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When Are Bus Lanes Warranted?

Considering Economic Efficiency, Social Equity and Strategic Planning Goals

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Many cities are implementing bus lane networks to increased transport system efficiency and equity, but few are implementing them to the degree that is justified by their total long-term benefits.

Abstract

This report describes a framework for determining when bus lanes are warranted based on economic efficiency, social equity and strategic planning objectives. Bus lanes increased urban transport system efficiency and equity by favoring higher value trips and more space-efficient modes over lower-value trips and space-intensive modes. Bus lanes can carry more passengers than general traffic lanes, and so increase total capacity (people per traffic lane), increase transit system operating efficiency, directly benefit bus passengers, cause travellers to shift from automobile to transit which reduces various transportation problems, and support more transit-oriented development. This paper examines how these impacts are considered in conventional planning, describes examples of bus lane planning and evaluation, and discusses ways to optimize their implementation. Much of this analysis also applies to other transit improvements, such as increased service frequency, and other managed lane types such as HOV and HOT lanes. This paper should be of interest to policy analysts, transport planners and engineers, and transit advocates.

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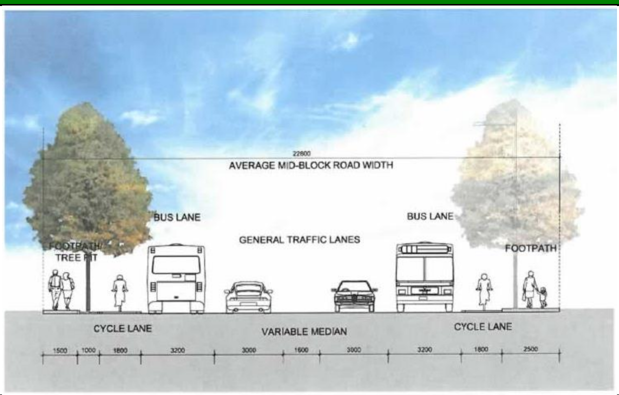
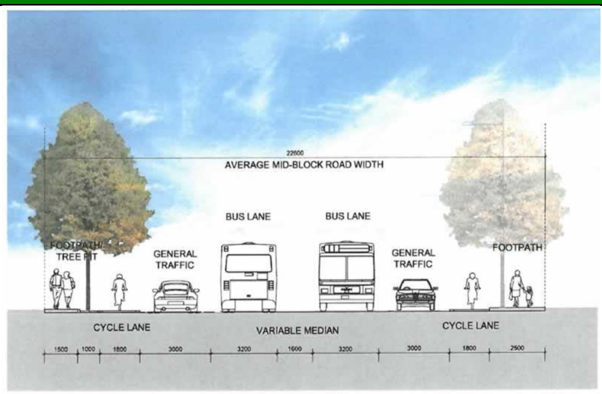
"A developed country is not a place where the poor have cars. It's where the rich use public transportation."
— Gustavo Petro, Mayor of Bogota, Columbia

1. Introduction

Cities are, by definition, places where many people and activities locate close together, so urban space, particularly road space, is always scarce and valuable. As a result, to be efficient and equitable urban road management must favor higher value trips and more space-efficient modes on congested corridors; this gives travellers incentives to choose more efficient modes when possible, for example, using buses and ridesharing (car- and vanpools) when commuting on busy urban corridors.

There are several possible ways to favour higher value and space-efficient trips, including road pricing, or priority intersection treatments and dedicated lanes for certain vehicles such as freight trucks, buses and High Occupancy Vehicles (HOVs). This report focuses on bus lanes (Figure 1), and their variations such as HOV and High Occupant Tolls (HOT) lanes. Bus lanes can significantly increase transport system efficiency and equity; this study suggests that they are widely justified. However, few cities implement comprehensive bus lane networks, and many proposed bus lanes have been delayed, abandoned, or compromised (such as allowing lower occupant vehicles, motorcycles and alternative fuelled vehicles) due to inadequate benefit analysis and political opposition.

Figure 1 **Examples of Bus Lane Designs** (Arbury 2010)

Curb Bus Lanes	Center Bus Lanes
	

Arterial bus lanes can be located along the curb or center median.

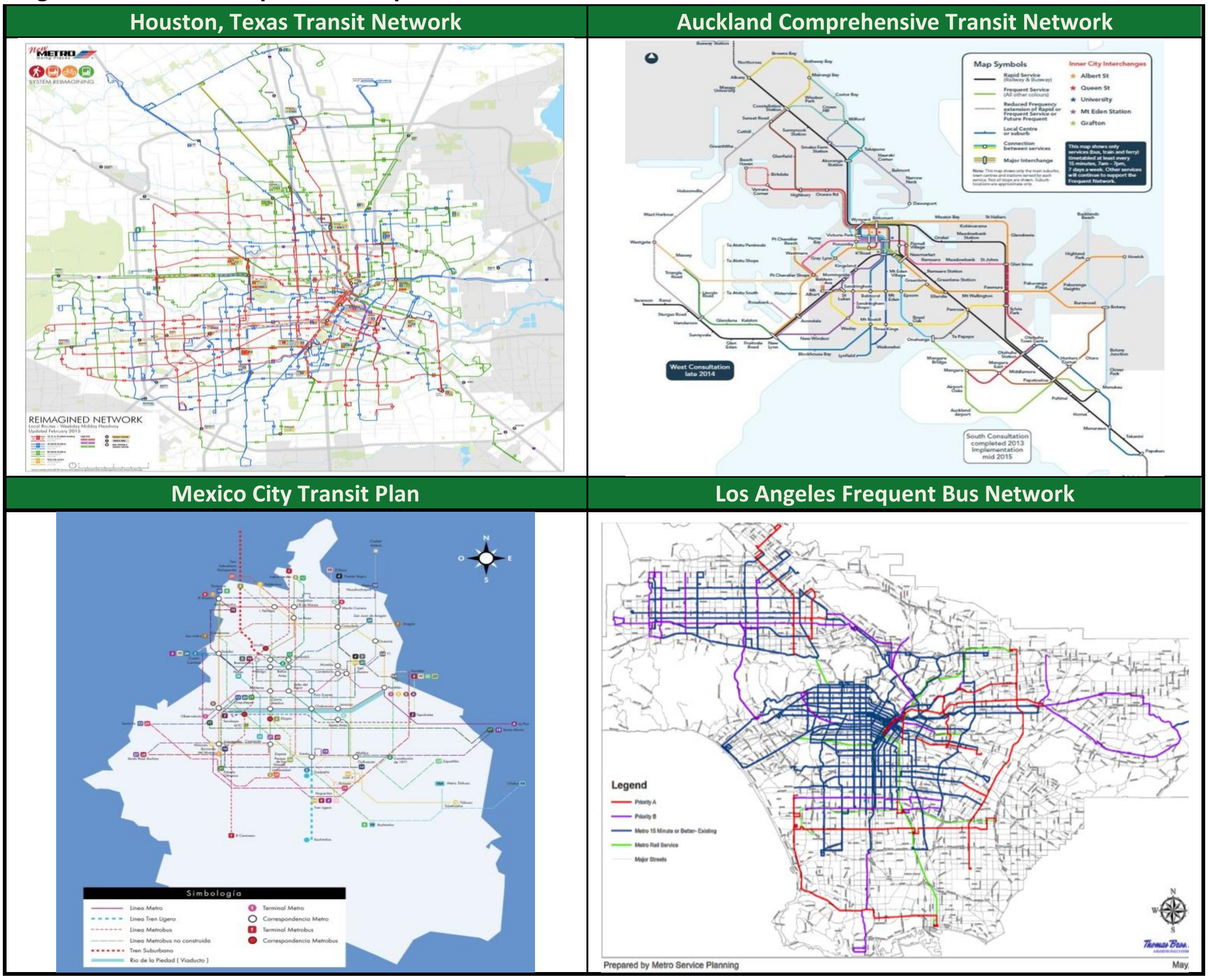
This paper explores these issues. It discusses bus lane benefits and costs, examines how they are evaluated in conventional planning, provides guidance for identifying when bus lanes are justified, and describes ways to support their implementation. This is part of broader discussions concerning how best to improve public transit, efficiently manage road space, and evaluate transport system performance. Many of these conclusions apply to other transit improvements and roadway management strategies. This analysis should be of interest to policy analysts, transport planners and engineers, and transit advocates.

2. Bus Lanes and Variations

Bus lanes are roadway lanes dedicated to bus use. Variations include HOV lanes which accommodate buses and rideshare vehicles that carry at least the designated minimum number of passengers (often 2+ or 3+), and High Occupant Toll (HOT) lanes which accommodate buses, rideshare and toll-paying vehicles. They sometimes accommodate other vehicle types including motorcycles, alternative fuelled vehicles, and freight trucks.

Several current urban transport planning trends support bus lane development. They are a public transit improvement strategy (Kittleson & Associates 2013), a type of managed lanes (FHWA 2015), an important feature of Bus Rapid Transit (BRT) systems (APTA 2010; ITDP 2013), and a common component of Complete Streets policies which design streets to accommodate multiple users (SGA 2015). Many cities are developing comprehensive rapid bus networks (Boyle 2013; Hook, Lotshaw and Weinstock 2013; Walker 2015), as illustrated in Figure 2. They are important but often overlooked and undervalued. For example, although London is most famous for its subway system and congestion pricing, its bus network is a critical part of its transport system (TfL 2014).

Figure 2 **Examples of Comprehensive Bus Network Plans**



Many cities are developing comprehensive rapid bus networks that depend on bus lanes to be effective.

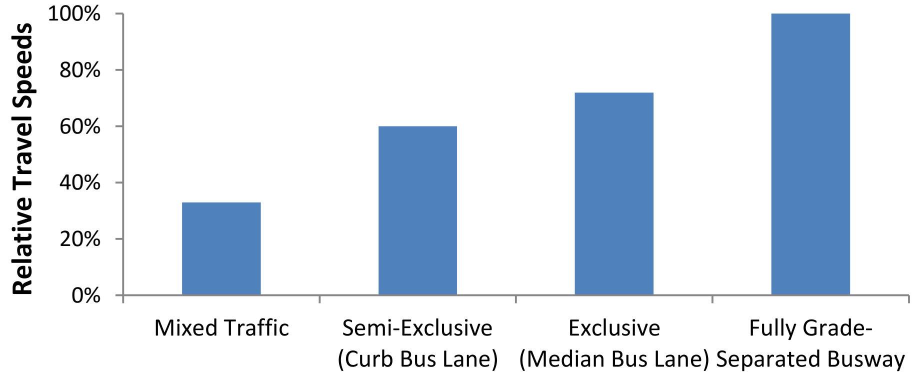
3. Bus Lane Impacts

This section examines how bus lanes affect travel, and their overall benefits and costs.

Travel Impacts

On congested roadways, bus lanes can significantly increase bus travel speeds and reliability (the chance of arriving on schedule) (Boyle 2013). Under congested conditions, dedicated lanes can double or triple bus travel speeds (Figure 3), but since only a minor portion of total bus travel occurs under such conditions, and congestion is just one of several causes of transit delay (passengers also spend time travelling to and from bus stops, waiting for buses, *dwell time* loading and unloading passenger, plus intersection delay), total impacts are usually more modest, typically reducing door-to-door trip duration by 5-15%; for example, from 40 to 36 minutes, with larger savings for longer trips and more congested conditions.

Figure 3 **Relative Travel Speeds By Facility Type** (Kittleson & Associates 2013)



Under typical congested urban conditions, curb bus lanes approximately double, and fully grade-separated busways (which eliminate stops at intersections) approximately triple, bus operating speeds.

Increases in public transit travel speed and reliability tend to attract more passengers (Handy, et al. 2013). Paulley, et al. (2006) estimate the elasticity of bus trips with respect to bus travel time is typically -0.4 to -0.6, so each 10% reduction in travel time typically increases ridership by 4-6%. These impacts that tend to increase over time. This suggests that by themselves, bus lanes that reduce transit travel times by 5-15% will increase total ridership 2-9%, with most increases occurring under urban-peak conditions. Much larger ridership gains are possible if bus lanes are implemented in conjunction with other pro-transit policies such as other service improvements and incentives; ridership gains of 10-40% are often reported by Bus Rapid Transit programs (EMBARQ India 2009; Weinstock, et al. 2009).

Not all of the additional transit trips substitute for automobile travel; some of the new passengers would otherwise walk, bike or rideshare. On the other hand, high quality transit tends to have leverage effects; an increase in transit travel can provide a proportionately larger reduction in automobile travel if transit helps create more compact, walkable, transit-oriented neighborhoods where residents tend to own fewer automobiles, drive less and rely more on alternative modes, reducing additional automobile trips beyond just those that shift from automobile to transit on that route (ICF 2008; Litman 2015).

Based on data from numerous bus priority projects, Harvey, Tomecki and Teh (2012) developed a Bus Priority Assessment Tool (BAT) that can predict the travel time savings, ridership gains, and automobile travel reductions from specific bus priority measures, and evaluate their ability to achieve various planning objectives.

Benefits and Costs

Table 1 categorizes various bus lane benefits and costs. By increasing travel speeds, bus lanes directly benefit bus passengers. They increase transit operating efficiency (more passenger-kilometers per bus-hour). Increased ridership increases fare revenues. To the degree that new transit trips displace automobile travel they reduce external costs including traffic and parking congestion, accident risk and pollution emissions. Bus lanes can be a catalyst for transit-oriented development, which, by reducing residents per capita vehicle travel, tends to provide additional indirect benefits.

Bus lanes can also impose costs. Bus lanes increase construction and enforcement costs, complicate traffic operations, reduce traffic capacity, and sometimes displace on-street parking. Some bus lanes, particularly high capacity BRT systems, require additional road space for stations, and wider sidewalks to improve pedestrian access.

Table 1 **Bus Lane Benefits and Costs** (Litman 2015)

Category	Improved Transit Service	Increased Transit Travel	Reduced Automobile Travel	Transit-Oriented Development (TOD)
Indicators	*Service Quality (speed, comfort, etc.)*	*Transit Ridership (trips or mode share)*	*Automobile Travel Reductions*	*Portion of Development in TODs*
Benefits	Improved transit operating efficiency Improved bus passenger travel speed and reliability Option value (value of having options that may sometime be useful) Equity benefits (since existing users tend to be disadvantaged)	Direct benefits to new users Increased fare revenue Increased public fitness and health (by stimulating more walking or cycling trips)	Reduced traffic and parking congestion, and resulting facility cost savings Consumer savings Reduced chauffeuring burdens Increased traffic safety Energy conservation Air and noise pollution reductions	Additional vehicle travel reductions ("leverage effects"), such as a shift to walking Improved accessibility, particularly for non-drivers Reduced infrastructure costs from more compact development Farmland and habitat preservation
Costs	Additional construction, operation and enforcement costs Reduced traffic capacity and more congestion in adjacent lanes Reduced parking supply	More crowded buses	Reduced automobile business activity	Various problems associated with denser development

Bus lanes can have various benefits and costs that should be considered in evaluation. Some of these impacts are indirect and long-term, so their evaluation requires predictive modeling of travel and land development.

Bus lanes increase travel options, reflecting the principle of *consumer sovereignty*. Without bus lanes urban travellers must choose between congested automobile or congested bus travel; with bus lanes they choose between congested automobile or uncongested bus travel. In most cases, new bus passengers are better off overall (they gain consumer surplus) or they would not change mode.

These benefits depend on the magnitude of transportation system changes, including increases in bus speeds and resulting time and money savings, increases in ridership and reductions in automobile travel, plus changes in land use development patterns. Impacts on motorists depend on whether the bus lanes attract enough peak-period automobile trips to offset any reduction in general traffic capacity. Bus lane economic analysis therefore requires models that can predict these impacts, including the cumulative impacts of integrated transit service improvements and ridership incentives. Current transport models are poor at predicting such impacts and so tend to underestimate bus lane benefits (Brown and Paling 2014; Chen and Naylor 2011; Rodier and Spiller 2012).

Bus lane traffic congestion impacts can be difficult to quantify since congestion tends to maintain self-limiting equilibrium; urban-peak traffic volumes tend to increase to the point that congestion delays discourage any additional peak-period vehicle trips. As a result, marginal increases in roadway capacity or automobile trip reductions generally provide little long-term congestion reductions since the additional capacity is soon filled with latent demand. However, the quality of alternative modes affects the point of congestion equilibrium: if alternatives are poor, congestion can become severe before enough travellers change, but if alternatives are relatively fast and convenient travellers will be more willing to change. Congestion does not disappear, but is less severe than would otherwise occur (Aftabuzzaman, Currie and Sarvi, 2011; Litman, 2014). Even if bus lanes only shift a fewer percent of total travel from automobile to transit, this consists primarily of peak-period trips, which provides relatively large congestion reductions. For example, although Los Angeles has only 11% transit commute mode share, one study found that transit reduces regional congestion costs by 11% to 38% (Anderson 2013).

Bus lanes can help achieve social equity objectives (Darshini, Joshi and Datey 2013). They provide a fairer allocation of road space, so bus passengers receive their fair share of public road space and are not delayed by congestion caused by private automobile traffic, which reflects the principle of *horizontal equity* (people should bear the costs imposed by their activities). They also increase economic opportunity for physically, economically and socially disadvantaged people, which reflects the principle of *vertical equity* (public policies should help disadvantaged people).

4. Transformative Potential of Bus Lane Networks

A comprehensive bus lanes network can help cities achieve strategic goals of creating more efficient, multimodal transport systems and more compact, transit-oriented development.

Most cities, in both affluent and developing countries, are to various degrees automobile-dependent due to transport and land use planning which favors automobile over walking, cycling and public transit (Kodukula 2011). For example, in most cities, high roadway traffic volumes and speeds make walking and cycling difficult and dangerous, and create congestion which delays public transit vehicles. This creates a self-reinforcing cycle of increasing automobile travel and degraded walking, cycling and transit conditions. Many experts recommend policy reforms to create more multimodal cities, in order to achieve economic efficiency and social equity goals (ADB 2009; Boarnet 2013). This requires transport systems where rich and poor will use the most efficient mode for each trip: walking and cycling for local travel; transit when travelling on busy travel corridors; and automobiles only when they are most efficient overall.

Until recently, efforts to create multimodal cities tended to focus on rail transit, but these are costly and require decades to fully develop. Many experts now recommend bus transit improvements, alone or in conjunction with rail transit, to create multimodal transport systems (Embarq 2013; Suzuki, Cervero and Iuchi 2013). An integrated bus lane network supported by other pro-transit policies can make public transit travel speeds competitive with automobile travel, giving travellers more reasons to choose transit. This creates a positive feedback cycle of improved transit services, more diverse transit ridership, more political support for pro-transit policies, and more transit-oriented development (Levinson 2015). Convenient and attractive transit services will attract more middle-class households to transit-oriented neighborhoods where they own fewer vehicles, drive less and rely more on walking, cycling and transit.

However, these impacts and benefits can be difficult to predict; current travel models are not very sensitive to qualitative transit service improvements or the synergistic effects of multiple pro-transit policies (Chen and Naylor 2011), and conventional economic evaluation tends to overlook many benefits, such as the household savings, parking cost savings, public safety and health benefits that result from reduced automobile ownership (Litman 2015). As a result, conventional travel models tend to underestimate the full benefits of bus lane network development. The result is a burden-of-proof issue: how much evidence must transit-advocates provide to demonstrate that bus lanes will achieve their potential long-term benefits? Because motorists often bear the immediate costs (they have less roadway capacity) and are politically influential, the burden of proof is often very high, resulting in far smaller bus lane networks than is optimal considering all benefits.

5. Factors Affecting Bus Lane Impacts and Benefits

A key factor in bus lane benefit analysis is the amount of travel they shift from automobile to bus. If mode shifts are small, converting a general traffic lane into a bus lane will provide smaller transit passenger time savings, increase traffic congestion on general traffic lanes, and provide minimal vehicle travel reduction benefits (reductions in downstream congestion, parking cost savings, and reductions in traffic accidents and pollution emissions); as mode shifts increase so will transit passenger time savings, congestion reductions, and other vehicle travel reduction benefits. A typical arterial lane can carry up to 800 vehicles per hour, so converting a general traffic lane into a bus lane will increase congestion in other lanes if *fewer* than 800 peak-period automobile drivers shift to transit, and will reduce congestion if *more* than 800 peak-period drivers shift. In addition to reducing traffic congestion on that roadway, automobile to transit mode shifts tend to reduce downstream traffic congestion, for example, reducing vehicle traffic on a highway can help reduce surface-street congestion.

Bus lane development often causes only modest short-term mode shifts, since it takes time, often years, for travellers to fully adjust to these changes. As a result, automobile traffic congestion will initially increase, although over time this congestion declines and total benefits increase, as more travellers shift mode. In that situation, the evaluation should compare the short-term increase in motorist delay against long-term impacts and benefits.

Many factors affect these shifts. In most situations, bus lanes can only save a minor portion of a trip's total time, typically two to ten minutes in a thirty- to sixty-minute commute, which is less than the incremental access and waiting time required for public transit travel. Other factors affect transit mode choice including the transit service convenience and comfort, the price of fares, quality of walking and cycling, road and parking pricing, and the social acceptability of transit travel (Alam, Nixon and Zhang 2015). As a result, total impacts and benefits depend on the degree that other pro-transit policies (Table 2) are implemented with bus lanes.

Table 2 **Examples of Pro-Transit Policies** (VTPI 2015)

Service Improvements	Incentives	Land Use Changes
• Increased service which increases frequency and reduces crowding • Nicer vehicles • Nicer stations • Better user information • More convenient payment systems	• Efficient road and parking pricing • Commute trip reduction programs • Fare reductions • Transit marketing and promotion	• More compact and mixed development around frequent transit routes • Improved walking and cycling conditions • More affordable housing along frequent transit routes

Many pro-transit policies can encourage public transit ridership, which increases bus lane impacts and benefits.

Bus lane benefit analysis is affected by the quality of traffic models used to predict future traffic impacts. Conventional models are ineffective at evaluating many of these factors, particularly qualitative factors such as comfort and prestige (Rodier and Spiller 2012). In addition, many current models lack congestion feedback (they ignore the tendency of traffic congestion to reach equilibrium). As a result, they tend to underestimate the mode shifting, and exaggerate the intensity of congestion in general traffic lanes, caused by bus lane development.

6. Evaluation Perspectives

Bus lanes can be evaluated in various ways that lead to very different conclusions about their benefits and the conditions in which they are justified, as described below.

Traffic (Vehicle Travel)

Conventional planning tends to evaluate roadway performance based primarily on vehicle travel conditions using indicators such as traffic speeds, congestion delay and roadway level-of-service (LOS). This only justifies bus lanes if they cause enough peak-period drivers to shift to buses so that congestion declines on adjacent lanes, which typically requires shifts of 800 peak-period drivers on arterials and 2,000 drivers on urban freeways.

Mobility (Person Travel)

Mobility reflects the travel speed of people, rather than vehicles. This support bus lanes if they provide net travel time savings, so bus passenger time savings more than offset any increase in motorists travel times.

Economic Efficiency

Economic efficiency considers total economic benefits and costs. This justifies bus lanes if they provide net benefits, considering all impacts, including bus and automobile passenger travel time, transit operating costs, downstream congestion, parking costs, accident and pollution damages.

Accessibility

Accessibility refers to people's ability to reach desired services and activities, taking account both mobility (travel speed and costs) and travel distances required to reach destinations. This tends to justify bus lanes if they increase mobility or are a catalyst for more compact, mixed development.

Social Equity

Horizontal equity assumes that people with similar needs and abilities should receive equal shares of public resources, which suggests that buses, should have priority over lower occupancy vehicles, since they use less road space per passenger-kilometer, and so impose less congestion than lower occupant vehicles. *Vertical equity* assumes that policies should favor disadvantaged people, and so tends to support bus lanes to the degree that they are used by people with disabilities and low incomes. Social equity objectives tend to justify bus lanes because they more fairly allocate road space and tend to benefit disadvantaged people.

Strategic Planning Objectives

A basic principle of good planning is that individual, short-term decisions should support strategic, long-term goals. This tends to justify bus lanes, even if they increase traffic congestion in the short-run, if they help create more efficient transport systems, and so help achieve long-term goals.

Table 3 compares various bus lane evaluation perspectives. More comprehensive evaluation tends to justify more bus lane implementation.

Table 3 **Bus Lane Evaluation Perspectives**

Perspective	Planning Goal	Performance Indicators
Vehicle traffic	Maximize vehicle traffic speeds	Vehicle travel speeds and delay, roadway LOS
Mobility	Maximize passenger travel speeds	Multimodal LOS (travel speed by various modes)
Accessibility	Maximize people's ability to reach desired services and activities	Time and money required to reach various services and activities (e.g., schools, jobs, shops, etc.)
Social equity	People receive a fair share of public resources, such as road space	Degree that roadway management favors space-efficient and affordable modes (ridesharing and bus)
Economic Efficiency	Transport management favors higher value trips and more efficient modes.	Efficient pricing of congested facilities. Freight and HOV priority.
Strategic Planning	Individual, short-term decisions support strategic, long-term goals	Degree that roadway policies and planning reflect strategic goals.

Different perspectives reflect different assumptions concerning what type of roadway management is efficient and equitable, and how roadway performance should be evaluated.

7. Bus Lane Warrants

This section describes various ways to define bus lane warrants, which determine when bus lanes are justified.

Previous Literature

Several previous publications have defined bus lane warrants. Kittleson Associates (2013) summarizes various factors to consider when evaluating transit priority features, including bus lanes. Danaher (2010, Table 5) summarizes the warrants for various transport system management strategies, including bus lanes, used by eighty North American transportation agencies. AECOM (2012) evaluated current Australian bus and HOV lane warrants, and the effects of converting urban arterial bus lanes into HOV lanes that allow vehicles with at least two (T2) or at least three (T3) passengers. The study concludes that on most corridors, lanes are most efficient if they are limited to buses and at least three passenger (T3) rideshare vehicles. It described various Bus and HOV facility warrants developed by Australian planning organizations, such as summarized in Table 4.

Table 4 **ACT Bus and HOV Facility Warrants** (AECOM 2012)

Project Type	Warrants
Segregated Busway. When warrants are met a busway should be investigated for the corridor	All of the following conditions met: • > 75 buses per one hour peak direction at time of commissioning. • > 80% increase in-bus travel time in congested conditions without bus priority. • < 85% of buses arrive on time.
Conversion of traffic lane. Conversion of an existing general traffic lane to an exclusive bus lane is preferred. Dependent upon the location (such as physical, environmental financial considerations) conversion to transit / HOV lane may be acceptable, if similar outcomes with exclusive bus lane	*Bus lane* if three or more of the following are met: • Buses carry 65% - 80% of the volume of people moved in the adjacent general traffic lane • > 12 buses per hour. • There is a 35% - 65% increase in bus travel times in congested conditions without bus priority. • < 75% of buses arrive on time without bus priority. *HOV lane* if the following exist: • Buses carry 40% - 65% of the volume of people carried in the adjacent general traffic lane. • > 10 buses per hour. • < 40% increase in bus travel times when conditions are congested and no bus priority.
Road widening. When an additional traffic lane is being provided (i.e., road widening) the preference is for this additional lane to be converted to an exclusive bus lane. If warrants are not met then a transit lane should be considered in the additional lane being provided.	Bus lanes if the following is met • The bus services carry more than 50% of people being carried in the adjacent traffic lane. • 10 buses per hour. There should be a plan for the corridor to move public transport towards a medium level of warrant (> 80% of people being carried in adjacent general traffic lane and > 15 buses / hour)
Queue Jump. Should be provided when travel times or service reliability improvements can be achieved	Queue jumps are warranted where: • > 50% of people being carried in the adjacent traffic lane. • > 10% increase in travel time when congestion is present.
Signal Priority. Should be provided when travel times or service reliability can be improved	Signal Priority is warranted where: • Queue jumps are already in place. • > 10% increase in travel time when congestion is present.
Bus bays. To be provided on corridors with bus or transit lanes where they improve the efficiency of bus operations or the safety of buses, general traffic cyclists or passengers	• If the service headway is less or close to the average dwell time, bus bays are warranted. • If a road safety audit identifies the need for a bus bay. • Where parking consistently hinders access to bus stops.

The Australian Capital Territory (ACT) developed these bus and HOV lane warrants. Other Australian transportation organizations have developed similar criteria.

Brown and Paling (2014) recommends the following special lane (truck, bus, HOV, etc.) warrants:

- Special lanes have project Benefit/Cost Ratio over 1.0, or Net Present Values over 0.
- Special lanes increase monetized productivity (value of time and operating costs).
- Special lane increases total corridor person trips.
- Special lanes (excluding truck lanes) carry more people than adjacent traffic lanes.
- Special lanes operate at level of service D or better.
- Bus stop volume-capacity ratio is less than 1.0 (along bus route as a proxy for reliability).

PPK (2000) recommends considering the following factors when determining bus lane warrants:

- *Person carrying capacity* – the special vehicle lane should carry at least as many people as the adjacent traffic lane, irrespective of whether the general purpose lanes are operating at capacity.
- *Public transport operations* – lane use (for example, by motorcycles, HOV and alternative fueled vehicles) should be restricted to ensure that public transport operations are not unacceptably affected, and operational issues cannot be resolved (such as conflicts with turning traffic and pedestrian volumes).
- *Marketing* – where minimum criteria cannot be met upon opening, a short-term programme to boost lane usage will be required along with regular performance reporting and monitoring.
- *Economic efficiency* – the special vehicle lane should have a benefit-cost ratio of 1.0 or greater.

Auckland Transport (2011) developed warrants for special vehicle lanes based on the public transport service frequency, the hierarchy of the corridor in the public transport network, the level of service in the special vehicle lane, and the degree it supports the city's strategic planning objectives.

Bitzios Consulting (2004 and 2007) discusses factors to consider when evaluating bus priority systems, including bus lanes, including:

- Bus passenger volumes relative to a general traffic lane.
- Bus frequency.
- Degree that bus service is delayed by congestion.
- On-time transit operation.

They conclude that bus priority treatments can sometimes be justified, even if they currently carry fewer passengers as general traffic lanes if that can cause automobile to bus mode shifts.

Prior to 2003, the Seoul Metropolitan Government considered bus lanes warranted on urban arterials with 1,800 passengers per hour for the Right Side (curb) bus lanes, and 4,500 passengers per hour for exclusive Left Side (median) bus lanes, or at least 60 to 120 buses per peak hour, but Kim (2003) argues that standard is excessive since it can lead to bus lanes being rejected on highly congested urban streets where low traffic speeds limit bus volumes. He suggests that bus lanes are warranted where they would maintain bus speeds above the speed of general traffic during peak periods (excluding bus stop dwell time), or at least roadway Level-Of-Service D.

NCHRP Report 155, *Bus Use of Highways: Planning and Design Guidelines*, proposed the bus lane warrants summarized in Table 5.

Table 5 **Bus Lane Warrants** (Levinson, Adams and Hoey 1975)

Treatment	Minimum One-Way Peak-Hour Volume		Related Land Use and Transportation Factors
	Buses	*Passengers*	
Bus streets or malls	80-100	3,200-4,000	Commercially oriented frontage.
Curb bus lanes, normal flow	50-80	2 000-3 200	Commercially oriented frontage.
Curb bus lanes, normal flow	30-40	1,200-1,600	At least 2 lanes available for other traffic in same direction.
Median bus lanes	60-90	2,400-3,600	At least 2 lanes available for other traffic in same direction; ability to separate vehicular turn conflicts from buses.
Contraflow bus lanes, short segments	20-30	800-1,200	Allow buses to proceed on normal route, turn around or bypass congestion on bridge approach.
Contraflow bus lanes, extended	40-60	1,600-2,400	At least 2 lanes available for other traffic in opposite direction. Signal spacing greater than 150-m intervals

A National Cooperative Highway Research Program report recommends these bus lane warrants.

This indicates the wide range of possible bus lane warrants. The most restrictive (they require the most peak-period buses or transit passengers to justify a bus lane) are based on roadway traffic impacts, and so only justify bus lanes if they reduce congestion on other lanes. Less restrictive warrants (they require fewer buses or passengers to justify bus lanes) also recognize the value of bus passengers' travel time, and so can justify bus lanes even if they increase automobile travel time, provided that total (bus and automobile passenger) travel times decline; plus the value of increased transit service efficiency and automobile travel reductions that reduce downstream congestion, parking costs, accidents and pollution emissions. The least restrictive (they require the fewest buses and transit passengers to justify bus lanes) also consider social equity objectives, such as improved mobility for disadvantaged travellers, and strategic planning goals, such as efforts to create more multimodal transportation systems and support transit-oriented development.

Some factors to consider when evaluating bus lanes are discussed below.

Travel Efficiency

Travel efficiency bases bus lane warrants on total passenger travel time. Since buses generally carry more passengers than automobiles, bus lanes are often justified if they reduce total passenger travel times, even if they reduce speeds in general traffic lanes. For example, if bus lanes cause 1,000 bus passengers to save 5 minutes per peak-hour trip, these lanes are justified even if, by increasing general traffic lane delays they cause 2 minutes of incremental delay to 2,000 automobile passengers, since the total transit passenger time savings (5,000 minutes) is larger than the total automobile passenger incremental delay (4,000 minutes). Some economists base travel time valuations on wages, which tends to reduce the value of bus travel time savings, but this is controversial and generally not applied in developed countries since the savings are primarily personal travel time, and so represent a transfer from lower- to higher-income travellers.

Economic Efficiency

Comprehensive economic evaluation considers other bus lane benefits, besides travel time savings, such as transit efficiency gains, consumer financial savings, social equity objectives, plus various benefits from reduced automobile travel including traffic and parking congestion reductions, road and parking facility cost savings, and reduced accidents and pollution emissions. Considering these additional benefits, bus lanes may be justified even if they carry fewer passengers than a general traffic lane, if they provide net economic savings.

Because these impacts are diverse and sometimes difficult to measure, comprehensive evaluation should describe, and as much as possible, quantify the impacts listed in Table 1 of this report, including possible long-term and indirect impacts provided by transit-oriented development. Analysis reports should describe impacts that are not quantified, and discuss how this affects results. For example, when comparing various potential congestion reduction strategies, economic analysis should note that bus lanes tend to achieve additional planning objectives, besides reducing congestion, as illustrated in the following table.

Table 6 **Comparing Strategies**

Planning Objective	Roadway Expansions	Flyovers	Bus Lanes
Traffic congestion reduction	✓	✓	✓
Parking congestion reduction			✓
Roadway facility costs savings			✓
Consumer savings and affordability			✓
Increased traffic safety			✓
Improved mobility options for non-drivers			✓
Energy conservation			✓
Pollution reduction			✓
Strategic planning objectives (more compact, multimodal development)			✓
Improved public fitness and health			✓

Roadway expansions and intersection flyovers can reduce congestion on that road link, but provide few other benefits, and to the degree that they induce additional vehicle travel, they can exacerbate problems such as downstream congestion, parking problems, accidents and pollution emissions. Public transit improvements, such as bus lanes, tend to provide a greater range of benefits.

Consumer Sovereignty and Social Equity

Road space can be allocated based on a corridor's peak-period mode share, so bus lanes are warranted if enough road users travel by bus. This responds to consumer demands (travellers who prefer to use transit, provided it is relatively fast) and ensures that non-drivers receive a fair share of public road space. For example, if buses carry 33% of peak-period passengers, it is efficient and fair to devote 33% of available road right-of-way to bus lanes. This analysis should consider corridor roadway capacity, including road lanes on parallel routes, so for example, if buses carry 33% of travel on a corridor that has three two-lane arterials, it would be appropriate to devote one of those roads to bus lanes. To the degree that disadvantaged people rely on bus transport, bus lanes may be justified with somewhat lower mode shares in order to help achieve vertical equity objectives.

Strategic Planning Goals

Another way to define bus lane warrants is based on the degree that it helps support strategic goals, such as efforts to create more resource efficient and multimodal transport systems, and to encourage more compact development. Multimodal communities have most houses, jobs and major public services (schools, hospitals, recreation centers, etc.) located within a ten-minute walk from frequent public transit services. Bus lanes are therefore warranted wherever needed to create such a transit network.

This indicates that bus lanes are generally warranted where, after all economically-justified pro-transit policies are implemented, they would attract more than 800 peak-hour passengers (about 20 buses) on urban surface streets or 1,800 peak-hour passengers (about 40 buses) on grade-separated urban highways, since they carry more passengers than a general traffic lane, and provide additional benefits, including helping to achieve social equity objectives and strategic planning goals. Roadways with moderate transit demand and congestion may have HOV lanes which allow car- and vanpools in addition to buses, but not if this degrades bus travel speed or operating efficiency.

The following factors can affect bus lane benefits and therefore their justification:

- Current and latent bus travel demand, and therefore potential bus passenger volumes.
- The portion of travelers who cannot drive (they lack a driver's license or vehicle) and therefore the social equity benefits of improving public transit services.
- The intensity of traffic congestion on affected corridors, and therefore the magnitude of travel time and transit operating cost savings provided by bus lanes.
- The magnitude of automobile to transit mode shifts, and the range of benefits provided by urban automobile travel reductions, and therefore the total traffic reduction benefits.
- Implementation costs, including construction and incremental operating costs (including increased traffic law enforcement), and increased congestion on general traffic lanes.
- The degree that bus lanes are implemented in conjunction with other pro-transit policies that improve transit service quality and encourage transit use.
- The degree that bus lanes help achieve strategic planning goals, including increasing public transit operating efficiencies and roadway network congestion reductions, reducing accidents and pollution emissions, achieving social equity objectives, transformational change to create more multimodal transport systems, and supporting transit-oriented development.

5. Bus Lane Examples

This section describes examples of both successful and unsuccessful bus lane projects.

Implementation Examples

Brown and Paling (2014) and Harvey, Tomecki and Teh (2012) describe various examples of special travel lanes, including bus lanes, including information on the planning, design, operation and travel impacts of some of these projects.

Bus Rapid Transit Programs

There are many examples of successful Bus Rapid Transit (BRT) systems, as described in the BRT Database (www.brtdata.org) and other sources (Embarq 2013). The BRT Standard (ITDP 2012) identifies specific attributes that a bus system must have to be considered BRT, which generally includes bus lanes on congested roadways.

Indian Cities

Indore and New Delhi, India provide examples of BRT that failed due to incomplete analysis of their long-term benefits, and criticism by politically powerful groups (Bruno 2014). Local citizen organizations and media argued that dedicated bus lanes increase traffic congestion and risk. This criticism led to High Court rulings that opened the lanes to private automobiles. The government commissioned a study of BRT system impacts that considered a narrow range of benefits, for example, measuring vehicle traffic delay rather than passenger traffic delay, weighting values of travel time based on traveller incomes (which increases the value of cars and reduces the value of buses and bicycles), and evaluated performance and safety impacts based on public opinion rather than objective analysis (CSIR 2012). There was no discussion or analysis of the possibility of addressing the traffic problems by implementing *more* bus lanes and *more* pro-transit incentives in order to reduce total automobile traffic on the corridor.

Seattle HOV Lanes

The HOV lanes on Interstate-5 through downtown Seattle is an example of failure because political pressure forced the Washington State Department of Transportation to allow 2+ vehicles (a car with just two occupants can use the lane). As a result, the HOV lane is often as congested as general traffic lanes (WSDOT 2015).

Evaluation Examples

Several studies have evaluated the impacts and benefits of BRT systems (EMBARQ India 2009; Weinstock, et al. 2009), individual bus lanes (AECOM, 2012), and other bus priority treatments (Harvey, Tomecki and Teh, 2012). Many of these studies evaluate bus lanes based primarily on their direct traffic impacts (whether they reduced congestion on adjacent lanes) or total travel time (whether bus passenger travel time savings offset any increase in automobile travel time), and most evaluate individual bus lanes; few consider additional benefits, such as reduced downstream traffic congestion, parking cost savings, reduced accidents and pollution emissions from reduced automobile travel; and fewer use advanced traffic models to evaluate the total traffic impacts of integrated programs that include comprehensive bus lane networks supported by cost effective pro-transit policies.

6. Criticisms and Responses

Bus lanes often face various types of criticisms.

To maintain their speed advantage, bus lanes should operate with traffic volumes significantly below their maximum potential capacity. As a result, such lanes are often criticized by envious motorists who complain about the "empty lane syndrome," referring to their apparent underuse, even if they carry more people than general traffic lanes and provide net travel time savings. Such criticism often leads to political pressure to allow more vehicle types, such as motorcycles, lower-occupant and alternative fuel vehicles, which may spoil the bus lane's performance.

Many proposed bus lanes have been rejected, or their performance compromised, due to underestimates of the bus lane's total benefits, or failure to effectively communicate these benefits to decision-makers and the general public (Schaver 2015). Optimal implementation requires comprehensive evaluation of their impacts, as described in the following section.

The lack of economically-justified bus lane networks probably reflects the following factors:

- Automobile-oriented planning practices which undervalue the benefits of high quality transit and exaggerate the costs to motorists of shifting road space from automobiles to buses.
- The greater political influence of motorists compared with bus passengers.
- The lack of examples of successful bus network improvements compared with the many successful examples of roadway and rail transit projects.
- Risk aversion. Excepting on corridors with high existing bus ridership, bus lane development requires faith that these transit service improvements will attract sufficient passengers to justify their costs and offset the reduction in roadway capacity in general traffic lanes.

Table 7 summarizes various bus lane criticisms and possible responses.

Table 7 **Bus Lane Criticisms and Responses**

Critic	Criticism	Responses
Rail transit advocate	Buses are inferior to rail transit	Buses are cost effective and can complement rail transit, for example, by providing rail station access. Rail advocates should support all types of pro-transit policies.
Automobile advocate	Bus lanes reduce road and parking capacity, causing congestion	Bus lanes can help reduce total vehicle traffic and related congestion, accident and pollution problems, and chauffeuring burdens, so motorists benefit.
HOV advocate	Rideshare vehicles (van- and carpools) are more flexible than transit, so build HOV rather than bus lanes	Van- and car-pools may be justified on some routes, but if they degrade lane performance they should be excluded to maximize transit service performance
Taxpayer	Buses require costly subsidies	With dedicated lanes, buses are more efficient, and generally require less subsidy than other modes

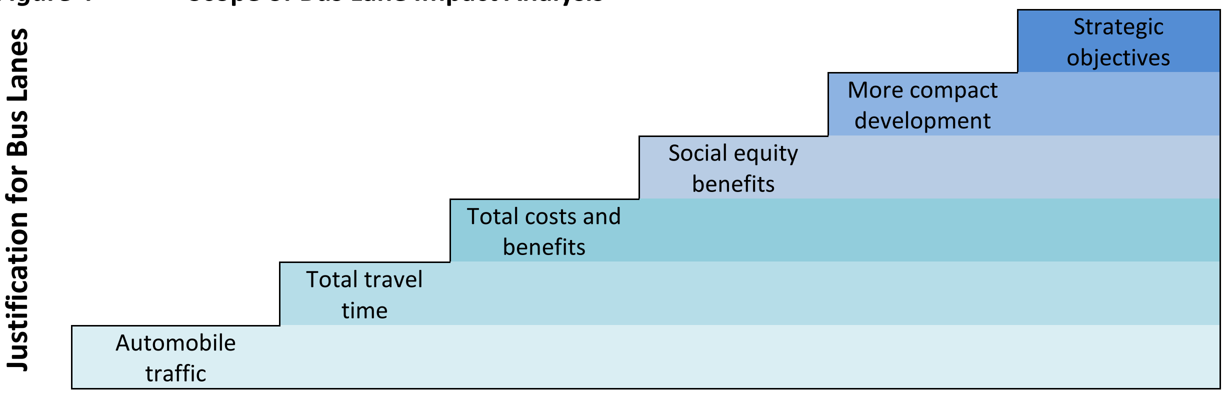
Bus lane development may require responding to various criticisms.

7. Conclusions

Bus lanes can provide various benefits including passenger time savings, operating efficiencies and increased fare revenues, social equity objectives, vehicle travel reduction benefits (reduced traffic and parking congestion, facility cost savings, traffic safety, energy conservation and pollution emission reductions), plus support for strategic planning goals. Even people who never use buses enjoy many of these benefits. All of these impacts should be considered when evaluating bus lanes.

Bus lanes are evaluated in various ways that can result in very different conclusions concerning the justification for bus lanes. A narrow perspective only considers direct traffic impacts, and so only justifies bus lanes if they attract enough drivers to reduce congestion on adjacent lanes. More comprehensive evaluation also considers other factors, including total travel time savings, total economic costs and benefits, social equity impacts, benefits of more transit-oriented development, and support for strategic planning objectives (Figure 4). More comprehensive evaluation, better transport models for predicting future impacts, a longer analysis period, and bus lanes implemented with other pro-transit policies tend to justify more bus lanes.

Figure 4 **Scope of Bus Lane Impact Analysis**



More comprehensive evaluation considers more bus lane benefit, which tends to justify more bus lanes.

This analysis indicates that bus lanes are generally warranted where, after all economically justified pro-transit policies are implemented, they carry more people during peak periods than adjacent general traffic lanes, and so result in total time savings, which typically means carrying more than 800 peak-hour passengers (about 20 buses) on surface streets or 1,800 peak-hour passengers (about 40 buses) on grade-separated highways. Bus lanes may be justified with lower ridership levels if they provide additional indirect benefits by reducing automobile travel or stimulating transit-oriented development. The following factors tend to increase the justifications for high quality public transit, and therefore reduce the minimum bus ridership to warrant bus lanes.

- More intense traffic congestion on a corridor, resulting in larger time and money savings.
- More travelers who for any reason cannot own or operate an automobile.
- More latent demand for high quality transit by discretionary travelers (people who would otherwise drive), and therefore larger mode shifts and vehicle travel reduction benefits.
- Strategic targets for reducing downstream traffic and parking congestion, road and parking facility costs, accidents, fuel consumption or pollution emissions.
- Complementary pro-transit policies and programs to be implemented with bus lanes.
- Financial constraints which preclude more costly transport system improvements such as expanded roadway and subways.
- A strong desire for transformative policies to create more compact and multimodal communities.

Here are guidelines for selecting urban roadway management strategies.

1. Where transit demand and congestion are *low*, bus travel can be encouraged with operational improvements, intersection priority strategies and traffic laws that require motorists to yield to buses entering the traffic flow.
2. Where transit demand and congestion are *moderate*, roadways should have HOV lanes, which accommodate buses and rideshare vehicles. As congestion increases the minimum number of rideshare vehicle passengers should increase.
3. Where transit demand and congestion are *high*, urban roadways should have bus lanes. Higher bus volumes justify Bus Rapid Transit features including center (median) lanes, attractive stations with rapid loading, and improved pedestrian and cycling access. Very high bus volumes can justify multiple bus lanes for express buses, and special highway ramps and intersection flyovers.

Current traffic models are poor at predicting the impacts of transit service quality improvements, and current economic evaluation practices tend to undervalue many transit benefits, which undervalues bus lanes. Bus lane development often increases congestion on adjacent lanes in the short term, although this usually declines over time as travellers respond to the transit service improvements, particularly if bus lanes are developed in conjunction with other pro-transit strategies. Although a single bus lane may provide only modest short-term benefits, an integrated bus lane network implemented with other pro-transit policies can be the fastest and most cost-effective way to transform automobile-dependent cities into multimodal metropolises where all types of travellers can choose the most efficient mode for each trip.

Bus lane development faces obstacles, including conventional planning which undervalues public transit, rail transit advocates who undervalue buses, and automobile interests that resist road space reallocation to favor space-efficient modes, even if this increases efficient and equity overall. Creating a comprehensive bus lane network requires a more complete understanding of their potential long-term benefits.

Transit users in general and bus passengers in particular tend to be politically disenfranchised. Many are youths, poor, people with disabilities, immigrants and visitors. This helps explain many decision-makers reluctance to implement economically-justified bus lanes. To build support for bus lane development advocates must effectively communicate the resulting benefits, demonstrate the cost efficiency of bus lanes compared with other transport system improvements, address concerns and criticisms, and build coalitions with interest groups that have reasons to support efficient and equitable urban transport, including transportation professionals, businesses interested in economic development, and social equity advocates who want to improve affordable travel modes. It can be useful to remind motorists that they may become transit users in the future, for example, if they lose their driving privileges or relocate to a more transit-oriented community, and so may themselves directly benefit from bus lanes.

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