans will adopt one or more new metrics that more holistically capture the potential positive impacts of BRT. In keeping with the tentative recommendation of the 2015 PATH report, this report also endorses person throughput as an impact metric for proposed BRT routes under Caltrans jurisdiction, given the agency's specific interest in preserving or improving the performance of particular state-owned corridors. This report also introduces a simple spreadsheet tool to estimate a BRT project's traffic impact and show how improved bus service can boost corridor performance. Representatives of Caltrans D4, D7, and D11 were interviewed after tentative development of the tool, expressed support of a transition towards person throughput, and offered feedback on how the tool might best suit most district employees' needs.

1. Context

1.1 Bus Rapid Transit (BRT)

This report documents the second phase of ongoing research under the auspices of the California Partners for Advanced Transportation (PATH). The project focuses on bus rapid transit (BRT), a type of enhanced urban bus service using some combination of signal priority, special platforms, designated lanes, and outside fare collection to improve speed and trip quality. Specifically, this report builds on a previous PATH report that explored the consequences of converting a lane of traffic for exclusive bus use, with particular interest in how the California Department of Transportation (Caltrans) decides whether to approve a designated BRT lane on sections of state highway.

While many cities recognize the role of public transportation in mitigating urban congestion and pollution, no simple formula can determine the appropriate type of mass transit for a given location. Conventional bus service has existed for over a century, with vehicles often sharing congested streets and passengers boarding or alighting on existing sidewalks. Trams or streetcars served most Western cities around the same time, and certain larger regions also introduced more intensive rail infrastructure, sometimes along entirely grade-separated tracks either elevated or underground. Trains running in exclusive rights-of-way could carry an unprecedented number of passengers, reached higher speeds than any contemporary urban transportation mode, and established a design and service concept described for decades by the term "rapid transit." Hundreds of rapid transit systems, characterized by electrification, fixed guideways (rails or concrete beams), and near-total separation from other traffic, operate today in dozens of cities worldwide (World Metro Database, 2016).

"Rapid transit" may itself be an evolving definition; as modern cities invest in new public transportation, a tradeoff often arises between cost and type of service. Both capital and operations/maintenance expenses can be much lower for buses than for rail. However, simply expanding traditional bus systems, whether temporally (by offering longer operating hours and higher service frequency) or geographically (by widening the service area) often fails to address

the inherent challenges facing existing bus traffic: namely, low speeds and frequent delays due to roadway congestion. The construction of new rail lines, or even the addition of new trains on existing tracks, might lead to faster and more reliable service, but such projects can be prohibitively expensive and must follow more rigid routes and schedules than buses. When properly designed and operated, BRT can combine the advantages of both modes: lower construction costs and greater route flexibility than rail, yet higher passenger capacity and faster speeds than conventional buses. In the United States, the average light rail system costs \$70 million per mile, compared to \$25 million per mile, including new pavement, for BRT (AC Transit, 2016). An ideal BRT user experience might compare to that of rail, but along a corridor built and priced like a road. The boarding area in



Figure 1: Passengers on an enclosed island platform await buses in Curitiba, Brazil. Curitiba's BRT system, Rede Integrada de Transporte, was the first in the world when it opened in 1974, and features futuristic glass tubes as stations. Such raised and protected boarding areas not only improve safety, but can also provide a greater sense of isolation from traffic than for conventional bus riders. Source: Wen Xinyang, Xinhua, 2015.

Figure 1 resembles a metro platform.

1.2 Characteristics and Challenges of BRT

Just as the passenger perception of BRT combines that of bus and rail, so does the infrastructure necessary to accommodate it. According to the Institute for Transportation and Development Policy, “full” BRT requires five essential features: (1) a dedicated right-of-way reserved for buses, (2) separation from curbs, pedestrians, and turning vehicles, (3) off-board fare collection, presumably on station platforms or at entrances to boarding facilities, (4) prohibited turns across bus lanes at intersections, and (5) platform-level boarding (ITDP, 2016). Since widening streets may not be feasible, BRT can, often controversially, require converting one or more general-purpose lanes into exclusive bus lanes. Fulfilling all five ITDP criteria would likely require acquiring slightly more than one exclusive lane per direction, because level boarding platforms themselves occupy additional space parallel to the BRT lanes. Figure 2, on the following page, is a labeled diagram of BRT in New York City, whose design aspects approximate IDTP criteria.

While such proposed changes to the built environment may not present a significant political hurdle in developing countries whose citizens already travel primarily by public transportation, in the United States, and especially in California, drivers are populous and vocal constituents. In

addition to motorist opposition, another challenge facing BRT in developed countries could stem from passenger perception: a tendency to compare so-called “rapid transit” to rail (rather than to conventional buses) might lead users to demand more significant travel time savings than their counterparts may expect of BRT systems elsewhere in the world. Separately, depending on the intensity of BRT infrastructure in question, residents and businesses along the corridor might oppose a project out of concern for property values, aesthetics, or ease of access for prospective customers. Finally, as briefly described in the following subsection, a BRT project is seriously jeopardized if it triggers a significant and adverse environmental impact. While avoiding such negative environmental consequences is important, this report will explain how California’s traditional definition of environmental impact for transportation projects may have been misplaced. In any event, agencies responsible for transportation proposals must address some or all of these legal and political concerns for any projects, BRT or otherwise, to move forward.

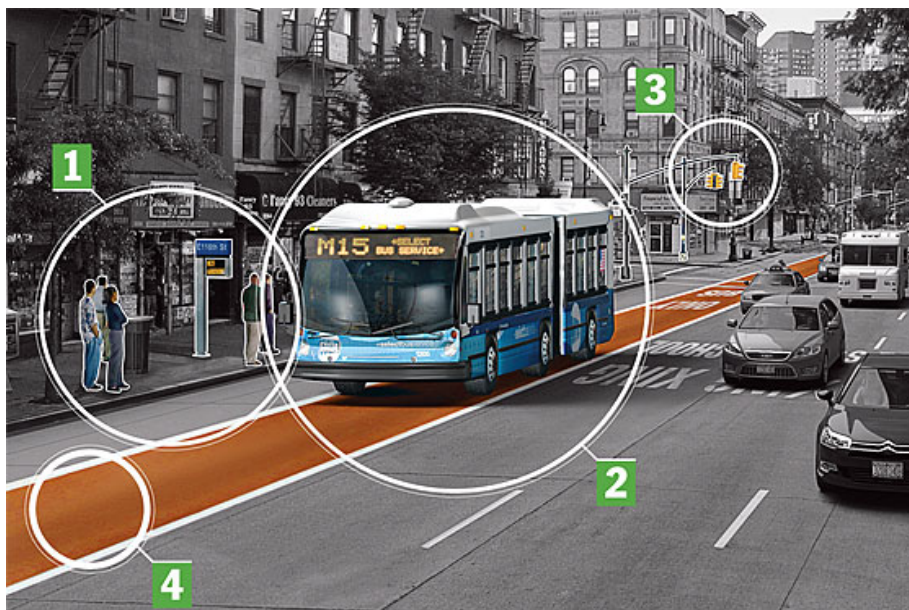


Figure 2: *New York City’s Select Bus Service represents an enhancement of the city’s local buses. The labels refer to (1) off board fare collection, (2) ability to board at any door, (3) signal priority and restricted left turns, and (4) a dedicated and camera enforced bus lane.*
Source: NYC Dept. of Transportation, 2010

Environmental Review for Transportation Projects

Throughout history, transportation projects have almost always spawned changes to the social, economic, and physical characteristics of surrounding areas, but only since 1970 has United States legislation explicitly mandated that decision makers proactively evaluate potential impacts. Today, all agencies seeking federal funding or approval for a project fall under the National Environmental Policy Act (NEPA). Compliance with NEPA first involves preparation of an environmental assessment (EA), a document evaluating the likelihood of the proposed project affecting not only air and water quality, but also wildlife, housing, historical preservation sites, property values, or the socioeconomic well-being of surrounding communities. If the EA predicts significant consequences in one or more of the above categories, the responsible agency must follow up with a more involved document called an environmental impact statement (EIS).

Also enacted in 1970, the California Environmental Quality Act (CEQA) further establishes an environmental review process at the state level. Just as the NEPA process calls for an EIS, the CEQA process involves submission of an environmental impact report (EIR). All projects in California requiring state or local approval fall under CEQA; some may also need federal approval and undergo both NEPA and CEQA processes. While CEQA therefore applies to many more projects at a smaller geographic scale than NEPA, its scope is limited to a project's potential impact on physical surroundings (not social or economic conditions). Under CEQA, the environment comprises "land, air, water, minerals, flora, fauna, noise, or objects of historic or aesthetic significance." If an EIR finds that one or more project alternatives may trigger adverse environmental changes, the agency must evaluate ways to mitigate that impact.

1.3 Measures of Effectiveness (MOEs) and Level of Service (LOS)

Project approval under CEQA hinges on measured or projected performance under selected analysis criteria sometimes called Measures of Effectiveness (MOEs). Just as with the applicable laws, the relevant MOEs depend on the project's surrounding jurisdictions (e.g. federal, state) as well as its funding source(s). Transportation professionals have long employed LOS to evaluate traffic conditions. Qualitatively, LOS is a measurement of vehicle delay, which is incurred either at intersections or on uninterrupted stretches of roadway. A rubric that assigns letter grades, LOS gives an A to free-flowing traffic and an F to a site with severe impediments to vehicular flow. Quantitatively, LOS captures two fundamental numerical characteristics exhibited by traffic, flow and density, which are temporal and spatial measurements, respectively. Flow refers to the number of vehicles passing a certain point in a given time window, and density is a snapshot of the number of vehicles in a certain zone at a single point in time. A stronger LOS grade would mean higher flow and lower density.

The California Legislature formally integrated LOS standards into the CEQA guidelines in 1990 (OPR, 2013). For the next 23 years, a premise of CEQA analysis was that since poor LOS scores meant congestion, and since congestion in turn constituted a negative environmental consequence, then LOS was a proxy for environmental impact. Under those guidelines, compliance with this traffic component of CEQA would require mitigating congestion and raising (or at least maintaining) the LOS score. There is some environmental justification for institutionalization of LOS standards, especially at more discrete or granular scales. A single motor vehicle does emit more noise, particulates, and other pollutants under congested conditions; indeed, for any finite number of cars, free flowing traffic is environmentally preferable to continual acceleration and deceleration (Zhang and Batterman, 2013). From any aggregate or regional perspective, however, the environmental reasoning behind a LOS metric does not hold up to scrutiny. These ironies are captured in Figure 3, a humorous drawing by artist Andy Singer, and, more importantly, motivated the passage of Senate Bill 743.

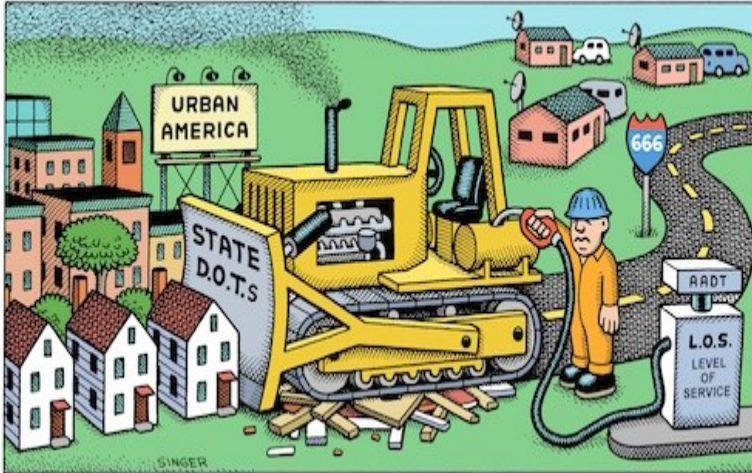


Figure 3: In a satirical drawing, a bulldozer, representing state departments of transportation, razes a city, representing “urban America,” to make room for a new highway. The fuel pump feeding the bulldozer reads “L.O.S. Level of Service” and represents the tendency of LOS analysis to encourage sprawl. Source: Andy Singer, 2004, reprinted with permission, 2017

1.4 The Impetus for Senate Bill 743 (SB 743)

In 2013, the Governor’s Office of Planning and Research (OPR) identified six main drawbacks when using LOS as a CEQA standard for determining environmental impact (Governor’s Office of Planning and Research, 2013). The issues with LOS were economic as well as environmental, and are listed below.

- LOS was (and remains) a complex and expensive calculation, requiring estimation, assumptions, microsimulation, and substantial field observation. Analysis of LOS under CEQA required tedious side-by-side comparison of different traffic parameters under hypothetical “build” and “no build” scenarios.
- Infill growth, or what OPR calls “last in development,” could worsen LOS scores in already dense areas, where existing vehicular traffic may already have reached a critical LOS threshold. LOS would therefore encourage construction in less developed areas.
- Mitigating LOS often meant adding more vehicle capacity, an ineffective way to reduce regional environmental impacts. While a single free flowing car might pollute less than a single car in stop-and-go traffic, high volumes of free flowing vehicles rapidly become more environmentally problematic than a smaller number congested vehicles. Worse still, LOS-based improvements have empirically failed to maintain freely flowing traffic in the long term; often, volumes increased and congestion stayed the same. The long term phenomenon of induced demand, coupled with prioritization of LOS, can ultimately turn a low-volume, congested corridor into a high-volume, equally congested corridor.
- The scale of LOS is prohibitively small, and adhering to LOS standards might relieve local congestion while exacerbating regional congestion. Mitigation measures undertaken based on LOS criteria mean the broader network could fall prey to Braess’ Paradox, the counterintuitive phenomenon of adding capacity but worsening congestion.
- LOS penalized transit, bicycle, and pedestrian improvements as impediments to cars.
- LOS implied false precision; the many estimates and calculations that inform an LOS statement are not traditionally reported as error in the final assigned letter grade.

It was in recognition of these six drawbacks that the legislature enacted SB 743 of 2013, requiring OPR to amend CEQA guidelines and eliminate or reduce reliance on LOS.

1.5 Senate Bill 743: Transitioning to Alternative Measures of Effectiveness

SB 743, a step towards developing alternative evaluative metrics for transportation projects, built on SB 1636 of 2002, which empowered city and county governments to establish “infill opportunity zones” where project approval does not require meeting LOS thresholds. Any location within 300 feet of a BRT corridor, for example, qualifies under SB 743 as zone for compact residential or mixed use development. Its ten-part definition of BRT is similar to the one published by the ITDP: (1) coordination with land use planning, (2) exclusive right-of-way, (3) improved passenger boarding facilities (4) limited stops, (5) passenger boarding at the same height as the bus, (6) prepaid fares, (7) real-time passenger information (8) traffic priority at intersections (9) signal priority, and (10) unique vehicles (Gov. Code § 65088.1(b)).

SB 743 delegated the task of recommending alternative criteria to OPR itself, both within and beyond transit priority areas. Finally, it removed LOS from CEQA, and endorsed only new MOEs that “promote the reduction of greenhouse gas emissions, the development of multimodal transportation networks, and a diversity of land uses” (SB 743 § 21099(b)). Seeking a simple, equitable, affordable, and environmentally representative metric, OPR recommended vehicle miles traveled (VMT) as a default alternative MOE for transportation projects (OPR, 2016).

Subdivision (b)(1) intentionally appended the word “generally” to its endorsement of VMT because OPR recognized the broad range of project types and lead agencies covered by CEQA and the reality that, “in appropriate circumstances, a lead agency may tailor its analysis to include other measures” (OPR, 2014). The technical aspects are detailed in a 2016 OPR publication in a section entitled *Technical Advisory on Evaluating Transportation Impacts in CEQA*. Specifically OPR states that funding BRT could even be a legitimate justification for *expanding* a roadway and adding toll lanes, because BRT causes a presumed reduction in vehicles miles traveled even if its dedicated infrastructure directly reduces the vehicle throughput capacity of a roadway (OPR, 2014).

While implementing BRT could also reduce VMT, so might other lane conversion projects, yet BRT can deliver a higher flow of people than cars or conventional buses. Importantly, the metric recommended by this project should fall within the scope of Caltrans’ priorities. For that reason, based on the findings of the 2015 BRT Toolbox phase, this report assumes *person throughput* to be the preferred alternative MOE for BRT projects. Even if accounting for increased vehicle delay, substantially improving bus service could increase total corridor capacity, measured in flow of people per hour, and also reduce the average per-person trip time. Person throughput has advantages over VMT analysis due to its jurisdictional concerns; Caltrans expects to improve or sustain only its own corridors. If an aggregate VMT reduction occurred due to trips averted on nearby city or county roads, there would not be a clear motivation for Caltrans to approve alteration of its own facility. Person throughput, measured solely on a Caltrans corridor, can be a

tangible indication of positive corridor performance. Measures of effectiveness are further discussed in the following section, which outlines the research findings of multiple academic institutions and public agencies on BRT, lane conversion, and the consequences to other traffic.

2. Literature Review

2.1 Academic Research on BRT, Traffic, and Tradeoffs

In the United States, particularly in California, the question of narrowing or eliminating general-purpose lanes (whether to accommodate cyclists, pedestrians, or transit) can be politically charged. As indicated earlier, individual car owners and auto-oriented businesses often vocally oppose proposed infrastructure changes that would prioritize modes other than private automobiles. These constituent groups enjoy strength in numbers; per capita car ownership in the United States far exceeds that of any other large country. Many California residents rely heavily on private automobiles for daily commute trips, their 332 billion annual vehicle miles contributing 36 percent of GHG emissions statewide, and are highly sensitive to any potential increases in vehicle delay (California Air Resources Board, 2014). In contrast, cities in developing countries (where mass transit remains the dominant commute mode) can expect more public support for projects benefiting BRT passengers at the expense of private motorists. Possibly because of such regional economic and political differences, while several peer-reviewed papers and reports discuss dedicated BRT lanes and their effect on surrounding traffic flow, few use American cities as case studies.

Chen et al. (2007), in *Impacts of Exclusive Lanes and Signal Priority on Bus Rapid Transit Effectiveness*, conducted VISSIM traffic microsimulation of Beijing's North-South Central Axis BRT route, and found that dedicated median BRT lanes increase the capacity of a BRT corridor while possibly restricting other vehicles' ability to pass one another.

Zhu et al. (2012), in *Simulated Analysis of Exclusive Bus Lanes on Expressways: Case Study in Beijing, China*, considered three other planned Beijing BRT routes and, also using VISSIM, modeled traffic conditions for both curbside and median BRT lanes. They concluded that dedicated BRT lanes improved not only transit performance, but general traffic as well, and that, of the two lane configurations examined, median BRT lanes were marginally more efficient.

Patankar et al. (2007), in *Impacts of Bus Rapid Transit Lanes on Traffic and Commuter Mobility*, reached similar conclusions about the potential for exclusive BRT lanes in India, however, given the composition of typical Indian traffic (often characterized by a chaotic assortment of two- and three-wheeled motor vehicles), their findings may not be relevant to this study.

Siddique and Khan (2006), in *Microscopic Simulation Approach to Capacity Analysis of Bus Rapid Transit Corridors*, modeled present and future traffic conditions along existing dedicated BRT lanes in downtown Ottawa. They estimated the delay imposed by BRT on crossing traffic, a measurement that, while relevant to the broader question of lane conversion tradeoffs, is perhaps secondary to the delay incurred by other vehicles on the corridor itself.

Ang-Olson and Mahendra (2011), in *Cost/Benefit Analysis of Converting a Lane for Bus Rapid Transit*, documented the findings of a National Cooperative Highway Research Program

(NCHRP) project quantifying the costs and benefits of converting a lane for BRT. They compared Build with No Build scenarios under 11 different cost/benefit models (including Cal-B/C, Caltrans' own life cycle cost benefit analysis model) and many infrastructural, behavioral, and economic assumptions. One such assumption was that a dedicated BRT facility would replace exactly one general purpose lane; in practice, left turn pockets and passenger boarding platforms tend to require more than a single lane of right-of-way. Other than this oversimplification, costs included capital, operations, and maintenance, while benefits could be positive or negative (negative benefits were termed "disbenefits," to represent disutility). Sensitivity analysis pinpointed the most influential variables, and the team's conclusions emphasized two parameters in particular: pre-project mode share and person throughput. Specifically, they recommended BRT lane conversion in corridors whose daily person throughput and transit mode share exceed 40,000 and 15%, respectively. While their analysis attempted to quantify a fairly comprehensive set of costs, it ignored other positive consequences of BRT such as economically productive land use changes, ease of parking, improved employment accessibility, and enhanced overall transit reliability. The scenarios may therefore underestimate the extent of BRT-induced advantages by excluding indirect benefits that would still factor into a public expenditure decision.

2.2 Previous Caltrans and PATH Documents

Caltrans' website expresses its "commitment to improve public transportation in [California]"¹, and a *Director's Policy 27* released in 2007, and reaffirmed in 2013, specifically supports BRT as a mode capable of boosting person throughput, mitigating congestion, and reducing pollution on key segments of the state highway network (Caltrans, 2013). A copy of the Director's Policy can be found in Appendix B. A subsequent Caltrans *Deputy Directive 98* released in 2008, and reaffirmed in 2013, even established a hierarchy of leadership roles within Caltrans to ensure productive and expeditious collaboration with BRT stakeholders (Caltrans, 2013). A copy of this Deputy Directive can be found in Appendix C. While officially encouraging of BRT, the supportive language in high-level policy may not trickle down to implementation at the project level; indeed, even in Deputy Directive 98 Caltrans encourages BRT "where appropriate." This introduces a degree of subjectivity, and, perhaps in part because of this ambiguity, several internal PATH studies before this one have explored what constitutes appropriateness.

The earliest PATH report in the Caltrans BRT research database, *Evaluation of Cost-Effective Planning and Design Options for Bus Rapid Transit in Dedicated Bus Lanes* addressed a similar subject to this project: tradeoffs that occur when BRT vehicles are given an exclusive lane. For this project, Li et al (2009) performed VISSIM simulation while considering the feasibility of a single bidirectional BRT facility on roads on which spatial or traffic constraints would not reasonably allow for two full length bus lanes side by side. Buses would only cross each other in dedicated stretches functionally similar to rail sidings, and, if their schedules were not properly synchronized, one or both buses would decelerate while approaching the passing zones. Their

¹ http://www.dot.ca.gov/hq/MassTrans/Trans_Tech.html

findings were twofold: (1) a single bidirectional lane barely causes any travel time increases on buses with headways over 20 minutes, and (2) with headways of less than 15 minutes, intersection delays and imperfect passing coordination do lead to overall travel time increases.

Miller (2011), in *State and Federal Development Procedures for Bus Rapid Transit: Managing Differences and Reducing Implementation Delays*, explored twelve BRT projects within California and four out-of-state in context of occasional tension between state and federal project development procedures (PDPs). Agencies must follow both procedures whenever a BRT project takes place on a section of state highway and receives federal funding from the New Starts Program. Of the 16 total projects, only four had experienced implementation delays. Of those four, however, three incurred delays attributable to conflicting PDPs, whether between state and federal DOTs or simply among municipalities in whose jurisdictions the BRT project fell. Miller's findings are relevant to this project because of potential conflicts when local agencies choose to adopt VMT while others may still use LOS. During the years that both CEQA and Caltrans required LOS analysis, no such conflicts existed, but Miller's recommendations for inter-agency cooperation may apply when different authorities' review processes call for different metrics.

Two of the five PATH coauthors responsible for the 2009 report discussed above collaborated again six years later, joining three other researchers to spearhead this BRT Toolbox project. Their first report, which constituted a prequel to this report, was released in early 2015 and described contemporary BRT planning practices worldwide as well as Caltrans approval criteria. Li et al (2015), in *BRT Toolbox: BRT Person-Throughput Vehicle Congestion Tradeoffs*, discussed the four operational BRT systems in the United States running in exclusive lanes. Two, in Los Angeles and Pittsburgh, did not require converting a general purpose lane and cannot offer precedents for the traffic impacts of lane removal. The other two, in Cleveland and Eugene (shown in Figure 4), do use converted BRT lanes but only on previously uncongested streets with ample capacity for mixed traffic in the remaining lane. Widening the geographical scope to include international BRT systems, they compiled several tables of bus facility types and examples of cities in which each had been implemented.



Figure 4: An Emerald Express bus pulls into a station in the median of Franklin Boulevard in Eugene, Oregon. While the Eugene-Springfield BRT required converting general-purpose lanes, previous traffic conditions were so relatively light that adding BRT lanes caused little or no congestion in the remaining lanes. Source: Darrell Clarke, 2008

The same PATH report touched on political as well as infrastructural differences across different regions. In the United States, transit agencies sometimes pursue BRT projects without consistent community support; a local example occurred in 2007 when residents opposed a section of AC Transit's proposed East Bay BRT line. Despite significant projected travel time savings as well as enhancements to pedestrian and bicycle infrastructure along the corridor, the Berkeley City Council rejected lane reconfiguration on Telegraph Avenue due to concerns about reduced parking and patronage of local merchants on only four blocks (the BRT corridor is over 10 miles long) between Dwight Way and the edge of UC Berkeley's campus (East Bay Times, 2012). The BRT line was ultimately truncated to terminate in Oakland. Conversely, in developing countries an opposite dynamic might play out: elite government officials, themselves less likely to ride public transportation, may ignore or underestimate popular demand (ITDP, 2007).

Geographically distinct BRT policies were discernable even among Caltrans districts, as revealed in this same 2015 PATH report. After conducting interviews with representatives of D4, D7, and D11 (the Bay Area, Los Angeles, and San Diego, respectively), the study identified several core similarities with nuanced differences across the three Caltrans districts containing the vast majority of California's 42 planned and operational BRT projects (NBRTI, 2015). All three districts, at that point shortly after SB 743, indicated that LOS remained the impact metric of choice. Within the LOS framework, though, D4 set a slightly lower (more congested) LOS score as its acceptability threshold. None of the three districts retained the traffic analysis expertise for thorough internal analysis of BRT projects; all three relied on local transit agencies to provide Synchro files for Caltrans review. Traffic engineers of D11 would selectively run Synchro simulations of certain corridor intersections, while D4 and D7 personnel would look primarily at Synchro outputs provided to Caltrans by agencies.

Most promisingly, however, the 2015 interview findings from PATH BRT research suggested openness to alternative metrics even at the Caltrans district level. Statements from D11 admitted the obsolescence of LOS for urban BRT projects and the risks posed by misplaced automobile-centrism typical of "traditional analysis" (Li et al, 2015). In the wake of SB 743, and the elimination of a congestion component to CEQA review, all three interviewed districts recognized the opportunity to update their own performance metrics. Their responses also indicated a lack of mode share data, likely for two reasons: (1) relative unavailability of corridor-level demand forecasting models, and (2) lack of familiarity at Caltrans with the tools that exist.

2.3 Bay Area Examples

Past BRT analyses conducted by transit agencies in California before SB 743 continued to focus on measures of vehicle delay. The Alameda-Contra Costa Transit District (AC Transit) oversaw all traffic studies behind the East Bay's first BRT line, expected to connect Oakland with San Leandro and to open in late 2017. Southeast of 42nd Ave, International Boulevard (the BRT alignment) is designated as State Route 185 and falls under Caltrans jurisdiction. As was common practice before SB 743, traffic impact investigations necessary for Caltrans approval occurred during the environmental review process and culminated in the release of one 119-page

Traffic Analysis Report in January 2012. The report lists, in intersection-by-intersection detail, the projected effects of BRT and documents compliance with all requirements, whose origins ranged from Caltrans to the Americans with Disabilities Act (ADA) to the Regional Transportation Improvement program (RTIP) criteria. A set of before-and-after scenarios report the expected project (or no-build) impact, measured both in LOS changes and in total delay. The 2012 report was specific to a single BRT project, but eight years earlier AC Transit had created a handbook aimed less at technical transportation professionals than at elected officials and community members. Entitled *Designing with Transit: Making Transit Integral to East Bay Communities*, the publication was explicitly intended as “a tool for partnership” with Caltrans, reiterates the numerous advantages of BRT, and even mentions the compatibility of buses with Caltrans lane width requirements. Its specific references to Caltrans clearly underscore the importance of a functioning and streamlined relationship between state and local transportation agencies when planning and approving new transit projects, especially ones like BRT that require repaving, restriping, and other physical changes to roadway infrastructure.

The San Francisco County Transportation Authority (SFCTA) pursued the city’s Van Ness Avenue BRT project, and since Van Ness is a Caltrans facility for the entire BRT corridor length, Caltrans exerted permitting authority over all aspects of design and construction. In 2014, Caltrans approved the SFCTA *Project Study Report*, which emphasized the increases in person throughput BRT would provide. The document also described the impacts in terms of LOS, but since analysis predicted no significant LOS degradation, that itself did not complicate the Caltrans approval process. Since the San Francisco Department of Public Works maintains Van Ness, and the Public Utilities Commission oversees street lighting, implementing BRT required partnerships including but not limited to collaboration with Caltrans (SFCTA, 2014).

Liaison and partnership with Caltrans involved many BRT planners and engineers at SFCTA and AC Transit. The project team interviewed a number of representatives from SFCTA and AC Transit. Their perspectives on relevant MOEs and the Caltrans approval process are summarized in Appendix A.

3. Development of a BRT Planning Tool

3.1 Methodology and Assumptions

One recurring theme across interviewees was the concept of person throughput, even when not used as the primary measure of effectiveness. Improved person throughput is a measurable benefit of converting a lane to BRT, and one that may resonate with Caltrans district staff, even if the lane conversion causes a reduction in *vehicle* throughput. Caltrans' objective may be roadway performance, but with flexibility as to the definition of "performance." The following section documents the basic calculations necessary to determine person throughput, and introduces a simple Excel tool for characterizing build and no-build scenarios along a potential BRT route.

Given the transit agencies' needs, the types of data reasonably available, and the necessity to demonstrate constant or improved performance of a particular Caltrans facility, the tool developed for this project emphasizes simplicity of input, side-by-side scenario comparison, and corridor-level analysis. Agencies and Caltrans district planners need only enter [number of] numeric values and receive [number of] estimated measures of effectiveness in return. The calculations consider a stretch of roadway, of a certain length in miles, designated by Caltrans as a particular class of highway and containing a number of general-purpose lanes for the direction in question, each lane with a capacity of cars (or car equivalents) per hour. Demand models would reveal the number of person-trips, per lane, under the parameters in question.

Calculations at this level required multiple assumptions, the most significant of which was that all trips along the corridor took place on buses or in cars. While a series of conditional "warnings" are coded into an adjacent Excel column to alert the user to possible overcrowding, the outputs assume that bus capacity can accommodate all demand. In addition to each vehicle having unlimited capacity, this tool assumes that the facility itself can serve whatever demand is entered as input; speed, also an input, would reflect congestion but the flows may not.

3.2 Input and Output: Step-by-Step Instructions on Completing Spreadsheet Tool

Inputs are in **bold** while outputs are in *italics*.

Inputs:

1. **Facility Type.** Select one of two types of Caltrans highway from a drop down list. Currently, options are only (1) Freeway and (2) Conventional Highway.
2. **Facility Length.** Enter the corridor length, in miles.
3. **Automobile Person-Trips per Lane per Hour.** Demand model outputs, or any other forecasts, should include a value for total demand, in person-trips per hour, and a distribution across modes. Take the automobile demand, in person-trips per hour, and divide by the total number of lanes.

4. **Transit Person-Trips per Lane per Hour.** Same as task (3), but for transit.
5. **Lane Capacity.** Enter the capacity, in *cars* per hour, of each lane.
6. **Number of General Purpose Lanes.** Enter the total number of general-purpose lanes per direction. Under the “Build” scenario in the third column, the value will be less than in the first two columns (which should be equal).
7. **Number of Exclusive BRT Lanes.** Enter the total number of BRT Lanes per direction. This input is only relevant in the third “Build” column, and is greyed out for the first two scenarios.
8. **Equivalence Ratio of Buses to Cars in Traffic.** Because heavy vehicles tend to operate more sluggishly and take up more space, buses may count more than cars in a volume-to-capacity calculation. Enter the number of cars equivalent to a bus (often between 1 and 2). If both vehicle types are presumed to contribute equally towards saturation, simply enter a value of 1. This may vary by incline; in life cycle analysis, for example, Caltrans assumes that on level terrain a heavy vehicle is equivalent to 1.5 cars (Caltrans, 2013).
9. **Average Bus Speed.** Enter the average speed, in miles per hour, of buses across the corridor. Include in this average speed any dwell time at stops, acceleration/deceleration lost time, and time spent in queue at intersections. Inputs (9) and (10) refer to the average speeds for the entire length of the facility, inclusive of all lost time resulting from (but not limited to) acceleration, deceleration, intersection delay, and, for buses, dwell time at designated stops. These speeds could be measured with bus GPS data and collected via probe vehicles.
10. **Average Car Speed.** Same as task (9). Include all sources of delay for cars.
11. **Bus Headway.** Enter the scheduled bus headway, in minutes, of all buses using the facility, even if they are not serving stops along the corridor. For example, between the Golden Gate Bridge and downtown San Francisco, Golden Gate Transit buses currently travel along Van Ness (and would use its BRT lanes) but do not stop anywhere along the proposed BRT line.
12. **Car Occupancy.** Enter the average number of occupants in a car, a figure likely obtained from a demand model, survey, or empirical observation.

Outputs:

13. **Bus Occupancy.** The number of passengers per bus, given the number of buses dispatched and the stated demand. While car occupancy is an input, bus occupancy is a calculated output.
14. **Volume-to-Capacity Ratio (GP Lanes).** The saturation in general-purpose lanes, expressed as a ratio between 0 and 1.
15. **Volume-to-Capacity Ratio (BRT Lanes).** The saturation in BRT lanes. This is only provided in the third “Build” column.
16. **Level of Service (GP Lanes).** Approximated by V/C ratio using Caltrans’ *Appendix K: Level of Service Definitions* PDF. The level of service for each lane (outputs (4) and (5)) are currently approximations based only on the V/C ratio (with cutoffs stated in Caltrans’ *Level of Service*

Definitions) but, if necessary, could be calculated more precisely using a Caltrans-provided table and inserted into Excel either manually or automatically by way of the *VLOOKUP* function.

17. **Level of Service (BRT Lanes).** Only relevant in third column. Approximated using the same PDF.
18. **Car Travel Time.** Travel time for cars, in minutes, for the entire corridor, given the facility length and speed input.
19. **Bus Travel Time.** Equivalent to output (18), but for buses.
20. **Total Travel Time.** The sum of two products: (1) bus travel time and bus demand, and (2) car travel time and car demand.
21. **Per Person Average Travel Time.** Total travel time divided by all people across all lanes.
22. **Person Throughput.** Total people passing through facility; assuming all demand is served during the hour in question.
23. **Vehicle Miles Traveled (VMT).** The sum of car and bus flows per hour, multiplied by the facility length, in miles.

3.4 Overview of 2014 Interviews with Caltrans Districts

As briefly mentioned in the literature review, Caltrans districts D4, D7, and D11 (representing the San Francisco Bay Area, Los Angeles, and San Diego, respectively) participated in an interview process that informed the 2015 BRT Toolbox report. The findings from that series of interviews, which were conducted throughout 2014, are summarized here to provide context for those same districts' feedback on the tool developed above. The tool should help support the initial traffic analysis performed at the Caltrans district level, by taking rough inputs and presenting multiple performance metrics, from person throughput to VMT, side by side.

- Caltrans D4 recognized the tradeoff between vehicle throughput and person throughput, and indicated the importance of evaluating both when reviewing a potential BRT project. This occurred in the environmental approval phase of SFCTA Van Ness BRT corridor. While LOS remained an MOE for D4 (with a need to maintain at least LOS C or the LOS from before the BRT project), there are other metrics that more appropriately capture the advantages of BRT, such as (in addition to person throughput) minimizing person-delay or vehicle-delay. The proposed system would be compared to one or more no-build alternatives, which leaves the analysis largely dependent on model accuracy.
- Caltrans D7's experience with BRT planning and decision making revolved largely around Route 1 of Santa Monica's Big Blue Bus. While D7 did not perform traffic analysis themselves, they reviewed local agencies' own calculations with attention to

LOS. Impacts resulting in LOS D or below would require mitigation. Since D7 used Synchro for traffic analysis, they were not equipped to forecast demand or mode shift.

- Caltrans D11 was informed by several San Diego area BRT projects, from the Mid-City Centerline Rapid Bus to the South Bay BRT. Just as for D7, Caltrans D11 did not *primarily* conduct independent traffic analysis, but would review and validate agencies' own analysis. For some limited intersections, D11 did run its own Synchro analysis. Also similar to D7, any LOS projections below LOS C necessitated mitigation.

In 2014, while the Caltrans Director's Policy on BRT was available, all three districts observed a shortage of (1) resources to support the policy, (2) tools to estimate mode shift, traffic diversion, and person throughput, and (3) information on specific approval thresholds to be established. While the tool does not specify a particular value of person throughput at which a project should be approved, it is a non-resource-intensive way to estimate BRT impacts by various metrics.

3.5 Interviews with Caltrans Districts to Review Spreadsheet Tool

The same three Caltrans districts (D4, D7, and D11) offered suggestions, via telephone interview, for improving the tentative model and increasing its usefulness to "uninitiated" Caltrans employees. All district interviewees expressed support for the twofold goal of lower VMT and higher person throughput, and provided four key points of feedback on the tool.

- In its current form, the tool requires design- and demand-related inputs, and returns performance-related outputs. Speed and headway are inputs; person throughput and VMT are outputs. Caltrans, however, might prefer to explore the level of investment necessary to justify dedicating a lane. This approach would favor a tool that returned service-related values like speed and headway as *outputs*, based on *inputs* of person throughput and VMT. Repeated calculations could help approximate the threshold at which BRT service could mean equal or greater performance than general-purpose lanes.
- If demand exceeds available bus capacity, then something must give way. If a bus should reasonably carry no more than a few dozen people, careful consideration should be given to the calculated bus occupancy and the ability of any BRT service to satisfy it.
- While all LOS estimates in the spreadsheet tool are only informational outputs, they still must be based on Caltrans' own measurement protocols, which in turn come from the latest edition of the Highway Capacity Manual. Since LOS depends on both travel speed and V/C ratio, the VLOOKUP function could produce LOS based on spreadsheet inputs.
- The passenger car equivalent factor, or the number of cars equal to a heavy vehicle, varies depending on the context. Life cycle analysis and traffic impact studies could involve two substantially different ratios. This must be clarified in the model.

The first of those four interview findings, concerning what should be inputs versus outputs in the tool, can be addressed in the near future as the spreadsheet is further refined for distribution to Caltrans employees. The same is true of the third point involving LOS; once a determination method is chosen, a simple Excel function can calculate LOS from relevant inputs.

The second and fourth points have already been integrated into the most recent version of the tool. Any bus occupancy output over 100 triggers an automatic warning in an adjacent column. The passenger car equivalent factor is an *input* whose value is chosen by those using the tool.

Before finalizing the tool, it would be appropriate to input the design and service parameters of one or more proposed BRT projects and evaluate if the tool's estimates of person throughput, travel time, and VMT approximate the values reached after the agencies' original calculations.

Review comments were received from the project panel after the draft report was submitted, including specific recommendations on the report and desires for improvements of the BRT planning tool. Changes of the report have been made following the comments and recommendations. Improvements of the BRT planning tool was also made to address the feedbacks from the project panel to include the notations of the calculations and performance measures, the descriptions of the input and output data as well the input and output relationships. The panel desires to have a web-based user interface, which can not only facilitate the easy use of the tool but also validate data for checking for any errors when inputting data. However, this tool can not be accomplished during this phase of the project. We propose to develop a new web-based interface in the next phase project together with further improvements of the tool after further feedback is received from the stakeholders.

4. Conclusion and Recommendations

While no “one size fits all” regulatory approach can be deployed for every BRT project, the research conducted for this report informs five broad recommendations that Caltrans districts could integrate into their BRT approval processes. Adopting planning practices that support BRT could not only facilitate construction of an environmentally and economically progressive transportation mode, but also align with the past decade of Caltrans’ own departmental policy.

- In keeping with SB 743, eliminate automobile delay as a metric for BRT projects. This report outlines why person throughput, rather than VMT, may be most appropriate for the corridor-level analysis necessary when considering BRT impacts on Caltrans rights-of-way. Interviews, particularly with the SFCTA, suggest that person capacity might even be preferable. In addition, since OPR has already provided a comprehensive list and evaluation of alternative metrics, Caltrans need not conduct its own research and can easily choose from a set of published options.
- Explore travel demand models during the project approval process. In addition to requesting traffic simulation (e.g. Synchro) files from transit agencies, obtain and analyze existing and predicted mode share calculations based on tour-based (e.g. SF-CHAMP) or trip-based (e.g. Alameda) forecasts. In addition to introducing an avenue of transparency and partnership between Caltrans and transit agencies, collaboration in demand modeling could help inform Caltrans district leadership of a BRT project’s viability.

This concludes the second iteration of research under the PATH BRT Toolbox project, but by no means represents exhaustive analysis, either of the tradeoffs involved in creating exclusive bus lanes or of how Caltrans assesses them. Immediate further studies could solicit feedback on the spreadsheet tool from transit agencies in other Caltrans districts, particularly D7 (Los Angeles) and D11 (San Diego), and compare their experiences in BRT planning with those in the Bay Area. Interviews with Caltrans district planners, the intended users of the tool, would also be valuable and could inform future decisions on what variables and scenarios to include. Other California-specific research could examine how other state agencies have responded to the provisions of SB 743, and consider how Caltrans might adopt some strategies from its peers.

The accompanying spreadsheet tool represents an initial effort in the development of a decision support tool for a high level feasibility assessment of a proposed BRT prior to major investment and environmental studies. We recommend that the BRT planning tool is disseminated to Caltrans districts for their trial use of this tool when BRT lane conversion. Feedbacks from Caltrans districts will be extremely helpful for further improvements of the tool.

Works Cited

AC Transit (2004). *Designing with Transit: Making Transit Integral to East Bay Communities*.
http://www.actransit.org/wp-content/uploads/designing_with_transit2.pdf

AC Transit (2012). *Transit Patronage and Forecasting Methodology Report*.
http://www.actransit.org/wp-content/uploads/ACT_EBBRT_TransitRidershipForecasting_0Main.pdf

AC Transit (2012). *Final Environmental Impact Statement: Traffic Analysis Report*.
http://www.actransit.org/wp-content/uploads/ACT_EBBRT_TrafficReport_0Main.pdf

American Public Transportation Association (2010). *Designing Bus Rapid Transit Running Ways*. Recommended Practice, APTA Standard Development Program.
<http://www.apta.com/resources/standards/documents/apta-bts-brt-rp-003-10.pdf>

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, DC.
https://educnet.enpc.fr/pluginfile.php/11265/mod_folder/content/0/BRT/2012_TRB_CostBenefit_Analysis_ConversiontoBRT.pdf?forcedownload=1

Bay Area News Group (2012). *My Word: Planned Bus Rapid Transit Will Hurt Businesses Badly*. East Bay Times.
<http://www.eastbaytimes.com/2012/07/09/my-word-planned-bus-rapid-transit-will-hurt-businesses-badly/>

California Department of Transportation (2007). *Director's Policy: Bus Rapid Transit Implementation Support*. DP-27.
<http://www.dot.ca.gov/hq/MassTrans/Docs-Pdfs/BRT/BRT-Implement-Dir-Support.pdf>

California Department of Transportation (2016). *SB 743 Implementation*.
<http://www.dot.ca.gov/hq/tpp/sb743.html>

California Department of Transportation (2017), *Local Development-Intergovernmental Review Program Interim Guidance*,
<http://www.dot.ca.gov/hq/tpp/documents/RevisedInterimGuidance11092016.pdf>

Governor's Office of Planning and Research (2013). *Preliminary Evaluation of Alternative Methods of Transportation Analysis*.
<https://www.opr.ca.gov/docs/PreliminaryEvaluationTransportationMetrics.pdf>

Governor's Office of Planning and Research (2014). *Updating Transportation Impacts Analysis in the CEQA Guidelines: Preliminary Discussion Draft of Updates to the CEQA Guidelines Implementing Senate Bill 743 (Steinberg, 2013)*.

https://www.opr.ca.gov/docs/Final_Preliminary_Discussion_Draft_of_Updates_Implementing_SB_743_080614.pdf

Chen, X., 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.

Institute for Transportation and Development Policy (2016). *The Scorecard 2016*.
<https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/>

Li, J., Song, MK, Li, M., Zhang, WB, and Miller, M. (2009). *Evaluation of Cost-Effective Planning and Design Options for Bus Rapid Transit in Dedicated Bus Lanes*. California PATH Research Report (UCB-ITS-PRR-2009-14).
http://nacto.org/docs/usdg/evaluation_cost_effective_planning_brt_li.pdf

Li, J., Chan, CY, Zhou, K., and Zhang, WB (2015). *Bus Rapid Transit (BRT) Toolbox: BRT Person Throughput-Vehicle Congestion Tradeoffs*. California PATH (CA15-2333).
http://www.dot.ca.gov/newtech/researchreports/reports/2014/CA15-2333_FinalReport.pdf

Miller, Mark (2011). *State and Federal Project Development Procedures for Bus Rapid Transit: Managing Differences and Reducing Implementation Delays*. California PATH (CA11-2026).
http://www.dot.ca.gov/newtech/researchreports/reports/2011/2011-08_task_2026-modal.pdf

Ojuri, Oluseyi (2015). *Assessing the Impact of California Senate Bill 743 on Transportation Planning, Traffic Impact Analysis, and Level of Service*. University of California, Irvine.
<http://escholarship.org/uc/item/99d758cb#page-1>

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

Rohde, Mike (2016). *World Metro Database*.
<http://mic-ro.com/metro/table.html>

San Francisco County Transportation Authority (2014). *Project Study Report – Project Report to Provide Project Approval*.
http://www.sfcta.org/sites/default/files/content/Planning/VanNessAvenueBusRapidTransit/Van%20Ness%20BRT%20PSR-PR_Approved_082614.pdf

Zhang, Kai, and Stuart Batterman (2013). *Air Pollution and Health Risks due to Vehicle Traffic*. Sci Total Environ, 307-316.
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4243514/>

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

Appendix A: Perspectives of Interviewed BRT Project Managers of Two Transit Agencies

Liaison and partnership with Caltrans involved many BRT planners and engineers at SFCTA and AC Transit, several of whom, through interviews, offered perspectives on relevant MOEs and the Caltrans approval process. Insights based on each interview are paraphrased below, followed by a brief analysis of the interviewees' experiences in light of known background information.

a.1 Interview Findings: AC Transit

Even before SB 743, Caltrans D4 *planners* supported AC Transit's BRT proposal for International Boulevard, the Caltrans facility assigned a BRT line as part of the East Bay BRT project. The D4 enthusiasm for multimodal activity on a Caltrans-owned highway was consistent with the Caltrans Director's Policy 27, and, as representatives of Caltrans, the planners were satisfied with person throughput as a performance metric. Cities of Berkeley, Oakland, and San Leandro also raised LOS questions about the BRT project, whose geographic limits span three cities and whose route followed multiple city streets (not administered by Caltrans) in addition to International Boulevard. These worries were assuaged as traffic simulation predicted little to no LOS degradation. Opposition from Berkeley merchants, resulted in the route being shortened despite evidence that such businesses would not lose customer access. Other delay factors include not only at planning level but design details such as drainage issues. These issues were not within the concerns by transit planners.

a.2 Interview Findings: SFCTA

Van Ness, a birds-eye visualization of which is visible in Figure 5, is an atypical BRT corridor because of its situation in a broader urban grid. While lane conversion and near-total elimination of permitted left turns may be mildly inconvenient for some affected motorists, these drivers can easily divert to myriad parallel high-capacity arterials. Moreover, by prohibiting left turns at all but two intersections along the two-mile corridor, the BRT project is actually projected to *increase* vehicle throughput in the two remaining lanes due to vastly fewer queues forming behind left-turning cars. Since existing conditions along Van Ness include local bus traffic, median BRT lanes are expected to mitigate yet another cause of general purpose lane delays. From the SFCTA perspective, reliance on person throughput is an improvement over LOS but may fail to capture the *potential* person throughput as increasingly frequent bus service, following an expected surge in citywide transit ridership, uses the dedicated lanes. Since person throughput may not change significantly, future capacity could be an alternative metric.



Figure 5: *In this bird's eye rendering of Van Ness Avenue, the red painted median BRT lanes are clearly visible. Only Muni and Golden Gate Transit buses will use the two dedicated lanes. Since the innermost lanes in each direction were historically subject to frequent delays as cars waited to complete left turns, prohibiting such turn movements is actually projected to increase vehicle throughput per lane. By narrowing the median and removing some trees and vegetation, reconfiguring Van Ness also increases visibility. Both are examples of how a BRT lane conversion might even improve conditions for mixed traffic in the remaining two lanes. Source: SFCTA, 2014*

Lane conversion and resizing involved all design exceptions to Caltrans' *Highway Design Manual* and each exception must be approved individually. Specifically, the design involving narrower travel lanes coupled with the removal of many central trees, improving visibility is an effective design compromise, but also points, beyond design exceptions, to a broader tradeoff between the priorities for managing traffic and goal for decreasingly auto-oriented goals. Following SB 743, Caltrans can no longer point to CEQA as another process requiring LOS analysis, and might be motivated to change its project approval criteria to facilitate effective support for BRT deployment. .

a.3 Interview Synthesis

All interviewees mentioned the role of a state geometrician, the Caltrans individual whose design authority effectively amounts to veto power (or at least the power to the time required for approval while the agency pursues design exceptions). Furthermore, they all pointed to a possible misapplication of Caltrans geometry requirements, which may be appropriate for high-speed limited access highways but incompatible with the multimodal needs of urban arterials—such as International or Van Ness—that happen to fall under Caltrans jurisdiction.

Each agency ran its own travel demand model (Alameda Model and SF-CHAMP) to forecast transit and automobile trips. Caltrans districts had expressed a desire to obtain and evaluate data using similar tour- or trip-based models (Li et al, 2015). If Caltrans were to integrate demand modeling into its review process, project approval could be informed by data on mode split and the effects of changing land use and transportation systems, rather than traffic simulation.

Transit agencies were aware of Director's Policy 27 on BRT, and of other guidance documents from pro-BRT Caltrans management, but express skepticism that such verbal support is implemented on the project level. Interviews confirmed that the proverbial "devil is in the details," and such details often fall under the purview of Caltrans staff either unaware of or unmotivated by certain Caltrans Headquarters memoranda. For International Boulevard, however, the Caltrans approval process, albeit drawn-out, was catalyzed by internal Caltrans accounting that favors relinquishing certain conventional state highways, including Route 185, to city and county ownership and control.

Interviewed representatives of two transit agencies also offered recommendations for future BRT planning along state highways.

With the guidance of each District Director at Caltrans, select a project-specific pre-CEQA leadership team that includes planners at the district and possibly insulated from the discipline rotation cycle of Caltrans engineers. This could eliminate delays caused by transitions between project managers.

Consider limiting Caltrans discipline representation at planning meetings. While Caltrans has a legitimate interest in ensuring all its disciplines can voice concerns, the current reality is that any internal criticism can stall progress towards project approval and extend an already multi-month process into multiple years. This report does not specify which disciplines or individuals should be included in planning meetings, but, for example, a chronological argument can be made that pavement or drainage experts have a greater role in building a BRT project than in defining its scope and feasibility. Restricting early meetings only to planning and operations staff could accelerate the process, while other experts could still weigh in before implementation.

Ensure replication of design exceptions, at least within a project, but ideally from one project to another. Any deviation from the Caltrans Highway Design Manual currently requires a location-specific design exception, approved in most cases by the state geometrician. Both Caltrans and transit agencies save time and resources when a single design exception, once granted, authorizes identical design of other infrastructure within the same project. On Van Ness, on the other hand, the SFCTA planned for individual median pedestrian refuges at intersections, but had to pursue many separate but redundant design exceptions because each would violate Caltrans lane width policy.

Appendix B: Caltrans Director's Policy (2013)

California Department of Transportation

*Flex your power!
Be energy efficient*

Director's Policy

Number: DP-27-R1
Effective Date: November 15, 2013
Supersedes: February 2007

TITLE Bus Rapid Transit Implementation Support

POLICY

The California Department of Transportation (Caltrans) recognizes and supports the concept and implementation of Bus Rapid Transit (BRT) as a potentially cost-effective strategy to maximize people throughput (emphasizing the movement of people, not just vehicles), reduce traveler delay, increase capacity, and foster energy savings on the California State Highway System (SHS), as well as on conventional highways. Caltrans will work closely with local jurisdictions, regional transportation planning agencies, transit operators, and other stakeholders to plan, develop, implement, and advocate for BRT systems.

This policy is consistent with existing directives to reach context-sensitive solutions through a collaborative, interdisciplinary approach involving all stakeholders in the development of the transportation infrastructure. This policy supports Caltrans' goal of Mobility – Maximize transportation system performance and accessibility.

"BRT can best be described as a combination of facility, systems, and vehicle investments that convert conventional bus services into a fixed-facility transit service, greatly increasing their efficiency and effectiveness to the end user." [Cited from the Federal Transit Administration, BRT Demonstration Program, December 2002.] BRT typically includes bus services that are, at a minimum, faster than traditional 'local bus' service and, at a maximum, include grade-separated bus operations. Features of BRT systems may include transit signal priority, dedicated lanes, High Occupancy Vehicle (HOV) drop ramps, faster passenger boarding, faster fare collection, and a system image that is uniquely identifiable. BRT represents a way to improve mobility at relatively low cost through incremental investment in a combination of bus infrastructure, equipment, operational improvements, and technology.

INTENDED RESULTS

The intended result of this policy is improved mobility options through the full integration of BRT as an investment alternative into system and comprehensive corridor planning documents and project development processes. BRT will provide any person in California with a degree of mobility that is in balance with other values.

"Caltrans improves mobility across California"

Appendix C: Caltrans Deputy Directive (2013)

California Department of Transportation

*Flex your power!
Be energy efficient!*

Deputy Directive

<i>Number:</i>	DD-98-R1
<i>Refer to Director's Policy:</i>	DP-27 BRT Implementation Support DP-26 Intelligent Transportation Systems DP-23-R1 Energy Efficiency, Conservation, and Climate Change DP-22 Context Sensitive Solutions DP-08 Freeway System Management
<i>Effective Date:</i>	07/23/2013
<i>Supersedes:</i>	DD-98 (October 2008)

TITLE Integrating Bus Rapid Transit into State Facilities

POLICY

The California Department of Transportation (Caltrans) supports the integration of Bus Rapid Transit (BRT) projects and operations on the California State Highway System (SHS) where most effective, through partnership with BRT stakeholders. Integrating BRT support elements on State facilities where appropriate, has the potential to increase the "person-throughput," reduce the rate of congestion for all highway users, mitigate pollution, reduce greenhouse gas emissions, and improve goods movement.

Caltrans ensures that relevant procedures, standards, and guidance include direction that addresses BRT during the preliminary planning concept stages, and throughout the formal stages of planning, design, construction, operation, and maintenance of its facilities and properties.

Costs associated with integrating BRT into standard Caltrans processes; (e.g., planning, design, construction, operations, and maintenance), are considered costs of delivering California's transportation system.

DEFINITION/BACKGROUND

BRT is defined by the Federal Transit Administration as a rapid mode of transportation that can provide the quality of rail transit and the flexibility of buses. The Transit Cooperative Research Program also defines BRT as "a flexible, rubber-tired form of rapid-transit mode that combines stations,

"Caltrans improves mobility across California"