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# Smart Congestion Relief

## *Comprehensive Evaluation Of Traffic Congestion Costs and Congestion Reduction Strategies*

**9 September 2014**

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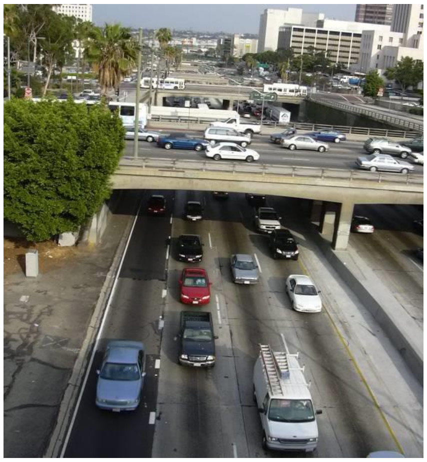

## Abstract

How traffic congestion is evaluated can significantly affect transport planning decisions. This report describes various factors that affect congestion cost estimates and the evaluation of potential congestion reduction strategies, including analysis scope, baseline speeds, travel time valuation, accident and emission impact analysis, induced travel analysis, and consideration of co-benefits. It discusses how these factors influence planning decisions, and describes best practices recommended by experts. It applies these methods to evaluate various congestion reduction strategies including roadway expansion, improve space efficient modes, pricing reforms, smart growth policies and demand management programs.

**Summaries of this research were published as:**

*Smart Congestion Relief*, Paper P12-5310, Transportation Research Board 2012 Annual Meeting

"Smarter Congestion Relief In Asian Cities: Win-Win Solutions To Urban Transport Problems"
*Transport and Communications Bulletin for Asia and the Pacific*, No. 82, December 2013
(www.unescap.org/publications/detail.asp?id=1581)

*Congestion Evaluation Best Practices*, Paper 12, presented at the International Transportation Economic Development Conference (https://tti.tamu.edu/conferences/ited2014), 12 April 2014, Dallas, Texas
(www.vtpi.org/ITED_congestion.pfd)

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## Executive Summary

*Traffic congestion* refers to the incremental delay caused by interactions among vehicles on a roadway, particularly as traffic volumes approach a roadway's capacity. Congestion can be evaluated in various ways that can result in very different estimates of its costs and the benefits of specific congestion reduction strategies. This report describes factors to consider when performing such evaluations.

Conventional congestion indicators, such as roadway Level-Of-Service (LOS), and the Travel Time Index (TTI) reflect congestion *intensity*, the decline in vehicle traffic speeds during peak periods. Such information is useful for making short-term decisions, such as how to travel across town during rush hour, but is unsuited for strategic planning decisions that affect the quality of travel transport options available, or development patterns. Comprehensive evaluation measures congestion *costs*, taking into account congestion *exposure* (the amount people must drive under urban-peak conditions).

Described differently, congestion evaluation is affected by whether the analysis measures *mobility* (travel speed) or *accessibility* (the time and financial costs required to reach services and activities). This is important because planning decisions often involve trade-offs between various accessibility factors. For example, roadway expansions tend to reduce motor vehicle delay but reduce pedestrian and cycling access, and therefore transit access since most transit trips include walking links, and often lead to more dispersed development which increases travel distances. Other congestion reduction strategies, such as transit improvements, can improve transport options and land use accessibility, not just mobility. Comprehensive evaluation considers all these impacts.

Various methodological factors affect congestion evaluation, including the selection of *baseline speeds* (the traffic speeds below which delay costs are calculated), travel time unit costs (dollars per hour assigned to congestion delay), assumptions about how speed affects vehicle fuel consumption and emission rates, consideration of generated and induced vehicle travel, and the scope of indirect impacts considered when evaluating potential congestion reduction strategies. Experts recommend the following for accurate and comprehensive congestion evaluation:

- Evaluate transport system performance based on overall *accessibility* (people's overall ability to reach desired services and activities) rather than just *mobility* (travel speed).
- Measure congestion *costs* rather than *intensity*. Intensity indicators, such as roadway level-of-service and the travel time index, do not account for congestion exposure (the amount residents must drive during peak periods).
- Measure delays to all travelers, not just to motorists. For example, account for pedestrian and cycling delays caused by wider roads and increased vehicle traffic (called the *barrier effect*), and congestion avoided if travelers shift to grade-separated transit.
- Calculate the marginal congestion costs *imposed* by road users, rather than just the costs they *bear*, when calculating efficient road prices or comparing the congestion costs of different modes.

- Use efficiency-optimizing baseline speeds, such as Level-Of-Service C, rather than freeflow speeds, since moderate traffic speeds maximize roadway throughput and fuel economy, and so tend to be most efficient overall. Acknowledge that freeflow speeds often exceed legal speed limits, and much of estimates congestion "costs" often consist simply of speed limit compliance.
- Use travel time values that reflect users' willingness-to-pay for incremental speed gains. This is typically 30-50% of average wages for personal travel, and total wage, benefits, equipment and product time costs for commercial travel. For value-priced lanes use willingness-to-pay by those who choose that option.
- Recognize variations in travel time values, and therefore the efficiency gains provided by policies that favor higher value trips over lower-value trips. This tends to increase the value of priced, freight and high-occupant vehicle priority strategies.
- Use accurate fuel efficiency functions. Vehicle fuel efficiency generally peaks at 40-50 miles per hour so reducing moderate congestion (from LOS C to B or A) tends to increase fuel consumption and emissions.
- Recognize that congestion tends to maintain self-limiting equilibrium: it increases to the point that delays limit further peak-period vehicle travel. As a result, traffic volumes and congestion costs seldom increase as much as predicted by extrapolating past trends.
- Account for *generated* and *induced* vehicle travel (additional vehicle travel resulting from reduced congestion) when evaluating roadway expansions. Generated traffic tends to reduce long-term congestion reduction benefits, and induced travel tends to increase external costs including downstream congestion, accident risk and pollution emissions.
- Account for increased crash costs that may result from congestion reductions that lead to high traffic speeds.
- Account for co-benefits when evaluating potential congestion reduction strategies. For example, some strategies also reduce parking costs, provide consumer savings and affordability, improve accessibility for non-drivers, increase safety and health, reduce pollution emissions, and support strategic land use objectives.
- Evaluate impacts on specific corridors. Although high-occupancy modes (ridesharing and public transit), may serve a small portion of total regional travel, their share is often much higher on major urban corridors, and so can provide significant congestion reductions.
- When evaluating impacts, discuss potential sources of bias and variability, and apply sensitivity analysis to test alternative assumptions.

Table ES-1 compares five types of congestion reduction strategies according to their congestion impacts, other costs and benefits, and degree they are considered in current planning.

***Table ES-1*** **Congestion Reduction Strategies**

| | Roadway Expansion | Improve Alt. Modes | Pricing Reforms | Smart Growth | TDM Programs |
|---|---|---|---|---|---|
| **Congestion impacts** | Reduces short-run congestion, but this declines over time due to generated traffic. | Reduces but does not eliminate congestion. | Can significantly reduce congestion. | May increase local congestion intensity but reduces per capita congestion costs. | Can reduce congestion delays and the costs to users of those delays. |
| **Other costs and benefits** | High costs. Minimal co-benefits. Tends to increase indirect costs by inducing vehicle travel. | Medium to high costs. Numerous co-benefits. | Low to high implementation costs. Costs users, generates revenue (an economic transfer). Numerous co-benefits. | Low to high costs. Numerous co-benefits. | Generally low to moderate implementation costs. Numerous co-benefits. |
| **Consideration in current planning** | Commonly considered and funded. | Sometimes considered, particularly in large cities. | Sometimes considered but seldom implemented. | Not generally considered a congestion reduction strategy. | Sometimes considered, particularly in large cities. |

*Different congestion reduction strategies have different types of impacts and benefits.*

This analysis indicates that conventional evaluation tends to be biased in ways that exaggerate congestion costs and roadway expansion benefits, and undervalue other congestion solutions. For example, the *Urban Mobility Report's* estimate that U.S. congestion costs total $121 billion was calculated using freeflow baseline speeds, relatively high travel time values, and optimistic assumptions of fuel savings and emission reductions. It therefore represents an upper-bound value; more realistic assumptions result in lower congestion cost estimates.

This analysis indicates that unpriced road expansions may provide short-term congestion reductions, but they decline within a few years due to generated traffic. Other strategies may provide smaller short-run congestion reductions but these increase over time and they provide more co-benefits. Conventional evaluation practices tend to overlook or undervalue many of these impacts and so tend to overvalue roadway expansions and undervalue other congestion reduction strategies.

Most cities are implementing some innovative congestion reduction strategies, but few are implementing all that are economically justified, considering all impacts. An optimal congestion reduction program involves the following steps:

1. Improve transport options including walking, cycling, public transit, ridesharing, carsharing and telecommuting, so users can choose the option that is most suitable for each trip. Target improvements to congested urban corridors. For example, provide more frequent transit services on congested urban corridors and mobility management programs at major commercial centers.
2. Implement support programs such as commute trip reduction and mobility management marketing programs wherever appropriate.
3. Manage roadways to favor space-efficient modes, such as bus lanes on urban arterials, transit-priority control systems, and urban highway High Occupant Vehicle (HOV) lanes.
4. If possible, apply congestion pricing (tolls or fees that are higher during congested periods), with prices set to reduce traffic volumes to optimal levels (level-of-service C or D). Ideally, this is applied system-wide, but if that is infeasible, apply it on the most congested corridors, such as major urban highways and bridges.
5. Regardless of whether or not congestion pricing is applied, implement efficient transport pricing reforms to the degree that is politically feasible, including revenue generating tolls, parking pricing, fuel price increases, and distance-based insurance and registration fees. These reforms are justified on various efficiency and social equity grounds. Revenues can be used to help finance roadway costs, improve space-efficient modes, or reduce other taxes.
6. Only consider urban roadway expansions if, after all of the previous strategies are fully implemented, all project costs can be recovered by user fees, which tests users' willingness-to-pay for the additional capacity. For example, if a roadway expansion would have $5 million annualized costs, it should be implemented only if peak-period tolls on that road will generate that much revenue.

This is a timely issue. Current trends are increasing the importance of more comprehensive and multi-modal analysis. It is important that decision makers and the general public understand these issues when choosing solutions to congestion problems.

## Introduction

*Traffic congestion* refers to the travel delay caused by interactions between vehicles on a roadway, particularly as traffic volumes approach a roadway's capacity. There are many possible ways to measure congestion costs and evaluate potential solutions; a congestion reduction strategy may seem effective and desirable if evaluated one way, but ineffective and harmful if evaluated another. It is important that people involved in such decisions understand these issues.

For example, compact, multi-modal cities such as New York, Boston and Philadelphia tend to have more *intense* congestion (greater peak-period speed reductions), but lower *congestion costs* (fewer annual hours of delay per capita) due to lower auto mode shares and shorter trip distances, which reduces congestion *exposure* (the amount residents must drive during peak periods). More dispersed, automobile-oriented cities such as Houston, Atlanta and Detroit tend to have less intense congestion but greater congestion costs. Compact cities rank worse if evaluated by congestion intensity indicators such as the Travel Time Index (TTI) but better if evaluated by congestion costs, as shown in Table 1.

***Table 1*** **City Rankings Change Depending On Indicators** (TTI 2013)

| Congestion Intensity (Travel Time Index) | Congestion Costs (Delay Hours Per Commuter) |
|---|---|
| 1. Los Angeles-Long Beach-Santa Ana CA (1.37) | 1. Los Angeles-Long Beach-Santa Ana CA (44.9) |
| **2. New York-Newark NY-NJ-CT (1.33)** | 2. Washington DC-VA-MD (44.3) |
| 3. Washington DC-VA-MD (1.32) | **3. Houston TX (41.0)** |
| **4. Boston MA-NH-RI (1.28)** | **4. Atlanta GA 39.4)** |
| **5. Houston TX (1.26)** | 5. San Francisco-Oakland CA (37.7) |
| **6. Philadelphia PA-NJ-DE-MD (1.26)** | 6. Dallas-Fort Worth-Arlington TX (36.6) |
| 7. Seattle WA (1.26) | **7. Miami FL (36.5)** |
| 8. Dallas-Fort Worth-Arlington TX (1.26) | **8. Boston MA-NH-RI (36.3)** |
| 9. Chicago IL-IN (1.25) | 9. Chicago IL-IN (36.2) |
| **10. Miami FL (1.25)** | **10. Philadelphia PA-NJ-DE-MD (35.4)** |
| **11. Atlanta GA (1.24)** | 11. Detroit MI (33.6) |
| 12. San Francisco-Oakland CA (1.22) | 12. Seattle WA (33.4) |
| 13. Detroit MI (1.18) | **13. New York-Newark NY-NJ-CT (29.7)** |
| 14. San Diego CA (1.18) | 14. San Diego CA (28.0) |
| 15. Phoenix-Mesa AZ (1.18) | 15. Phoenix-Mesa AZ (26.7) |

*More compact urban regions (blue) tend to have more intense congestion but lower congestion costs than sprawled, auto-oriented regions (red). Rankings change depending on which indicator is used.*

Congestion intensity indicators are useful for making short-term decisions, such as how best to travel across town during rush hour, but are unsuitable for strategic planning decisions that affect congestion *exposure*, the amount that travelers must drive under urban-peak conditions. More comprehensive and multi-modal analysis is needed for evaluating decisions that affect the quality of travel options or development patterns.

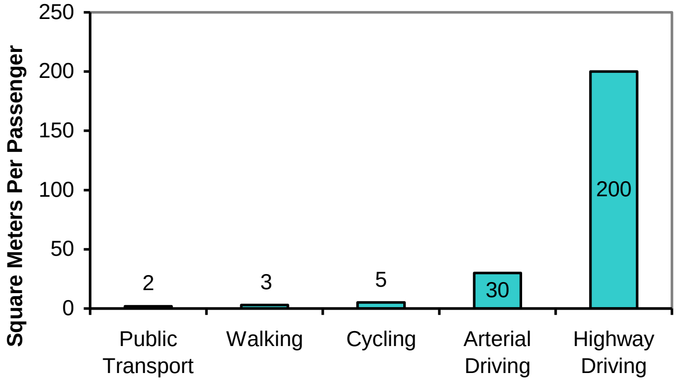
Described differently, intensity indicators reflect *mobility* (travel speed), while cost indicators reflect *accessibility* (people's overall ability to reach desired services and activities). Since accessibility is the ultimate goal of most transport activity and planning decisions often involve trade-offs between different accessibility factors, congestion cost indicators are most appropriate for identifying optimal transport system improvements.

Consider two examples. Assume that converting a general traffic lane into a bus lane reduces 10 minutes of delay for 20 buses carrying 1,000 passengers, but adds 5 minutes of delay for 800 cars carrying 900 passengers. If evaluated using congestion intensity indicators, bus lanes are considered to reduce transport system performance because delay per vehicle increases. However, if evaluated based on congestion costs, it is considered to improve performance, since delay per passenger declines.

Similarly, conventional traffic impact studies often indicate that infill development reduces transport system performance, measured using roadway LOS. As a result, such project are discouraged and burdened with special impact fees that are not imposed on urban-fringe. This favors lower-density, automobile-dependent development. More comprehensive evaluation, which accounts for the improved accessibility of infill development, and resulting reductions in vehicle trip generation and trip distance rates, justifies more support and lower impact fees for such development.

Conventional evaluation often only measures the congestion costs travelers *bear*, but some analyses, such as calculating mode shift benefits or optimal congestion reduction tolls, require calculating the congestion costs travelers *impose*. Road space requirements and therefore congestion costs imposed vary significantly between modes (Figure 1).

***Figure 1*** **Typical Road Space Requirements For Various Modes**



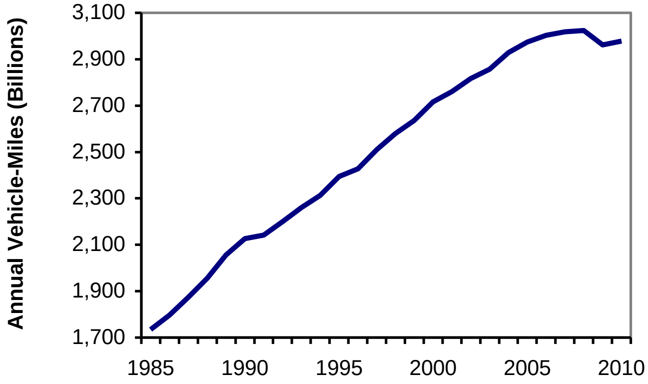
*Road space requirements increase with vehicle size and speeds (faster vehicles require more "shy distance" between them and other objects), and declines with more passengers per vehicle. Automobile travel requires ten to one hundred times as much road space as walking, cycling and public transport.*

In recent years, experts have developed more accurate and comprehensive congestion evaluation methods, but outdated practices are still widely used, and decision makers are often unaware of the biases in their results. This report investigates these issues. It discusses various ways to define and measure congestion impacts, and the implications of different perspective and methods. It describes best practices for measuring congestion costs and evaluating potential congestion reduction options, recommends ways to identify the most beneficial set of congestion reduction strategies, and describes examples of successful congestion reduction programs.

## Context: Changing Travel Demands and a New Planning Paradigm

This is a timely issue. Current demographic and economic trends are changing transport demands in ways that affect how traffic congestion should be evaluated. Motor vehicle travel demand grew steadily during the twentieth century, so it made sense to devote significant resources to roadway expansion. During that period there was little risk of overbuilding roadways since any additional capacity would eventually fill. However, vehicle travel is peaking in most developed countries (Figure 2) and current demographic and economic trends (aging population, rising fuel prices, urbanization, increasing health and environmental concerns, and changing consumer preferences) are increasing demand for walking, cycling and public transport (Litman 2006; OECD 2012).

***Figure 2*** **U.S. Annual Vehicles Mileage Trends** (USDOT 2010)



*Vehicle travel peaked about 2006, while demand for other modes (walking, cycling and public transport) is growing. It is therefore rational to shift resources previously devoted to roadway expansion to other types of transport system improvements.*

Transport planning is now experiencing a *paradigm shift*, a fundamental change in the way problems are defined and solutions evaluated, as summarized in Table 2. The old planning paradigm evaluated transport system performance based primarily on vehicle travel speeds using indicators such as roadway Level-Of-Service (LOS), traffic speeds and congestion delay. This approach is criticized for biasing planning in favor of automobile-oriented solutions (Roth 2009). The new paradigm evaluates transport system performance based on overall accessibility, considers other planning objectives, impacts, and modes.

***Table 2*** **Transport Planning Paradigms** (ADB 2009; Litman 2013a)

| | Old Paradigm | New Paradigm |
|---|---|---|
| **Definition of *Transportation*** | Mobility: movement of people and goods, particularly automobile travel. | Accessibility: people's ability to research desired services and activities. |
| **Planning goals** | Maximize motor vehicle travel speed and affordability. | Improve overall accessibility and transport system efficiency. |
| **Modes considered** | Automobile, truck and transit. | Multiple modes and transport services. |
| **Performance indicators** | Vehicle travel speeds, roadway Level-of-Service, cost per person-mile. | Quality of transport options. Proximity of destinations. Per capita transport costs. |
| **Favored transport improvements** | Roadway and parking facility expansions. Vehicle improvements. | Multi-modal improvements. Transportation demand management. Smart growth policies. |

*This table compares the old and new transport planning paradigm.*

Table 3 illustrates the scope of modes and impacts considered in conventional transport planning which evaluates transportation system performance based primarily on congestion intensity indicators such as roadway Level-Of-Service (LOS) and the Travel Time Index (TTI). These only measure delay and associated increases in fuel costs that congestion delays cause cars and transit buses; they indicate nothing about other modes (rail transit and non-motorized modes) or other impacts (passenger comfort, parking costs, safety and security, and the quality of mobility for non-drivers).

***Table 3*** **Conventional Analysis Scope** (Litman 2014a)

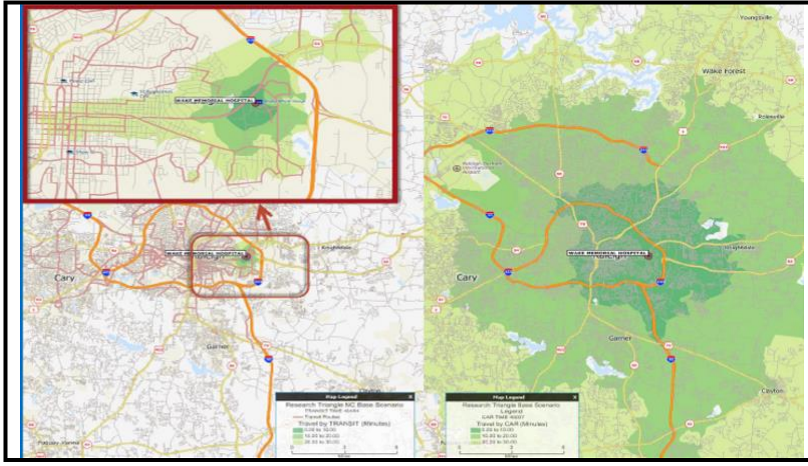
| | | More Modes ➔ | | |
|---|---|---|---|---|
| | | Automobile | Public Transit | Walking/Biking |
| ➔ Impacts More | Travel speed | **Auto Delay** | Bus delay | |
| | Consumer costs and affordability | Fuel costs | Bus fuel costs | |
| | Travel convenience and comfort | | | |
| | Parking convenience and costs | | | |
| | Safety and security | | | |
| | Mobility for non-drivers | | | |
| | Pollution emissions | | | |
| | Public fitness and health | | | |

*Conventional evaluation considers a limited set of modes and impacts; automobile delay receives the most consideration (darkest blue cell), increased fuel costs and bus delay receive less consideration (lighter blue cells), and other impacts often receive little. The new planning paradigm requires more comprehensive and multi-modal analysis.*

Recent research is improving our understanding of how transport and land use factors affect overall accessibility, and the trade-offs between these factors. For example, Ewing and Cervero (2010) found that a 10% increase in roadway connectivity reduces average travel distances 1.2%. Levine, et al. (2012) found that urban density has about ten times as much influence on the number of destinations motorists can access in a given time period as a proportional increase in traffic speeds. Levinson (2013) found that taking into account peak-period traffic speeds (and therefore congestion delays) and travel distances, denser cities such as Los Angeles, San Francisco, New York have greater automobile job access than more sprawled cities such as Dallas, Houston and Atlanta. Kuzmyak (2012) found that residents of urban neighborhoods with good travel options, connected streets and more nearby services drive a third fewer daily miles and experience less congestion delays than otherwise similar residents in automobile-dependent communities.

New tools can help apply accessibility-based evaluation (CTS 2010). For example, multi-modal level-of-service ratings can rate the walking, cycling and public transit service quality of individual roads and neighborhoods (Dowling, et al, 2008). New transport models measure the time and money required to reach various destinations, such as the number of jobs or retail services available within a given travel time by various modes, taking into account travel speeds, network connectivity and the distribution of these destinations, as illustrated in Figure 3. Such analyses can be disaggregated to indicate accessibility for specific groups or trips, such as children’s ability to walk and bicycle to school, low-income non-drivers’ accessibility to healthcare services and grocery stores, or the number of service jobs within reasonable travel time of adolescents’ homes. This type of analysis can help identify critical barriers and help prioritize improvements.

***Figure 3*** **Multi-Modal Access Mapping** (Slavin, Rabinowicz and Flammia 2013)



*These maps illustrate the time required to access a hospital by automobile and public transit from various locations. This is an example of multi-modal accessibility analysis that accounts for various modes, travel speeds, network connectivity and geographic proximity.*

Table 4 summarizes various accessibility factors, and compares their current evaluation practices with what is required for comprehensive and multi-modal planning. For example, comprehensive evaluation recognizes that improving walking and cycling conditions, improving public transit comfort, increasing roadway connectivity, reducing the distances between homes, worksites and services, and improving mobility substitutes such as telecommunications and delivery services, may be as important transportation system improvements as increasing motor vehicle traffic speeds.

***Table 4*** **Consideration of Accessibility Factors In Transport Planning**

| Factor | Consideration in Conventional Evaluation | Required for Comprehensive Evaluation |
|---|---|---|
| ***Automobility*** – motor vehicle traffic speed, congestion delays, vehicle operating costs, crash rates per mile or kilometer | Usually considered using indicators such as roadway level-of-service, average traffic speeds and congestion costs and crash rates. | Impacts should be considered per capita (per capita vehicle costs and crash casualties) to take into account the amount that people travel. |
| ***Quality of other modes*** – walking, cycling and transit speed, convenience, comfort, safety and affordability | Considers public transit speed but not comfort. Non-motorized access is often ignored. | Multi-modal performance indicators that account for convenience, comfort, safety, affordability and integration. |
| ***Transport network connectivity*** – density of connections between paths, roads and modes, and therefore the directness of travel between destinations | Traffic network models consider regional road and transit networks but often ignore local streets, non-motorized networks, and intermodal connections. | Fine-grained analysis of path and road network connectivity, and connections between modes, such as the ease of walking and biking to transit stations. |
| ***Land use accessibility*** – development density and mix, and therefore travel distances | Often ignored. Some integrated models consider some land use factors. | Fine-grained analysis of how land use factors affect accessibility by various modes. |
| ***Mobility substitutes*** –delivery services and telecommunications that reduce the need to travel | Only occasionally considered in conventional transport planning. | Consider these accessibility options in transport planning. |

*Conventional planning evaluates transport system performance based primarily on regional travel speed. Additional factors must be considered for comprehensive accessibility evaluation.*

## Quantifying and Monetizing Congestion Costs

Various methods are used to *quantify* (measure) and *monetize* (measure in monetary units) congestion costs. This section describes the methods recommended by experts (Grant-Muller and Laird 2007; Rao and Rao 2012; TC 2006; Wallis and Lupton 2013).

### *Congestion Indicators*

Table 5 describes various congestion indicators. Some only measure vehicle traffic delay at a particular location, others are more comprehensive (they consider overall travel delay, speeds and distances) and multi-modal (they consider delays to all travelers, not just motorists).

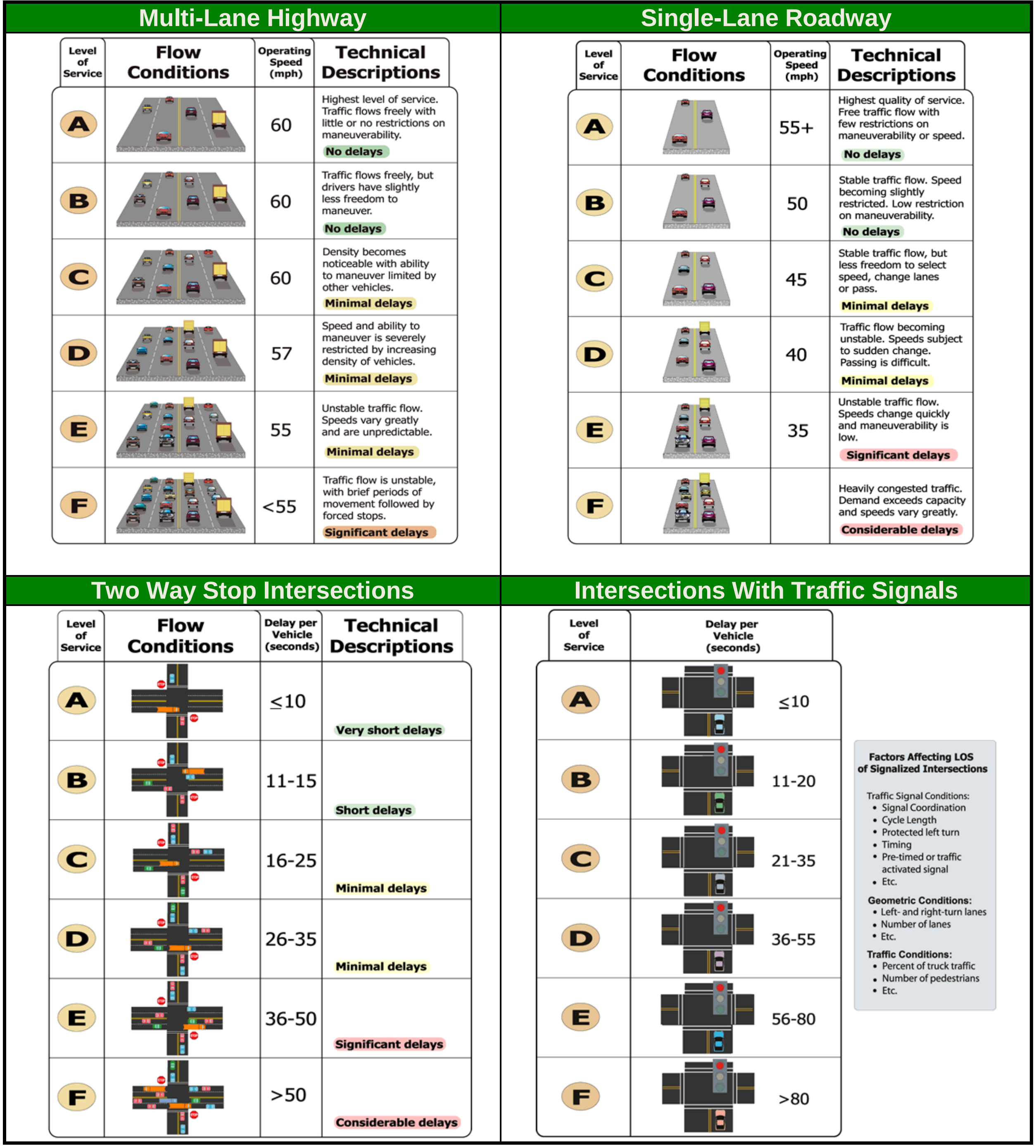
***Table 5*** **Common Congestion Indicators** ("Congestion Costs," Litman 2009)

| Indicator | Description | Compre-hensive? | Multi-Modal |
|---|---|---|---|
| Roadway Level Of Service (LOS) | Congestion intensity at a particular location, rated from A (uncongested) to F (most congested). | No | No |
| Multi-modal LOS | Congestion delays to various modes, rated from A to F. | No | Yes |
| Travel Time Index | The ratio of peak period to free-flow traffic speeds. | No | No |
| Average Traffic Speed | Average vehicle travel speeds at a particular location. | No | Yes if for all modes |
| Commute Duration | Average time per commute trip. | No | Yes if for all modes |
| Per Capita Travel Time | Total average time residents devote to travel. | Yes if for all modes | Yes if for all modes |
| Percent Travel Time In Congested Conditions | Portion of peak-period vehicle or person travel that occurs under congested conditions. | No | Yes if for all modes |
| Congestion Duration | Average duration of congested conditions. | No | No |
| Congested Lane Miles | Number of lane-miles congested during peak periods. | No | No |
| Annual Hours Of Delay | Hours of extra travel time due to congestion. | Yes if for all modes | Yes if for all modes |
| Annual Delay Per Capita | Hours of extra travel time divided by area population. | Yes if for all modes | Yes if for all modes |
| Excess Fuel Consumption | Total additional fuel consumption due to congestion. | No | No |
| Congestion Cost Per Capita | Hours of delay times monetized value of travel time, plus additional fuel costs, divided by area population. | Yes | Yes if for all modes |
| Planning Time Index | Earlier departure required when traveling during peak periods | No | No |
| Barrier Effect | Walking and cycling delay caused by wider roads | No | No |

*Various indicators are used to evaluate congestion. Some are more comprehensive and multi-modal than others.*

Figure 4 illustrates examples of roadway levels-of-service, a widely-used indicator of congestion intensity which rates traffic conditions from A (freeflow) to F (highly congested).

***Figure 4*** **Roadway Levels Of Service** (*HCM 2000*, Ex. 21-3)



**Multi-Lane Highway**

| Level of Service | Flow Conditions | Operating Speed (mph) | Technical Descriptions |
|---|---|---|---|
| A | | 60 | Highest level of service. Traffic flows freely with little or no restrictions on maneuverability.<br>**No delays** |
| B | | 60 | Traffic flows freely, but drivers have slightly less freedom to maneuver.<br>**No delays** |
| C | | 60 | Density becomes noticeable with ability to maneuver limited by other vehicles.<br>**Minimal delays** |
| D | | 57 | Speed and ability to maneuver is severely restricted by increasing density of vehicles.<br>**Minimal delays** |
| E | | 55 | Unstable traffic flow. Speeds vary greatly and are unpredictable.<br>**Minimal delays** |
| F | | <55 | Traffic flow is unstable, with brief periods of movement followed by forced stops.<br>**Significant delays** |

**Single-Lane Roadway**

| Level of Service | Flow Conditions | Operating Speed (mph) | Technical Descriptions |
|---|---|---|---|
| A | | 55+ | Highest quality of service. Free traffic flow with few restrictions on maneuverability or speed.<br>**No delays** |
| B | | 50 | Stable traffic flow. Speed becoming slightly restricted. Low restriction on maneuverability.<br>**No delays** |
| C | | 45 | Stable traffic flow, but less freedom to select speed, change lanes or pass.<br>**Minimal delays** |
| D | | 40 | Traffic flow becoming unstable. Speeds subject to sudden change. Passing is difficult.<br>**Minimal delays** |
| E | | 35 | Unstable traffic flow. Speeds change quickly and maneuverability is low.<br>**Significant delays** |
| F | | | Heavily congested traffic. Demand exceeds capacity and speeds vary greatly.<br>**Considerable delays** |

**Two Way Stop Intersections**

| Level of Service | Flow Conditions | Delay per Vehicle (seconds) | Technical Descriptions |
|---|---|---|---|
| A | | ≤10 | **Very short delays** |
| B | | 11-15 | **Short delays** |
| C | | 16-25 | **Minimal delays** |
| D | | 26-35 | **Minimal delays** |
| E | | 36-50 | **Significant delays** |
| F | | >50 | **Considerable delays** |

**Intersections With Traffic Signals**

| Level of Service | Delay per Vehicle (seconds) |
|---|---|
| A | ≤10 |
| B | 11-20 |
| C | 21-35 |
| D | 36-55 |
| E | 56-80 |
| F | >80 |

**Factors Affecting LOS of Signalized Intersections**

Traffic Signal Conditions:
- Signal Coordination
- Cycle Length
- Protected left turn
- Timing
- Pre-timed or traffic activated signal
- Etc.

**Geometric Conditions:**
- Left- and right-turn lanes
- Number of lanes
- Etc.

**Traffic Conditions:**
- Percent of truck traffic
- Number of pedestrians
- Etc.

*These images from the 2000* ***Highway Capacity Manual*** *illustrate and describe various roadway levels of service. There are similar rating for intersections (see [www.dot.ca.gov/ser/forms.htm](http://www.dot.ca.gov/ser/forms.htm)).*

### *Baseline Speeds*

A key congestion analysis factor is the *baseline* (also called *threshold*) speed below which delays are calculated. For example, if the baseline speed is 60 miles per hour (mph), and actual traffic speeds are 50 mph, the delay is 10 mph. Baseline speeds can be defined in the following ways:

- *Free-flow speeds*: traffic speeds measured during uncongested conditions (LOS A).
- *Speed limits*: maximum legal speeds on a road (LOS A or B).
- *Capacity-maximizing speeds*: maximizes roadway vehicle traffic capacity (LOS C or D).
- *Efficiency-optimizing speeds:* reflects users' willingness-to-pay for faster travel (also called *consumer-surplus maximizing* or *deadweight loss minimizing*, usually LOS C or D).

As traffic speeds increase so does the space required between vehicles (*shy distance*) for a given level of driver effort and safety. For example, a typical highway lane can efficiently carry more than 1,500 vehicles per hour at 45-54 mph, about twice the 700 vehicles that can operate comfortably at 60+ mph. Urban arterial capacity tends to peak at 35-45 mph. Maintaining freeflow speeds under urban-peak conditions is more costly than most motorists are willing to pay, and therefore economically inefficient. As a result, freeflow and speed limits are typically level-of-service (LOS) **A** or **B**, while capacity-maximizing and efficiency optimizing speeds are typically LOS **C** or **D** (Table 6).

***Table 6*** **Typical Highway Level-Of-Service (LOS) Ratings** (TRB 2000)

| LOS | Description | Speed (mph) | Flow (veh./hour/lane) | Density (veh./mile) |
|---|---|---|---|---|
| A | Traffic flows at or above posted speed limit. Motorists have complete mobility between lanes. | Over 60 | Under 700 | Under 12 |
| B | Slightly congested, with some reduced maneuverability. | 57-60 | 700-1,100 | 12-20 |
| C | Ability to pass or change lanes constrained. Roads are close to capacity. Target LOS for most urban highways. | 55-57 | 1,100-1,550 | 20-30 |
| D | Speeds somewhat reduced, vehicle maneuverability limited. Typical urban peak-period highway conditions. | 45-54 | 1,550-1,850 | 30-42 |
| E | Irregular flow, speeds vary and rarely reach the posted limit. Considered a system failure. | 30-45 | 1,850-2,200 | 42-67 |
| F | Flow is forced, with frequent drops in speed to nearly zero mph. Travel time is unpredictable. | Under 30 | Unstable | 67-Maximum |

*This table summarizes roadway Level of Service (LOS) ratings, an indicator of congestion intensity.*

Capacity-maximizing or efficiency-optimizing baseline speeds are considered an *economic* approach which maximizes efficiency and consumer benefits (Wallis and Lupton 2013). Most recent congestion cost studies use capacity-maximizing or economic efficiency baseline speeds. For example, the Australian Bureau of Transport and Regional Economics recommends calculating congestion costs based on motorists willingness to pay for faster travel, described as, "the increase in net social benefit if appropriate traffic management or pricing schemes were introduced and optimal traffic levels were obtained" (BTRE 2007, p. 10). Using this method they estimate that congestion costs in major Australian cities totaled $5.6 billion in 2005, less than half the $11.1 billion calculated using freeflow speeds. Similarly, Wallis and Lupton (2013) estimate that, using capacity optimizing speeds, 2006 Auckland, New Zealand congestion costs totaled $250 million, a third of the $1,250 million cost estimate based on freeflow speeds. Transport Canada calculates congestion costs uses 50%, 60% and 70% of free-flow speeds, which they consider a reasonable range of optimal urban-peak traffic speeds.

For these reasons, most transport economists recommend capacity-maximizing or economic efficiency-optimizing or rather than freeflow baseline speeds (TC 2006; Wallis and Lupton 2013). One leading economist explains,

> "The most widely quoted [congestion cost] studies may not be very useful for practical purposes, since they rely, essentially, on comparing the existing traffic conditions against a notional 'base' in which the traffic volumes are at the same high levels, but all vehicles are deemed to travel at completely congestion-free speeds. This situation could never exist in reality, nor (in my view) is it reasonable to encourage public opinion to imagine that this is an achievable aim of transport policy." (Goodwin 2003)

Newer congestion cost studies use actual measured freeflow traffic speeds as a baseline, although these often exceed legal speed limits. For example, the *Urban Mobility Report* used a 64.6 mph freeflow baseline speed on Los Angeles freeways which have 55 mph speed limits, and a 64.0 mph baseline on Miami freeways that have 60 mph speed limits (Table 7; www.speed-limits.com), indicating that 55-60% of their estimated congestion "costs" consist of speed limit compliance. Uncongested traffic usually exceeds speed limits, which are normally set to reflect 85th percentile freeflow speeds. Assuming Los Angeles and Miami represent the higher range, probably between a quarter and a half of the UMR's estimated congestion costs consist of speed compliance.

***Table 7*** **UMR Peak Versus Freeflow Speed Table** (TTI 2012)

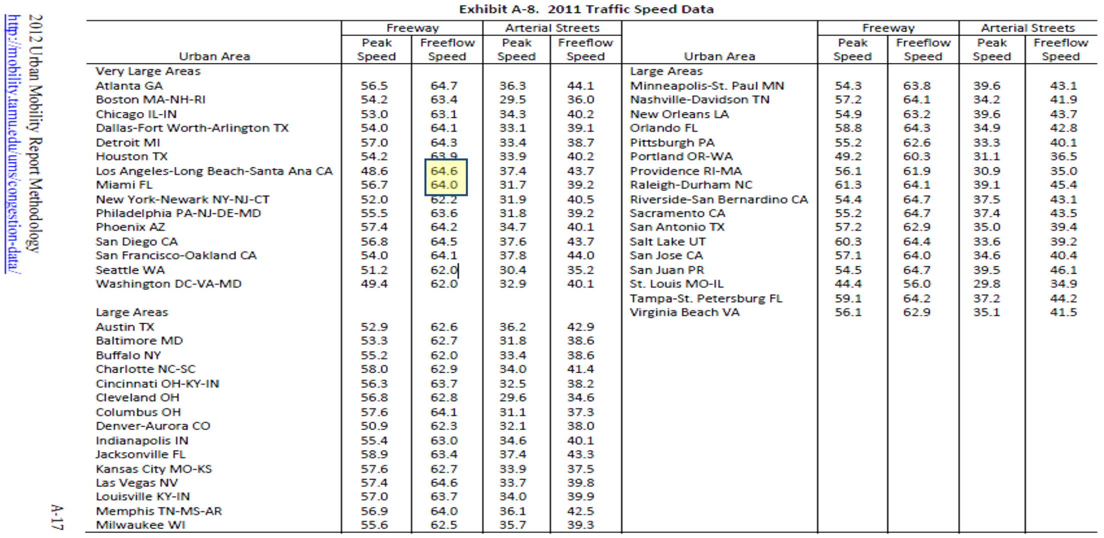


**Exhibit A-8. 2011 Traffic Speed Data**

| Urban Area | Freeway | | Arterial Streets | |
|---|---|---|---|---|
| | Peak Speed | Freeflow Speed | Peak Speed | Freeflow Speed |
| Very Large Areas | | | | |
| Atlanta GA | 56.5 | 64.7 | 36.3 | 44.1 |
| Boston MA-NH-RI | 54.2 | 63.4 | 29.5 | 36.0 |
| Chicago IL-IN | 53.0 | 63.1 | 34.3 | 40.2 |
| Dallas-Fort Worth-Arlington TX | 54.0 | 64.1 | 33.1 | 39.1 |
| Detroit MI | 57.0 | 64.3 | 33.4 | 38.7 |
| Houston TX | 54.2 | 63.9 | 33.9 | 40.2 |
| Los Angeles-Long Beach-Santa Ana CA | 48.6 | 64.6 | 37.4 | 43.7 |
| Miami FL | 56.7 | 64.0 | 31.7 | 39.2 |
| New York-Newark NY-NJ-CT | 52.0 | 62.2 | 31.9 | 40.5 |
| Philadelphia PA-NJ-DE-MD | 55.5 | 63.6 | 31.8 | 39.2 |
| Phoenix AZ | 57.4 | 64.2 | 34.7 | 40.1 |
| San Diego CA | 56.8 | 64.5 | 37.6 | 43.7 |
| San Francisco-Oakland CA | 54.0 | 64.1 | 37.8 | 44.0 |
| Seattle WA | 51.2 | 62.0 | 30.4 | 35.2 |
| Washington DC-VA-MD | 49.4 | 62.0 | 32.9 | 40.1 |
| Large Areas | | | | |
| Austin TX | 52.9 | 62.6 | 36.2 | 42.9 |
| Baltimore MD | 53.3 | 62.7 | 31.8 | 38.6 |
| Buffalo NY | 55.2 | 62.0 | 33.4 | 38.6 |
| Charlotte NC-SC | 58.0 | 62.9 | 34.0 | 41.4 |
| Cincinnati OH-KY-IN | 56.3 | 63.7 | 32.5 | 38.2 |
| Cleveland OH | 56.8 | 62.8 | 29.6 | 34.6 |
| Columbus OH | 57.6 | 64.1 | 31.1 | 37.3 |
| Denver-Aurora CO | 50.9 | 62.3 | 32.1 | 38.0 |
| Indianapolis IN | 55.4 | 63.0 | 34.6 | 40.1 |
| Jacksonville FL | 58.9 | 63.4 | 37.4 | 43.3 |
| Kansas City MO-KS | 57.6 | 62.7 | 33.9 | 37.5 |
| Las Vegas NV | 57.4 | 64.6 | 33.7 | 39.8 |
| Louisville KY-IN | 57.0 | 63.7 | 34.0 | 39.9 |
| Memphis TN-MS-AR | 56.9 | 64.0 | 36.1 | 42.5 |
| Milwaukee WI | 55.6 | 62.5 | 35.7 | 39.3 |
| Large Areas | | | | |
| Minneapolis-St. Paul MN | 54.3 | 63.8 | 39.6 | 43.1 |
| Nashville-Davidson TN | 57.2 | 64.1 | 34.2 | 41.9 |
| New Orleans LA | 54.9 | 63.2 | 39.6 | 43.7 |
| Orlando FL | 58.8 | 64.3 | 34.9 | 42.8 |
| Pittsburgh PA | 55.2 | 62.6 | 33.3 | 40.1 |
| Portland OR-WA | 49.2 | 60.3 | 31.1 | 36.5 |
| Providence RI-MA | 56.1 | 61.9 | 30.9 | 35.0 |
| Raleigh-Durham NC | 61.3 | 64.1 | 39.1 | 45.4 |
| Riverside-San Bernardino CA | 54.4 | 64.7 | 37.5 | 43.1 |
| Sacramento CA | 55.2 | 64.7 | 37.4 | 43.5 |
| San Antonio TX | 57.2 | 62.9 | 35.0 | 39.4 |
| Salt Lake UT | 60.3 | 64.4 | 33.6 | 39.2 |
| San Jose CA | 57.1 | 64.0 | 34.6 | 40.4 |
| San Juan PR | 54.5 | 64.7 | 39.5 | 46.1 |
| St. Louis MO-IL | 44.4 | 56.0 | 29.8 | 34.9 |
| Tampa-St. Petersburg FL | 59.1 | 64.2 | 37.2 | 44.2 |
| Virginia Beach VA | 56.1 | 62.9 | 35.1 | 41.5 |

2012 Urban Mobility Report Methodology
http://mobility.tamu.edu/ums/congestion-data/
A-17

*The Urban Mobility Report freeflow traffic speeds often exceed legal speed limits. In many cases more than half of the estimated congestion "cost" consists simply of speed limit compliance.*

### *Travel Time Valuation*

Another key congestion costing factor is the value assigned travel time and delay. There is extensive literature on this subject ("Travel Time Costs," Litman 2009; Grant-Muller and Laird 2007; USDOT 2011). Travel time values tend to be heterogeneous (variable). Most studies conclude that motorists are willing to pay, on average, 25-50% of their wage rate for travel time savings, although some travelers, such as commercial vehicles and people with urgent errands, are willing to pay significantly more (Howard and Williams-Derry 2012; NCHRP 2006; Parsons Brinckerhoff 2013; USDOT 2011).

On a typical roadway many motorists are price sensitive, they would prefer to shift travel time, route, mode or destination rather than pay more than about $10.00 per hour saved, so it would be economically inefficient to expand roads for them, but 20-30% of motorists have much higher values of travel time, they are willing to pay $50.00 to $100 per hour for time savings, so efficiency is increased if they are able to outbid lower-value traffic for scarce road space, and in some cases they can finance the addition of value priced lanes.

General traffic improvements, such as roadway expansions, should be evaluated based on what an *average* motorists' willingness-to-pay for reduced delay. Value priced lanes, which allow motorists to pay extra for an uncongested trip, should be evaluated based on the subset of motorists who would pay the fee.

### *Evaluating Mode Shift Travel Time Impacts*

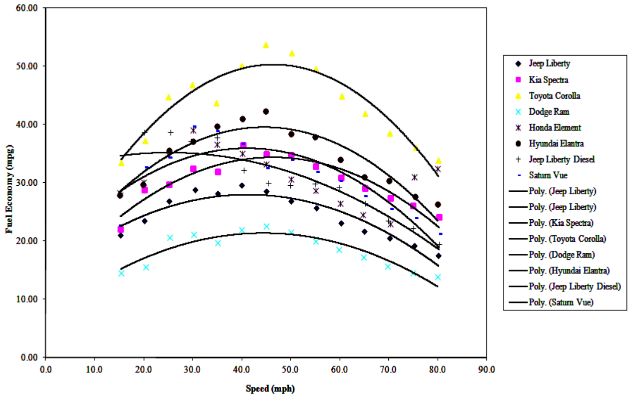
Some congestion reduction strategies shift travel from automobile to slower modes, such as cycling or public transit. There are sometimes debates concerning how to value this additional travel time. As previously mentioned, travel time unit costs (dollars per hour or cents per minute) are heterogeneous (variable), the value users place on travel time can vary due to specific conditions, needs and preferences. Under some circumstances time spent traveling may have positive value because it is enjoyable or provides healthy exercise, it may have low unit costs because users can be rest or work while traveling, or it may have high costs because it is uncomfortable or stressful ("Travel Time Costs," Litman 2009; Smith, Veryard and Kilvington 2009). In addition, slower modes are sometimes cheaper to user, so travelers may prefer a slower mode to save money.

It would be difficult to quantify all of these variables and trade-offs, for example, to tell a traveler under which circumstances they should use each mode. However, if travellers voluntarily shift from a faster to slower mode in response to positive incentives (the slower mode has become more convenient or comfortable to use, or they receive a financial reward) they must be directly better off overall (an increase in overall consumer welfare) or they would not shift. Conversely, if travelers shift mode in response to negative incentives (such as increased user charges) they are probably directly worse off, although their overall benefits can depend on indirect impacts; for example, if road tolls cause commuters to shift from driving to ridesharing or public transit, they may be directly worse off, but benefit overall if the toll revenue helps them in other ways.

### *Fuel Consumption and Emission Impacts*

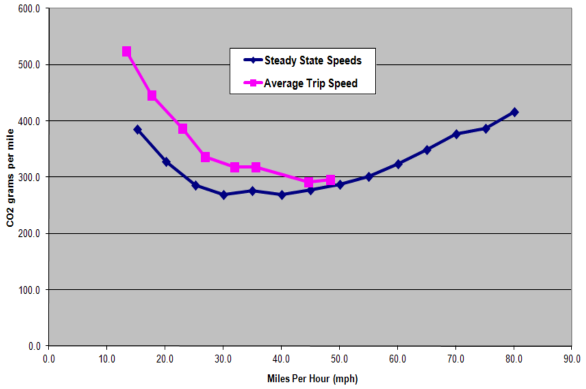
Other important factors are the formulas used to calculate how traffic speeds affect fuel consumption and pollution emissions. These are generally minimized at 40-50 miles per hour (mph), and increase above 55 mph (Barth and Boriboonsomin 2009; Bigazzi and Figliozzi 2012; ORNL 2012, Table 4.28), as illustrated in figures 5-A and 5-B.

***Figure 5-A***
**Speed Versus Fuel Economy** (USEPA Data)



*USEPA data indicate that vehicle fuel economy tends to peak at 40-50 mph and declines above 55 mph.*

***Figure 5-B***
**Speed Versus Emissions** (USEPA Data)



*USEPA data indicate that average emission rates tends to increase above about 50 mph.*

### *Safety Impacts*

Although many factors affect traffic crash risks, all else being equal, crash rates tend to decline with increase traffic congestion, and congestion reductions that increase traffic speeds tend increase crash severity and therefore traffic casualties (Kockelman 2011; Marchesini and Weijermars 2010). Total crash rates, tend to be lowest on moderately congested roads (V/C=0.6), and increase at lower and higher congestion levels, while casualty rates (injuries and deaths) often increase when congestion is eliminated (Zhou and Sisiopiku 1997). For example, using the TomTom Traffic Index (TomTom 2014), the five most congested U.S. cities (Los Angeles, San Francisco, Honolulu, Seattle and San Jose) average 5.6 traffic deaths per 100,000 residents, about half the 10.2 fatality rate of the ten least congested cities (Richmond, Birmingham, Cleveland, Indianapolis and Kansas City).

Per capita traffic deaths tend to increase with per capita vehicle travel, so roadway expansions that induce additional vehicle travel tends to increase traffic casualties (Luoma and Sivak 2012). One study estimated that the increased crash costs that result from reduced congestion offset 5-10% of congestion reduction benefits (Wallis and Lupton 2013).

### *Perspective –Internal Versus External and Marginal Versus Average*

Congestion cost evaluation can reflect various perspectives. Most studies calculate the congestion costs motorists bear, but for some applications, such as efficient road pricing or evaluating mode shift benefits, it is important to calculate the marginal (incremental) costs a traveler imposes on other road users, which is often higher than average values (Hau 1998). For example, when a road approaches its capacity, an additional vehicle may bear five minutes of delay but impose fifteen minutes of delay on other road users. Therefore its marginal congestion cost imposed is three times higher than the average congestion cost it bears. Similarly, if a three passenger car equivalent (PCEs) bus averages 30 passengers during peak periods, each passenger imposes one tenth the congestion cost of a car driver, and an additional passenger filling an otherwise unoccupied bus seat imposes virtually no marginal congestion cost.

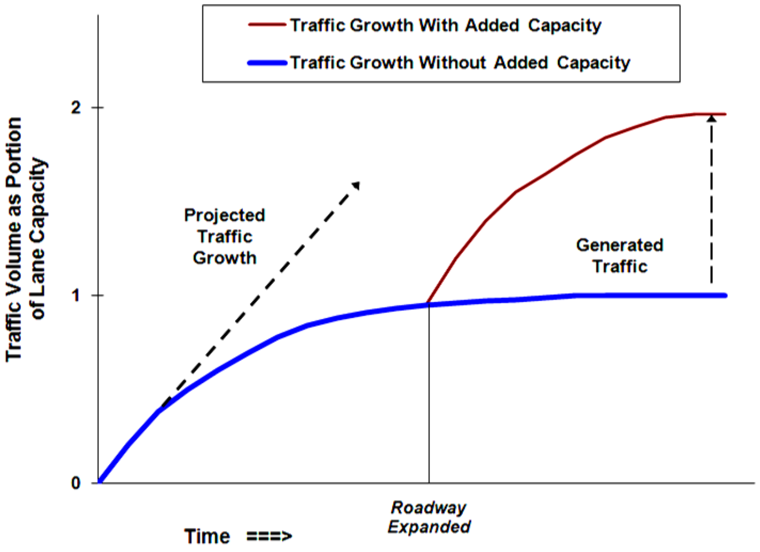
### *Analysis Scope*

Traffic congestion tends to vary by time and location, so congestion impact analysis is sensitive to temporal and geographic scope. For example, to evaluate how road user fees or transit service improvements affect congestion costs, the analysis should focus on specific travel corridors or districts; changes in fees or transit service in one area cannot be expected to reduce congestion elsewhere, so including them in the analysis can dilute the results. However, detailed data is seldom available, so congestion impact studies often use more aggregate analysis, such as regional data. There are generally many other factors that may affect congestion intensity, such as city size and density, and changes in employment rates and business activity. For example, since both transit ridership and congestion intensity tend to increase with city size, density and employment rates, so failing to account for these factors can lead to a false conclusion that increased transit ridership contributes to congestion (Litman 2014b).

### *Generated Traffic and Induced Travel*

Congestion cost evaluation is complicated by the tendency of congestion to maintain equilibrium: it increases until delays cause travelers to reduce peak-period trips by shifting travel times, routes, modes and destinations (Cervero 2003; Jaffe 2014; Litman 2001). For example, if roads are congested you might avoid some peak-period trips that you would make if roads are expanded, as illustrated in Figure 6. The additional peak-period vehicle travel on an expanded roadway is called *generated traffic*, and net increases in total vehicle travel are called *induced travel*.

***Figure 6*** **How Road Capacity Expansion Generates Traffic** (Litman 2001)



*Urban traffic volumes can grow until congestion limits additional peak-period trips, at which point it maintains a self-limiting equilibrium (indicated by the curve becoming horizontal). If road capacity is expanded, traffic growth continues until it reaches a new equilibrium. The additional peak-period vehicle traffic that results from roadway capacity expansion is called "generated traffic." The portion that consists of absolute increases in vehicle travel (as opposed to shifts in time and route) is called "induced travel."*

Generated and induces vehicle travel have the following implications for congestion evaluation (Litman 2001):

- Traffic congestion seldom becomes as severe as predicted by extrapolating past trends. As congestion increases it discourages further peak-period trips, maintaining equilibrium.
- Roadway expansion provides less long-term congestion reduction benefits than predicted if generated traffic is ignored.
- Induced vehicle travel increases various external costs including downstream congestion, parking costs, accident risk, and pollution emissions, reducing net benefits.
- Induced vehicle travel directly benefits the people who increase their vehicle travel, but these benefits tend to be modest because the additional travel consists of marginal-value vehicle mileage that users are most willing to forego if their costs increase.

## Congestion Cost Evaluation

*This section summarizes various monetized estimates of congestion costs, and compares congestion with other costs of transportation.*

### *Congestion Cost Estimates*

Various studies have monetized congestion costs for particular areas:

- Delucchi (1997) estimated that U.S. congestion costs, including incremental delay and fuel costs, totaled $34-146 billion in 1991 ($52-222 billion in 2007 dollars).
- Winston and Langer (2004) estimated that U.S. congestion costs total $37.5 billion annually (2004 dollars), a third of which consists of freight vehicle delays.
- Transport Canada research calculated congestion costs using various roadway speed baselines (TC 2006), as summarized in Table 8.

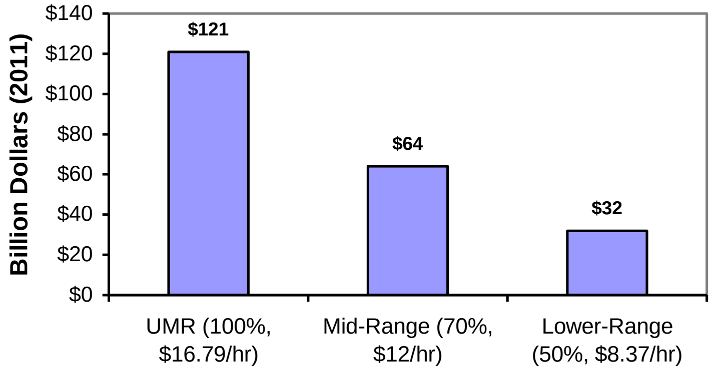
***Table 8*** **Total Costs of Congestion** (TC 2006, Table 5)

| City | Relative To Freeflow Speeds | | |
|---|---|---|---|
| | 50% | 60% | 70% |
| Vancouver | $403 | $517 | $629 |
| Edmonton | $49 | $62 | $74 |
| Calgary | $95 | $112 | $121 |
| Winnipeg | $48 | $77 | $104 |
| Hamilton | $6.6 | $11 | $17 |
| Toronto | $890 | $1,267 | $1,632 |
| Ottawa-Gatineau | $40 | $62 | $89 |
| Montreal | $702 | $854 | $987 |
| Quebec City | $38 | $52 | $68 |
| ***Totals*** | ***$2,270*** | ***$3,015*** | ***$3,721*** |

*Transport Canada calculates congestion costs based on 50%, 60% and 70% of freeflow speeds, which they consider the economically optimal range of urban-peak traffic speeds.*

- Dachis (2013) argues that conventional analysis underestimates total congestion costs by ignoring the negative effect it has on labor access (the quantity and quality of workers/jobs available to employers and workers). He concludes that including these impacts would increase monetized congestion costs by 25-85%.
- The Texas Transportation Institute's widely-cited *Urban Mobility Study* (the results of which are incorporated into various planning documents, such as the USDOT's annual *Conditions & Performance* report) estimated that U.S. congestion costed $121 billion in 2011, and by extrapolating past trends predicted that these costs will increase to $199 billion in 2020 (TTI 2012). These represent upper-bound estimates since they are based on freeflow baseline speeds, higher than recommended travel time costs, optimistic assumptions of fuel savings and emission reductions, and no consideration of induced travel impacts (Cortright 2011). More realistic assumptions result in far lower estimates. Figure 7 illustrates sensitivity analysis of its cost estimates.

***Figure 7*** **Congestion Cost Ranges** (Litman 2014a)

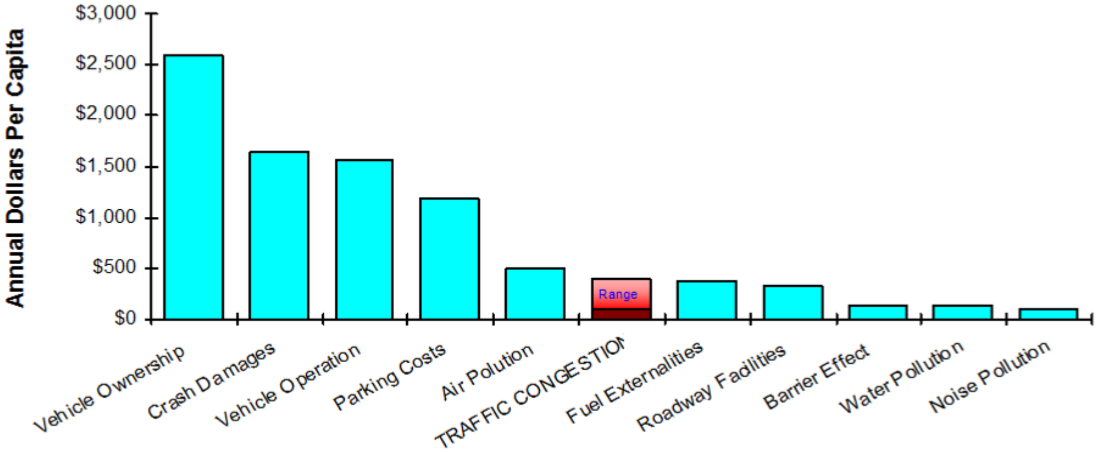


*The Urban Mobility Report's $121 billion cost estimate is based on higher baseline speeds and travel time unit costs than most experts recommend. The lower-range estimate in this graph is based on 50% of baseline speed and the U.S. Department of Transportation's lower travel time unit costs, reflecting reasonable lower-bound values.*

### *Congestion Compared With Other Costs*

It is helpful to compare congestion with other urban transportation costs. Several studies have monetized various transport costs (CE, INFRAS, ISI 2011; Litman 2009; TC 2005-08). This research indicates that congestion costs are moderate overall, larger than some but smaller than others. For example, U.S. congestion costs are estimated to range between $110 and $390 annual per capita (Litman 2014a; TTI 2012), compared with about $4,000 in vehicle costs, $1,500 in crash damages, $1,000 in parking costs, $500 in air and noise pollution costs and $325 in roadway costs, as illustrated in Figure 8.

***Figure 8*** **Costs Ranked by Magnitude** (Litman 2009)

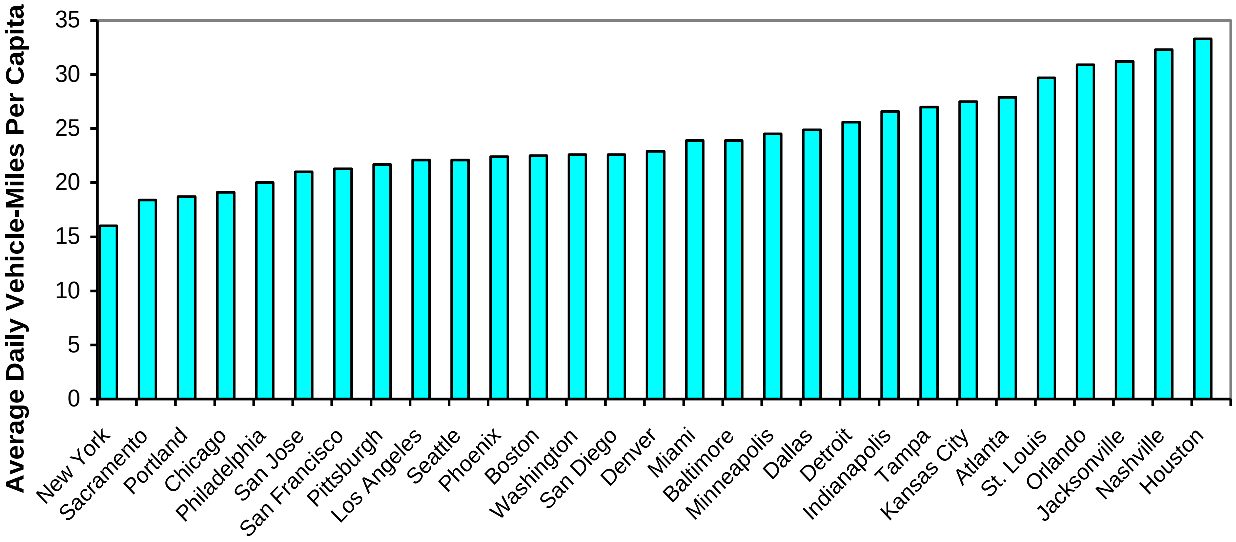


*Congestion cost estimates range between $110 and $390 annually per capita, depending on assumptions. Even the highest estimate is moderate compared with other transport costs.*

It is also useful to compare congestion with other factors that affect travel time and costs, including mode share, land use accessibility, and chauffeuring burdens. For example, the *Urban Mobility Report* indicates that congestion causes an average large city automobile commuter to spend 38 additional hours and 19 additional gallons on travel. More dispersed land use patterns, which increase average trip distances, or the need to chauffeur non-drivers due to inadequate travel options for non-drivers, can cause even larger increases in the total amount of time people spend traveling (Cortright 2010). Detailed analysis by Ewing and Hamidi (2014) indicate that sprawl significantly increases the total time and money residents spend in transport: each 10% increase in their Sprawl Index increases average journey-to-work drive time by 0.5%.

For example, residents of sprawled, automobile-dependent communities such as Jacksonville, Nashville and Houston drive about 50% more daily miles than residents of more compact, multi-modal regions such as New York, Sacramento and Portland (Figure 9). This additional vehicle travel requires about 104 additional hours and 183 additional gallons of fuel annually (assuming 35 miles per hour and 20 miles per gallon averages), much more than the additional travel time and fuel consumption caused by congestion, plus increases in other transport costs including road and parking facilities costs, accidents and pollution damages. This suggests that sprawl imposes more than three times as much incremental transportation costs as congestion.

***Figure 9*** **Vehicle Mileage in Major U.S. Urban Regions** (FHWA 2008)



*Per capita vehicle mileage varies significantly between U.S. urban regions.*

Similarly, in automobile-dependent communities, non-drivers require more *chauffeuring* (special vehicle trips to transport a passenger, also called *escort trips*). Drivers' chauffeuring burden can be estimated by multiplying the ratio of non-drivers to drivers, times non-drivers' trip generation rates, times the portion of these trips that require chauffeuring,[1] times their average trip duration, times two (for empty backhauls). Table 9 compares motorists' chauffeuring burdens in compact, multi-modal communities with sprawled, automobile-dependent communities. This suggests that the additional time and fuel costs required for chauffeuring in automobile-dependent communities is often greater than the time and fuel costs of congestion.

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[1] One survey indicates that 40% of parents who drive children to school return directly home (NCSRS 2011). School commutes are relatively easy to coordinate with work commutes and errands, chauffeuring with empty backhauls is probably more common for other types of trips, such as taking non-drivers to medical appointments, sport and social events, so this analysis assumes 50% of non-drivers' vehicle trips.

***Table 9*** **Chauffeuring Time Burdens**

| | Compact, Multi-Modal | Auto-Dependent | Differences |
|---|---|---|---|
| Ratio of non-drivers to drivers | 1/3 | 1/3 | |
| Non-drivers annual trips | 1,000 | 1,000 | |
| Portion of non-drivers' trips by auto | 20% | 80% | 60 points |
| Portion auto trips chauffeured | 50% | 50% | |
| Avg. chauffeured trip duration (min.) | 5 | 10 | 5 minutes |
| Empty backhaul factor | x 2 | x 2 | |
| Totals annual hours | 5.5 | 44 | 55 |
| Additional vehicle miles/fuel | 195/9.6 | 1,540/77 | 1,345/67 |

*Motorists spend 5.5 average annual hours chauffeuring non-drivers in compact communities compared with 44 annual hours in sprawled, automobile dependent communities. The additional travel time and fuel for chauffeuring is greater than congestion delays in most cities.*

As previously mentioned, travel time costs vary. Congestion increases drivers' stress, and so tends to have high costs per hour. Many people enjoy some driving on urban-fringe roads, and chauffeuring allows drivers to socialize with passengers, so some of the additional driving caused by sprawl may have lower travel time costs than congestion delays, but in other cases it is costly, for example when drivers must interrupt important activities for chauffeuring, and the additional vehicle travel also increases indirect and external costs, such as downstream traffic congestion, accidents and pollution emissions. Conventional planning recognizes the additional time and fuel costs caused by congestion but ignores similar impacts caused by automobile dependency and sprawl.

A congestion reduction strategy may be harmful overall if it increases other transport costs, but provides far greater total benefits if it reduces other costs. For example, if a roadway expansion reduces congestion 20%, but by degrading travel options and inducing sprawl it increases total travel time, vehicle costs, accidents, parking and pollution emissions 5% each, these cost increases more than offset the congestion reduction benefits. However, if improving space-efficient modes reduces congestion 10% and other costs 5% each, total benefits are far larger, as illustrated in Table 10.

***Table 10*** **Cost Analysis Example** (APC = Annual Per Capita)

| Cost Category | Current | Roadway Expansion | | Improve Alt. Modes | |
|---|---|---|---|---|---|
| | *APC Dollars* | APC Dollars | Change | APC Dollars | Change |
| Congestion costs (mid-value) | *$250* | $200 | -20% | $225 | -10% |
| Vehicle costs | *$4,000* | $4,200 | +5% | $3,800 | -5% |
| Crash damages | *$1,500* | $1,575 | +5% | $1,425 | -5% |
| Parking costs | *$1,000* | $1,050 | +5% | $950 | -5% |
| Air and noise pollution costs | *$500* | $525 | +5% | $475 | -5% |
| Roadway facility costs | *$325* | $341 | +5% | $309 | -5% |
| ***Totals*** | ***$7,575*** | ***$7,891*** | ***+4.2%*** | ***$7,184*** | ***-5.2%*** |

*In this example, per capita transport costs currently total $7,575. A roadway expansion that reduces congestion 20% but increases other costs 5% increases total costs 4.2% to $7,891. Alternative mode improvements that reduce congestion 10% and other costs 5% reduces total costs 5.2% to $7,184.*

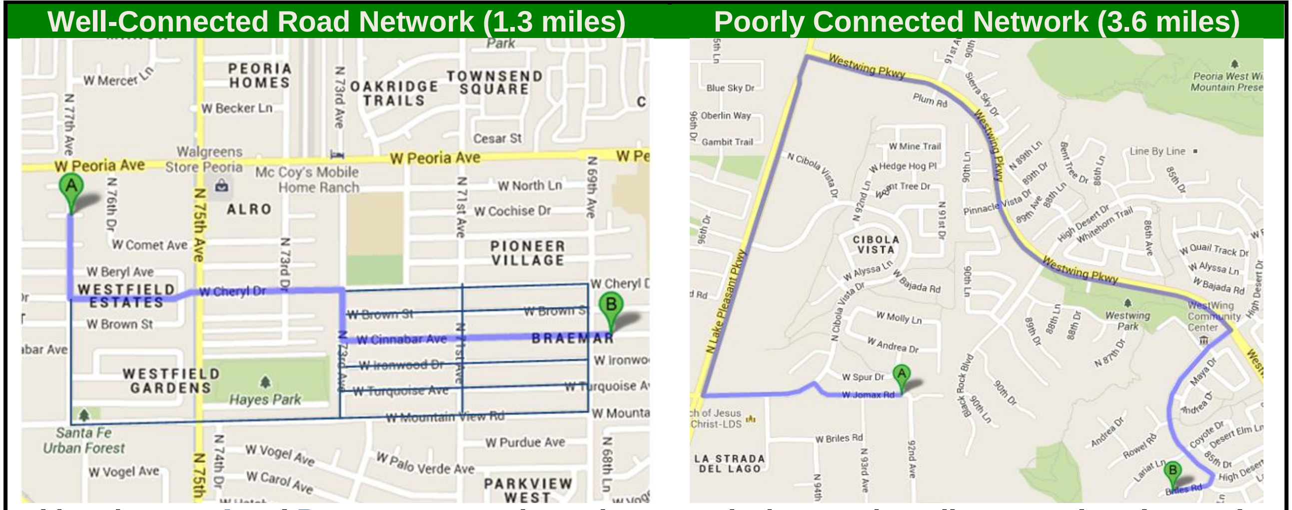
Other potential congestion reduction strategies involve similar tradeoffs. For example, one concept is to divide urban highway lanes in two, to accommodate more motorcycles and half-width commuter vehicles (Figure 10). This could reduce congestion but would probably increase vehicle ownership (most users to own skinny vehicles in addition to their general-purpose automobiles), residential parking and accident costs.

***Figure 10*** **Half-Width Commuter Vehicles** (www.commutercars.com)

*Motorcycles and half-width commuter vehicles are sometimes proposed as a congestion reduction strategy. Under optimal conditions they can double the maximum number of vehicles per highway lane, but they are usually owned in addition to a general purpose vehicle, and so tend to increase vehicle ownership, residential parking and accident costs.*

Similarly, a hierarchical road network with fewer roadway intersections and more one-way arterials may increase traffic speeds but reduces roadway connectivity and concentrate more traffic on major roadways, which reduces accessibility and increases travel distances (Figure 11). Wider roads, hierarchical roadway networks and sprawled development patterns may appear attractive if evaluated using conventional congestion indicators since they increase traffic speeds. However, they may not be justified if evaluated using more comprehensive and multi-modal performance indicators which consider impacts on all modes and all accessibility factors, and which account for indirect costs such from increased vehicle travel and automobile dependency.

***Figure 11*** **Comparing Roadway Networks**



**Well-Connected Road Network (1.3 miles)** **Poorly Connected Network (3.6 miles)**

*Although points **A** and **B** are approximately a mile apart in both maps, the well-connected road network offers more route options and has shorter travel distances. The poorly-connected, hierarchical network increases trip lengths, and by concentrating travel onto major arterials, increases traffic congestion.*

## Guidelines for Comprehensive and Multi-Modal Congestion Evaluation

*This section describes various factors that should be considered in a comprehensive and multi-modal congestion evaluation framework. For more discussion see Grant, et al (2011).*

### *Accessibility Analysis*

Comprehensive and multi-modal evaluation considers various accessibility factors, and therefore trade-offs between them. Accessibility factors include:

- *Automobility* – motor vehicle traffic speed, congestion delays, affordability, and crash rates per mile or kilometer.
- *Quality of other modes* – speed, convenience, comfort, safety and affordability of walking, cycling, public transport and other modes.
- *Transport network connectivity* – density of connections between paths, roads and modes, and therefore the directness of travel between destinations.
- *Land use accessibility* – development density and mix, and therefore travel distances.
- *Mobility substitutes* – telecommunications and delivery services that substitute for mobility.

Table 11 illustrates how various congestion reduction strategies affect various accessibility factors. For example, roadway expansions tend to reduce walking and cycling access, directly by creating barriers to their movement, and indirectly by inducing more dispersed development patterns which increase trip distances beyond convenient walking distances. Conversely, improving space-efficient modes, increasing connectivity and more compact development tend to increase accessibility in ways that do not increase mobility, and so are not necessarily recognized by indicators such as average traffic speed or roadway level-of-service.

**Table 11 Congestion Reduction Impacts on Accessibility Factors**

| Accessibility Factors | Roadway Expansion | Improve Alt. Modes | Efficient Pricing | Smart Growth | TDM Programs |
|---|---|---|---|---|---|
| Automobile access | + | +/- | +/- | +/- | +/- |
| Walking & cycling access | - | + | + | + | + |
| Public transport | + (bus) | + | + | + | + |
| Network connectivity | - | + |  | + | +/- |
| Land use accessibility | - | + | + | + | + |
| Mobility substitutes |  |  |  |  | + |

*(+ improves that access factor;   - degrades that access factor) Roadway expansions increase automobile access but by degrading walking conditions and encouraging more dispersed development and tend to reduce other forms of access. Improving space-efficient modes, pricing reforms and smart growth policies may reduce automobile access but improve access in other ways.*

### *Comprehensive Impact Analysis*

Comprehensive evaluation considers all significant *impacts* (benefits and costs), and *planning objectives* (specific things a community wants to achieve). Such analysis can be *qualitative* (described), *quantitative* (measured), or *monetized* (valued in monetary units) (DfT 2006; Litman 2003; NZTA 2010). Table 12 illustrates qualitative analysis of how five congestion reduction strategies affect ten planning objectives. Of course, actual impacts will vary depending on various factors so this analysis should be adjusted to reflect specific conditions.

**Table 12** **Qualitative Evaluation of Potential Congestion Reduction Strategies**

| Planning Objectives | Roadway Expansion | Improve Alt. Modes | Efficient Pricing | Smart Growth |
|---|---|---|---|---|
| **Congestion reduction** | Large short-term but declines | Small short-term but increases | Potentially large | Reduces traffic speeds but improves access options and reduces travel distances |
| **Roadway cost savings** | Increases roadway costs | Usually reduces total roadway costs | Usually reduces total roadway costs | Usually reduces total roadway costs |
| **Parking savings** | Increases costs | Reduces parking costs | Reduces costs | Reduces parking demand but may increase facility costs |
| **Consumer savings and affordability** | Mixed | Can provide large savings | Increases driving costs but provides other savings | Tends to reduce per capita transport expenditures |
| **Improved non-driver access** | Degrades walking conditions | Usually large benefits | Generally improves non-drivers' access | Large benefits |
| **Improved traffic safety** | Reduced crash rates offset by higher speeds and more vehicle travel | Usually increases safety | Usually increases safety | Usually increases safety |
| **Reduced pollution** | Reduced emission rates offset by more vehicle travel | Tends to reduce emissions | Tends to reduce emissions | Reduces emissions but may increase exposure to local pollutants |
| **Energy conservation** | Reduced fuel consumption rates but increased vehicle travel | Generally reduces per capita energy consumption | Generally reduces per capita energy consumption | Generally reduces per capita energy consumption |
| **Efficient land use** | Often causes sprawl | Supports more compact development | Supports more compact development | Supports more compact development |
| **Improved fitness and health** | Tends to reduce active transport | Usually increases active transport | Usually increases active transport | Usually increases active transport |

*Roadway expansion helps reduce congestion but tends to contradict other objectives. Other types of congestion reduction strategies tend to achieve more objectives.*

Table 13 illustrates quantitative evaluation in which potential congestion reduction strategies' impacts are rated from 3 (most positive) to -3 (most negative). These objectives can be weighted. For example, improved safety can be given twice the weight as energy savings, or vice versa (Litman 2003).

**Table 13 Quantitative Evaluation of Potential Congestion Reduction Strategies**

| Planning Objectives | Roadway Expansion | Improve Alt. Modes | Efficient Pricing | Smart Growth |
|---|---|---|---|---|
| Congestion reduction | 3 | 2 | 3 | 0 |
| Roadway cost savings | -3 | 2 | 3 | 3 |
| Parking savings | -2 | 2 | 3 | 3 |
| Consumer savings and affordability | 1 | 1 | 0 | 0 |
| Improved access for non-drivers | -2 | 3 | 3 | 3 |
| Improved traffic safety | -2 | 2 | 3 | 3 |
| Reduced pollution | -2 | 2 | 3 | 3 |
| Energy conservation | -2 | 2 | 3 | 3 |
| Efficient land use | -3 | 2 | 3 | 3 |
| Improved fitness and health | -3 | 3 | 3 | 3 |
| ***Totals*** | ***-15*** | ***21*** | ***27*** | ***24*** |

*This quantitative analysis rates each strategy's impacts on ten planning objectives from 3 to -3.*

Many of these impacts can be *monetized* (Litman 2009; TC 2005-08). Table 14 illustrates an example of monetized evaluation of congestion reductions on an urban roadway with one million annual peak-period vehicle-miles. Both roadway expansion and transport demand management (TDM) strategies (a combination of improving space-efficient modes, efficient pricing, smart growth policies, and targeted programs) are assumed to reduce congestion 33%, but roadway expansions would increase affected vehicle travel 10%, while the TDM strategies reduces vehicle travel 10%. Both strategies provide $45,000 annual congestion cost savings, but the roadway expansion benefits are largely offset by the additional costs of the induced travel, while the TDM strategies provide additional benefits (reduced road and parking costs, crashes, barrier effects, pollution and petroleum externalities, plus consumer savings from improved transport options) which approximately double the congestion reduction benefits.

**Table 14 Monetized Evaluation of Potential Congestion Reduction Strategies**

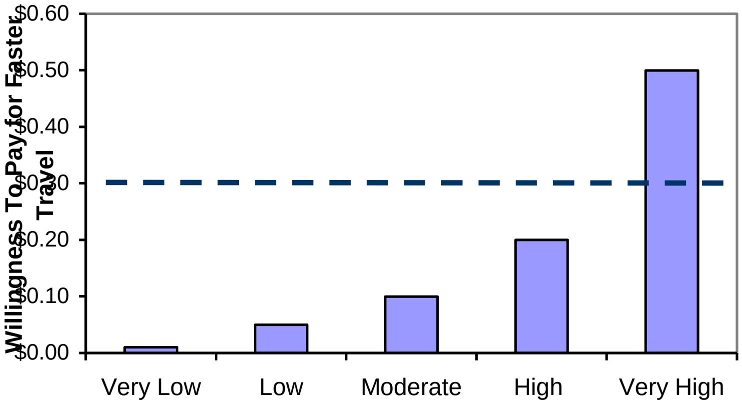
| Costs | Costs per Veh.-Mile | Roadway Expansion | Transport Demand Management |
|---|---|---|---|
| Vehicle Travel Change | | +10% | -10% |
| Congestion Costs | | -33% | -33% |
| Congestion | $0.15 | -$45,000 | -$45,000 |
| Roadway operations | $0.04 | $4,000 | -$4,000 |
| Parking subsidies | $0.10 | $10,000 | -$10,000 |
| Vehicle operation | $0.15 | $15,000 | -$15,000 |
| Crash damages | $0.10 | $10,000 | -$10,000 |
| Barrier effect (pedestrian/cycling delays) | $0.03 | $3,000 | $3,000 |
| Air and noise pollution | $0.05 | $5,000 | -$5,000 |
| Petroleum externalities | $0.02 | $2,000 | -$2,000 |
| ***Totals*** | | **$4,000** | **-$88,000** |

*Monetized analysis uses estimates of costs and benefits to calculate the value of a policy or project.*

### *Economic Efficiency and Consumer Surplus*

Economic efficiency recognizes the diversity of value provided by travel activity: some vehicles (urgent errands, freight trucks and buses carrying numerous passengers) tend to have high travel time values, while others have low value. Users would shift modes, routes or destinations if their costs increased or alternatives improved modestly. Figure 12 illustrates this concept, showing motorists' demand curve for faster travel. If expanding roadways to reduce congestion delays costs 30¢ per peak-period vehicle-mile, it is economically efficient to offer this option to the motorists whose willingness to pay exceeds this amount. Serving this demand reflects consumer sovereignty (the principle that consumer preferences should ultimately determine which goods and services are produced), and increases consumer-surplus (net user benefits), but it is economically inefficient to spend that amount to increase the travel speeds of motorist with lower willingness-to-pay. Expanding roads to accommodate lower-value peak-period vehicle travel means that society is spending two dollars to provide a benefit that consumers only value at one dollar, and is particularly harmful if the added capacity induces additional vehicle travel which increases external cost.

***Figure 12*** **Faster Traffic Demand Curve**



*On a typical road, users' willingness-to-pay for faster travel varies from very low to very high. If expanding urban roadways cost 30¢ per peak-period vehicle-mile, economic efficiency increases if motorists willing to pay this amount can purchase faster travel, but it would be economically inefficient to spend this amount to increase the travel speeds of motorists with lower willingness-to-pay.*

This has various implications for congestion evaluation:

- There are large potential benefits from favoring higher-value travel. A roadway becomes more efficient (it provides more value per lane or vehicle-mile) if regulations, pricing or incentives allow higher value vehicles to avoid congestion.
- A significant portion of motor vehicle travel may have negative net value: its marginal user benefits are less than their total marginal costs, including external costs such as roadway costs, parking facility costs, accident and pollution damages. It is economically inefficient to expand roads to accommodate such travel.
- Improving transport options (alternatives to driving) that serve latent demand also reflects consumer sovereignty, and increases consumer-surplus. For example, walking, cycling and transit improvements that increase use of those modes provide direct user benefits in addition to any indirect benefits from reduced automobile travel.
- Improving traveler convenience and comfort, for example, by providing better public transit user information and improving comfort, can reduce travel time unit costs (dollars per hour) equivalent in value to increasing travel speed.

Experience indicates that a 1¢ per vehicle-mile road toll typically reduces affected vehicle travel about 1%, with larger reductions on urban highways with good alternatives such as high quality public transport (PSRC 2008; Spears, Boarnet and Handy 2010). This reflects the value motorists place on their vehicle travel. For example, this indicates that about 20% of peak-period motorists value their trips at less than 20¢ per vehicle-mile, and 30% value it less than 30¢; if charged those amounts they would prefer to shift time, mode or destinations. Urban-peak travel has external costs (crashes, pollution, parking subsidies, barrier effect, petroleum externalities, etc.) of 20-30¢ per mile, and expanding urban roadways typically costs $0.50 to $1.50 per additional urban-peak trip accommodated (Litman 2009; TC 2005-08). As a result, a significant portion of urban-peak vehicle travel is probably worth less than its total costs, and if urban roadways are expanded, much of the additional vehicle travel accommodated is probably worth less than total marginal costs (roadway expansion and other external costs)

The potential benefits of policies that favor higher-value vehicle travel are potentially large. For example, freight, commercial and public transit vehicles often have values of time an order of magnitude higher than that of an average automobile, so giving them priority in traffic can provide large efficiency gains; their benefits more than offset losses to lower-value travelers.

Conventional congestion analysis generally ignores these issues. It seldom quantifies the economic efficiency gains of favoring higher value travel, the consumer surplus gains of serving latent demand, or the economic inefficiencies that result if roadway expansions induce additional vehicle travel that has marginal benefits worth less than marginal external costs. Comprehensive evaluation considers these factors.

### Social Equity

*Equity* refers to the distribution of costs and benefits, and whether they are considered fair and appropriate. There are three general categories of equity related to transportation:

1. *Horizontal equity* (also called *fairness*) is concerned with whether similar people and groups are treated similarly. It suggests that people with comparable incomes and needs should receive similar shares of public resources and bear similar cost burdens. It implies that user should "get what they pay for and pay for what they get" (the "user pays" principle) unless subsidies are specifically justified.
2. *Vertical equity with regard to income* considers the allocation of costs between different income classes, assuming that public policies should favor people who are economically disadvantaged. Policies that provide a proportionally greater benefit to lower-income groups are called *progressive*, while those that make lower-income people relatively worse off are called *regressive*.
3. *Vertical equity with regard to mobility needs* considers whether a transport system provides adequate service to people with mobility impairments and other special needs. This justifies universal design (facilities designed to accommodate all users, including people with impairments) and policies that provide basic mobility to disadvantaged people (such as bus services) even if this requires subsidies.

Conventional congestion evaluation tends to consider a limited set of equity issues, such as whether congestion reduction funds are fairly allocated among different jurisdictions, whether congestion pricing is regressive and unfair, and sometimes whether roadway expansions harm urban neighborhoods. These equity impacts tend to be overlooked:

- The inequity of higher-occupant vehicle (bus, van and carpool) passengers being delayed by traffic congestion caused by lower-occupant vehicle passengers who require 10 to 100 times more road space, and therefore the equity justification for bus and HOV lanes.
- The inequity of reduced pedestrian and cycling safety and accessibility caused by wider roads, increased traffic speeds, reduced roadway connectivity and sprawled development. This indicates that there is an equity justification for favoring narrower roads, lower traffic speeds, and other pedestrian and cycling improvements.
- The inequity of using general taxes to finance urban highway expansions, and therefore the equity of road tolls and other motorist user fees.
- The regressivity of congestion reduction strategies that favor automobile travel over more affordable modes (walking, cycling and public transport) and therefore forces lower-income households to own more vehicles than they can afford.
- The harm that automobile-dependent transport systems have on disadvantaged people.

More comprehensive equity analysis tends to support congestion reduction strategies that improve transport options, particularly affordable modes (walking, cycling and public transport), and oppose congestion reduction strategies that increase automobile dependency. It can also support congestion tolls, provided there are high-quality and affordable alternatives to urban-peak driving, and other pricing reforms that reduce unjustified subsidies for automobile travel.

### *Comprehensive Evaluation Summary*

Table 15 summarizes the major factors that should be considered in comprehensive and multi-modal congestion evaluation framework.

***Table 15*** **Comprehensive Congestion Evaluation Framework**

| | Accessibility Factors | Impacts | Economic Efficiency | Social Equity |
|---|---|---|---|---|
| Major factors to consider in comprehensive evaluation | • Automobile accessibility<br>• Accessibility by other modes<br>• Roadway connectivity<br>• Geographic proximity (land use density and mix) | • Traffic congestion<br>• Road and parking costs<br>• Accidents<br>• Consumer costs<br>• Mobility for nondrivers<br>• Energy consumption<br>• Pollution emission<br>• Efficient land use<br>• Public fitness | • Efficiency gains from favoring higher value trips<br>• Possibility that induced travel has negative net benefit<br>• Consumer surplus gains from new modes and services | • Fairness of benefit and costs allocation.<br>• Impacts on physically, economically and socially disadvantaged people.<br>• Unfairness of polices that favor automobile travel over other modes |
| Conventional congestion evaluation | Primarily considers automobile access; other accessibility factors are often overlooked. | Focuses on travel speed and vehicle operating costs. Other impacts are often overlooked or undervalued. | Generally ignores economic efficiency factors. | Generally considers a limited set of equity impacts. |
| Changes required for comprehensive evaluation | Consider all accessibility factors and trade-offs between them. Use multi-modal accessibility models. | Consider all significant impacts and planning objectives, including external costs and co-benefits. | Consider these economic efficiency factors. | Expand the range of equity impacts considered in evaluation. |

*This table summarizes major factors to consider in a comprehensive and multi-modal congestion evaluation framework. Conventional evaluation tends to overlook and undervalue many of them.*

These reflect different perspectives. For example, each of these perspectives can recognize benefits from improving transport options (walking, cycling, public transit, delivery services, etc.) and favoring higher value travel (HOV lanes, bus priority systems, efficient road and parking pricing). Although, they each reach that conclusion in different ways: an *impact perspective* recognizes its ability to reduce problems such as traffic and parking congestion, accidents and pollution emissions; an *economic efficiency perspective* recognizes consumer surplus gains from serving latent demand and favoring higher value travel; and a *social equity perspective* recognizes the value of improving transport options used by physically, economically and socially disadvantaged people. They are not mutually exclusive; each can be incorporated in comprehensive evaluation.

Planning that evaluates transportation system performance based primarily on vehicle travel speed and congestion delay, and overlook other accessibility factors and impacts, tends to exaggerate congestion compared with other transportation problems, exaggerates roadway expansion benefits, and undervalues other types of transport system improvements. These biases tend to result in more roadway capacity, reduced transport options, underpriced vehicle travel, and less accessible land use development patterns than is economically and socially optimal.

## Alternatives to Roadway Level-Of-Service

*This section evaluates various alternatives to roadway LOS.*

### *Multi-Modal Level-of-Service (LOS) and Quality of Service (QOS)*

*Description:* Multi-modal level-of-service analysis measures travel delay experienced by pedestrians, cyclists and public transport passengers, for example, by wider roads, heavy traffic, inadequate crosswalks, and transit delays, and therefore the potential benefits of transport system changes that reduce such delays. As previously mentioned, the latest *Highway Capacity Manual* (TRB 2010) provides guidance for multi-modal LOS analysis, and models are now available for automating this analysis (Dowling Associates 2010).

Multi-modal quality of service (QOS) analysis can account for factors other than travel speed, related to convenience, comfort, safety and affordability (FDOT 2012; Fehr & Peers 2012). Since pedestrians, cyclists and transit users are particularly affected by planning decisions (a motorist can purchase a more comfortable vehicle, but pedestrian, cycling and transit comfort depends on planning decisions, such as the sidewalk, road and transit vehicle design and maintenance), these qualitative factors tend to be important.

*Potential Criticisms:* Multi-modal LOS and QOS only considers travel conditions, they do not account for other accessibility factors such as transport network connectivity, and land use proximity. These indicators require new data on sidewalks, crosswalks, traffic conditions and transit service, which is costly to collect.

*Implementation strategies:* These models already exist and can be improved with targeted research. Data collection costs can be minimized if jurisdictions establish strategic plans which begin collecting the needed data during regular field work (for example, during regular land, road and utility line surveys).

### *Trip Generation, Vehicle Travel and Fuel Consumption Models*

*Description:* Trip generation models are widely used for traffic planning, and are a key input into roadway LOS analysis. Variations also calculate vehicle miles travel (VMT) and fuel consumption. Such models are widely used for transport, energy and emission modeling, and can be used for traffic and environmental impact analysis, assuming that projects which generate fewer trips, vehicle-miles, or less fuel consumption tend to impose lower traffic and environmental costs.

*Potential criticisms:* Trip generation, vehicle travel, fuel consumption, and roadway LOS impact models are all subject to uncertainties, particularly when evaluating the impacts of innovative transportation and land use changes for which there is limited experience, such as qualitative improvements in space-efficient modes, pricing reforms, transit-oriented development, and commute trip reduction programs (Arrington and Sloop 2010; SPACK Consulting 2010). Expanding and improving these models will require investments in research and data collection. Another possible criticism is that vehicle travel reduction targets could contradict other planning objectives, for example, by imposing restrictions that harm consumers and businesses, or by limiting development.

*Implementation strategies:* These models already exist and can be improved, particularly with research which identifies how various transportation demand management and smart growth strategies affect travel activity, and how these affect other planning objectives such as infrastructure costs, affordability, safety and health, and residents' satisfaction.

### *Multi-Modal Accessibility Modeling*

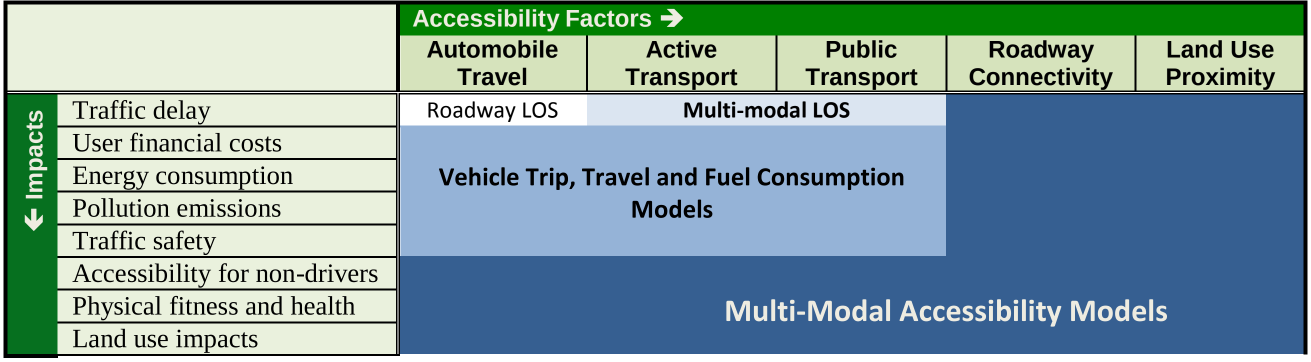
*Description:* New models evaluate accessibility based on the number of services (shops, schools, parks, etc.) and activities (such as jobs) that can be reached within a given time period and financial cost by various travel modes (Levine, et al 2012; Levinson 2013). Simplified versions include WalkScore, BikeScore, TransitScore, Transit Connectivity Index and a Transit Access Shed Indicator and Google Maps Commute Travel Time (HTAI 2013); although these tools only reflect single modes, they can be aggregated for multi-modal accessibility.

*Potential Criticisms:* Multi-modal accessibility models are a new approach to transport system performance evaluation. They require new data, and most only consider a limited set of accessibility factors, so it is important that people who apply these models and their results understand their limitations.

*Implementation strategies:* These models are developing rapidly; they are already suitable for many planning applications (for example, even relatively crude methods such as WalkScore and Google Maps commute time applications are widely used by consumers, businesses and researchers to quantify accessibility) and their availability and utility is increasing rapidly. It should be possible to standardize these methods so they can be used in transport system performance evaluation.

Table 16 compares the scope of accessibility factors and impacts considered by these various evaluation methods. Roadway LOS (white square) considers just one impact for one mode: peak-period travel delay. It may measure fuel consumption and pollution emission rates per vehicle-mile, but because it does not account for per capita mileage and it cannot measure total per capita fuel consumption or pollution emissions. Multi-modal LOS (light blue) also considers delay to active (walking and cycling) and public transport modes. Vehicle trip generation, travel and fuel consumption models (medium blue) can reflect additional impacts, including fuel consumption and emissions, parking and accident costs. Multi-modal accessibility models (darkest blue) also consider the effects of roadway connectivity and land use proximity on the time and costs required to reach various destinations, and therefore accounts for the largest range of impacts.

***Table 16*** **Scope of Accessibility Factors and Impacts Considered**



| | | Accessibility Factors → | | | | |
|---|---|---|---|---|---|---|
| | | **Automobile Travel** | **Active Transport** | **Public Transport** | **Roadway Connectivity** | **Land Use Proximity** |
| ↓ Impacts | Traffic delay | Roadway LOS | **Multi-modal LOS** | | **Multi-Modal Accessibility Models** | |
| | User financial costs | **Vehicle Trip, Travel and Fuel Consumption Models** | | | | |
| | Energy consumption | | | | | |
| | Pollution emissions | | | | | |
| | Traffic safety | | | | | |
| | Accessibility for non-drivers | | | | | |
| | Physical fitness and health | | | | | |
| | Land use impacts | | | | | |

*Roadway LOS (white square) only considers one impact (delay) for one mode (automobile). Multi-modal LOS (light blue) considers delay for additional modes. Vehicle trip, travel and fuel consumption models (medium blue) indicate additional impacts. Multi-modal accessibility models consider the widest range of accessibility factors and impacts, and so are the most comprehensive and multi-modal.*

## Measuring Efficiency

*Efficiency* refers to the ratio of inputs (costs) to outputs (benefits). Roadway traffic efficiency can be measured in various ways that give different conclusions about what congestion reduction strategies are most efficient and beneficial overall.

- *Vehicle Travel*. Vehicle travel measures roadway efficiency based on vehicle travel speeds. This is the perspective reflected in conventional roadway performance indicators such as roadway level-of-service, traffic speeds and vehicle congestion delay.
- *Mobility*. Mobility-oriented evaluation measures roadway efficiency based on people and freight travel speeds and costs. This recognizes that travel time savings to multi-occupant vehicles provides more benefits, and therefore more efficiency gain, than are provided by the same travel time savings by lower-occupancy vehicles; for example, each minute of travel time savings for a bus carrying 50 passengers has the same value as one minute saved by 50 vehicles. This perspective is multi-modal; it recognizes that a portion of travelers cannot or should not drive, so a transport system is inefficient if it fails to serve these demands and forces motorists to chauffeur non-drivers. These are factors that are generally ignored with a vehicle-oriented perspective and this perspective is reflected in transport models which measure travel speeds and hours of delay per person.
- *Accessibility*. Accessibility measures transport system efficiency based on the generalized cost (time and money) required for people to access desired services and activities, and for freight to be delivered. This is the perspective reflected in transport models which measure the time or generalized costs required to access important services and activities, such as the number of jobs or commonly-used services (stores, schools, healthcare facilities, etc.) that can be accessed by residents in an area.
- *Economic Efficiency*. Economic efficiency measures roadway efficiency based on users' willingness-to-pay (wtp) for travel time savings. This recognizes that travel time values are heterogeneous (varied); multi-occupant vehicles, commercial vehicles and travelers with urgent errands often have much higher than average time values, while some vehicle trips have only marginal net value, users would shift time, route, mode or destination if their costs increased by small amounts. This recognizes the efficiency gains that can be achieved if transport systems use regulations or pricing to favor higher value trips and more space-efficient modes on congested roadways, and the possibility that roadway expansions may be economically inefficient if marginal costs (total roadway expansion costs plus any external costs) are less than marginal benefits (the value to users of the additional peak-period vehicle travel). This perspective is reflected in more sophisticated transport models which recognize travel time heterogeneity and calculate the net benefits gained by favoring higher value trips.

The following pages have examples of how different ways of measuring roadway efficiency can result in different conclusions about which congestion reduction strategies are best overall.

### Bus Lanes

A vehicle-travel perspective evaluates transport system performance based on vehicle traffic speeds – alternative modes are only valued if they reduce automobile traffic congestion – so bus lanes are only justified if they reduce congestion delay on adjacent lanes. For example, consider an urban arterial with six lanes that each carry 800 vehicles per peak hour, including 2,250 automobiles with 1.1 average occupants and 50 buses with 40 average passengers (a bus has three passenger-car equivalents), or 2,475 automobile occupants and 2,000 bus occupants. If evaluated using vehicle-travel indicators, a bus lane is only justified if it would cause more than a third of drivers to shift to bus travel, so the reduction in automobile capacity is more than offset by reduce automobile demand. This is a significant burden so few arterials would have bus lanes.

A *mobility-oriented perspective* evaluates transport system performance based on person-speeds, using models that measure total traveler time costs. This recognizes that a minute saved by a bus carrying 40 passengers is worth about 36 times as much as a minute saved by an automobile carrying 1.1 occupants. This can justify bus lanes even if they slightly reduce automobile travel speeds, provided the increased automobile occupant travel times are more than offset by total bus passenger travel time savings. Bus lanes are also justified on most urban arterials that have more than about 24 buses during peak hours, since those buses carry more passengers than a general traffic lane. Mobility-oriented indicators recognize that a road system becomes more efficient if it favors space-efficient modes over space intensive modes (an automobile traveler requires 10 to 100 times as much road space as a bus passenger).

An *accessibility-oriented perspective* recognizes that travel times and costs should be measured door-to-door, rather than on individual links, and so recognizes the efficiency gains that result from more integrated transport networks (more connected road networks and better connections between walking, cycling, automobile and public transit services), and more accessible land use development. Accessibility-oriented evaluation supports bus lanes integrated with transit-oriented development, for example, having bus lanes that connect major employment, education, shopping, healthcare and recreation centers

An *economic efficiency perspective* recognizes all of the previously described factors (the value of favoring higher-occupancy vehicles), and also recognizes that some vehicle trips have higher economic value than others, and that some peak-period vehicle trips may have marginal net value, and so are quite price sensitive. This perspective justifies efficient pricing that allows higher-value trips priority over lower-value trips and tests users' willingness-to-pay for road improvements; which prevents society from spending $2.00 to provide additional road capacity that users only value at $1.00; such capacity expansion would be economically inefficient. Efficient pricing favors more space-efficient travel (bus occupants pay less per passenger-mile than car occupants) and higher value trips (vehicle users can pay for faster travel for commercial vehicles and urgent errands), which can avoid the need for special bus and truck lanes.

### *Active Mode (Pedestrian and Cycling) Improvements*

Active mode improvements can include improved sidewalks, paths, crosswalks and bicycle parking facilities, plus reduced vehicle traffic speeds and other traffic management strategies that make active modes more convenient and attractive to use.

A *vehicle-travel perspective* assumes that the primary planning goal is to maximize travel speed, and so tends to consider walking and cycling inefficient and of little value. For example, most traffic modeling recognizes the delay that increased traffic imposes on other motor vehicles but ignores the delay it imposes on active modes (called the *barrier effect*). *Mobility-, accessibility- and economic-efficiency-oriented perspectives* tend to recognize the various roles that walking and cycling play in an efficient transport system, including mobility to non-drivers (and therefore reducing the need for drivers to chauffeur non-drivers), public transit access, and support for more compact development.

### *Pricing Reforms*

Efficient transport pricing includes road tolls, parking fees, distance-based insurance premiums and fuel tax increases that charge motorists more directly for the costs imposed by their vehicle use (currently only about half of roadway costs and an even smaller portion of non-residential parking costs). A *vehicle-travel perspective assumes* that increasing vehicle travel and vehicle travel speeds are inherently beneficial, and demand management strategies are solutions of last resort to be applied only where roadway expansion is infeasible. It tends to consider road tolls as a roadway expansion finance strategy, and generally opposes applying tolls on existing roadways (Poole 2009).

*Mobility-*, *accessibility-* and *economic-efficiency-oriented perspectives* recognize that efficient pricing , favors space-efficient modes and higher-value trips, and so can increase transport system efficiency by encouraging travelers to shift from peak to off-peak; from space intensive modes (automobiles) to more space efficient modes (walking, cycling and public transit); or to choose closer destinations.

### *Smart Growth Policies*

*Smart growth* refers to policies that encourage more compact, mixed, multi-modal development. A *vehicle-travel perspective* tends to consider compact development inefficient since increased density may reduce traffic speeds (Melia, Parkhurst and Barton 2011), although empirical evidence suggests that this is often offset by reduce trip generation (Kuzmyak 2012).

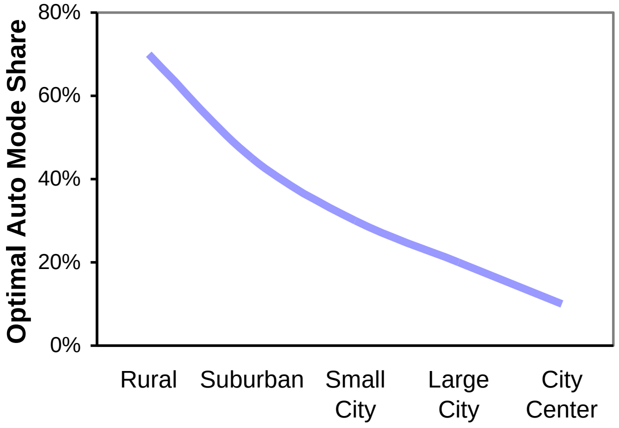
*Mobility-*, *accessibility-* and *economic-efficiency-oriented perspectives* recognize that smart growth can increase transport system efficiency if it encourages mode shifts and shorter travel distances. For example, they recognize that locating a school toward the center of a residential neighborhood may be more efficient than locating it along a major roadway, because more students can walk or bike to school and the distances are shorter. An *economic efficiency perspective* also recognizes the value of charging motorists directly for using roads and parking facilities, or offering comparable benefits to employees and students who use other modes and reduce their road and parking facility costs.

## Optimizing Urban Accessibility

Cities emphasize *accessibility* by locating activities close together, over mobility (travel speed). Urban residents often have more services and jobs within a five-minute *walk* than suburban and rural residents have within a five-minute *drive*, so they can drive less, spend less on transport, impose lower road and parking costs, have lower crash rates, and produce less pollution than in automobile-oriented locations.

Automobile travel requires more road space and so imposes more congestion costs than other modes. It also imposes more pedestrian delay, accident risk, parking and pollution costs per passenger-mile than most other modes. As a result, transport system efficiency, economic productivity, and community livability tend to increase if urban automobile travel is minimized, particularly under urban-peak conditions. Automobile travel need not be eliminated, but as cities become larger and denser, automobile mode share should decline, as illustrated in Figure 13.

***Figure 13*** **Optimal Peak-Period Automobile Mode Share**



*As cities become larger and denser, the optimal automobile mode share declines and the optimal share of resource efficient modes (walking, cycling and public transit) increases, particularly on major corridors during peak periods. Otherwise, traffic problems become severe, reducing economic efficiency and community livability.*

Optimal travel patterns will not generally occur on their own. Many city residents can afford cars. Efficient urban transport therefore requires policies that encourage affluent people to use space-efficient modes when appropriate, so traffic volumes stay within the roadway systems' capacity. As Bogotá Mayor Gustavo Petro explains, "A developed country is not a place where the poor have cars. It's where the rich use public transport."

## Current Congestion Evaluation

Various current studies evaluate congestion costs and potential congestion reduction benefits, including targeted studies such as the *Urban Mobility Report* (TTI 2012), the U.S. Department of Transportation's *Conditions and Performance Report to Congress* (USDOT 2010), and various benefit/cost models used to value transport programs and projects. Table 17 evaluates the degree that these reports consider the factors required for comprehensive congestion evaluation.

***Table 17*** **Evaluating The Scope of Current Congestion Cost Studies**

| Studies | Accessibility | Impacts | Economic Efficiency | Social Equity |
|---|---|---|---|---|
| | • Automobile travel quality<br>• Quality of other modes<br>• Roadway connectivity<br>• Geographic proximity (land use density and mix) | • Traffic congestion<br>• Road & parking costs<br>• Accidents<br>• Consumer costs<br>• Mobility for nondrivers<br>• Energy consumption<br>• Pollution emission<br>• Efficient land use<br>• Public fitness | • Efficiency gains from favoring higher value trips<br>• Possibility that induced travel has negative net benefit<br>• Consumer surplus gains from new modes and services | • Fairness of benefit and costs allocation.<br>• Impacts on physically, economically and socially disadvantaged people.<br>• Unfairness of polices that favor automobile travel over other modes |
| ***Conditions and Performance Report*** (annual report to Congress on transport system quality) | Considers highway and transit conditions, and discusses walking and cycling. Measures congestion using the travel time index. Does not account for roadway connectivity or land use accessibility. | Considers congestion, accidents, energy consumption, and pollution emissions, plus livability which could account for other factors such as public fitness and affordability. | Discusses congestion pricing and other pricing reforms, and includes analysis of the degree that roadway expenditures are covered by user fees. | Primarily concerned with geographic equity (whether benefits are distributed fairly between jurisdictions). Some discussion of basic mobility (portion of residents who have transit service available). |
| ***Urban Mobility Report*** (widely cited study of congestion costs and potential congestion reduction strategies) | Although it includes various congestion indicators, comparative analysis is based on the travel time index. Walking, cycling and transit are only considered if they affect automobile congestion. | Measures travel time, vehicle operating costs and pollution emissions. Ignores induced travel impacts. | Mentions road pricing as a possible congestion reduction strategy, but does not mention any other economic efficiency issues. | Ignores equity impacts. Tends to assume that transportation means driving (the terms "commuter" is often used when the analysis only considers automobile commuters while users of other modes are ignored). |
| ***Highway Capacity Manual*** (widely used roadway engineering manual) | The 2010 version includes level-of-service indicators for walking, cycling, and public transit plus automobile conditions. | Primarily measures travel time and safety, but implicitly considers basic mobility for non-drivers. | Does not explicitly evaluate economic efficiency or consumer surplus impacts. | Does not explicitly evaluate social equity impacts but does support improved mobility for non-drivers. |
| Benefit/cost models used to evaluate specific projects | Generally use transport network models to measure congestion delays, which often measure multiple modes and land use factors. | Primarily measures travel time, vehicle operating costs, crash rates and pollution emissions. Usually ignores other impacts. | Does not usually evaluate economic efficiency or consumer surplus impacts. | Does not usually evaluate social equity impacts |

*This table evaluates the degree that various transportation studies account for the various factors required for comprehensive and multi-modal evaluation. Current studies do not account for many of these factors.*

Some congestion evaluation studies overlook important factors required for comprehensive and multi-modal evaluation (Cortright 2011; Litman 2014a). They evaluate congestion intensity rather than total congestion costs; they ignore common trade-offs between accessibility factors, such as when roadway expansion increases traffic speeds but creates barriers to walking and cycling, reduces roadway connectivity or stimulates less accessible land use development patterns. Such studies only consider a limited set of impacts, and ignore many of the incremental costs of highway expansions and many co-benefits provided by other congestion reduction strategies. For example, they ignore vehicle ownership and parking costs and therefore the savings to households and businesses that result in improved commute options reduce automobile trips and allow some households to reduce their vehicle ownership.

The *Urban Mobility Report's* title implies that it evaluates overall urban transportation performance, but it actually only considers motor vehicle traffic congestion; it includes no analysis of other urban transport issues such as walking and cycling conditions, public transit service quality, parking congestion, affordability, accident risk, or overall energy consumption and pollution emissions. For accuracy it should be renamed the *Urban Traffic Congestion Report*.

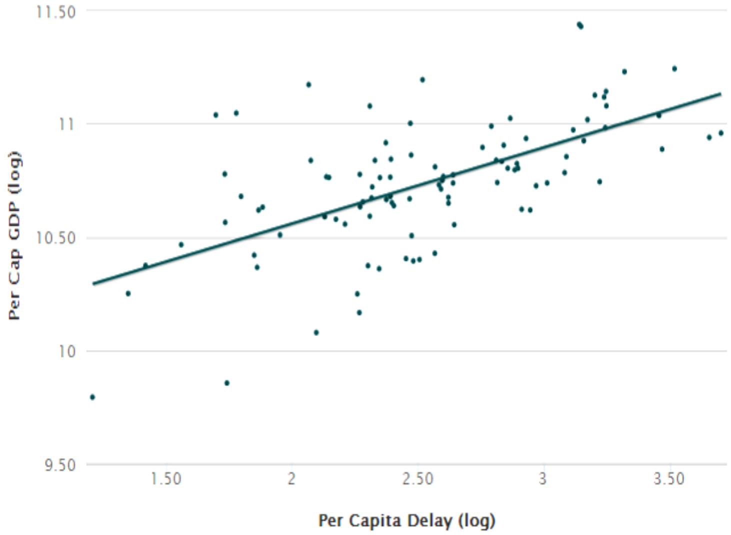
Few congestion evaluation studies reflect economic principles – they do not account for the economic efficiency gains provided by road pricing or other strategies that favor higher-value trips, or the possibility that roadway expansions could be inefficient if the marginal costs (roadway expansion costs plus any external costs of induced travel) are worth less than marginal benefits; an exception is the *Conditions and Performance Report*, which discusses these issues.

The scope of transport project economic evaluations varies depending on the quality of input data, the type of transport modeling (particularly the sensitivity of the model to factors such as transit service quality and congestion feedback, and whether it can report induced travel impacts), and the range of impacts considered. For example, transport models can predict how projects and programs affect automobile ownership and trip generation, and therefore impacts on vehicle ownership and parking cost. If models accurately measure how transport system changes affect walking, cycling, public transit and automobile access they can disaggregate impact by user type. It is also possible to estimate the economic efficiency benefits provided by policies that favor higher-value vehicle travel, and the consumer surplus impacts of price changes or serving latent demands. It is therefore possible for transport models to provide much more comprehensive and multi-modal analysis of how potential congestion reduction strategies affect overall transport system performance.

## Economic Productivity Impacts

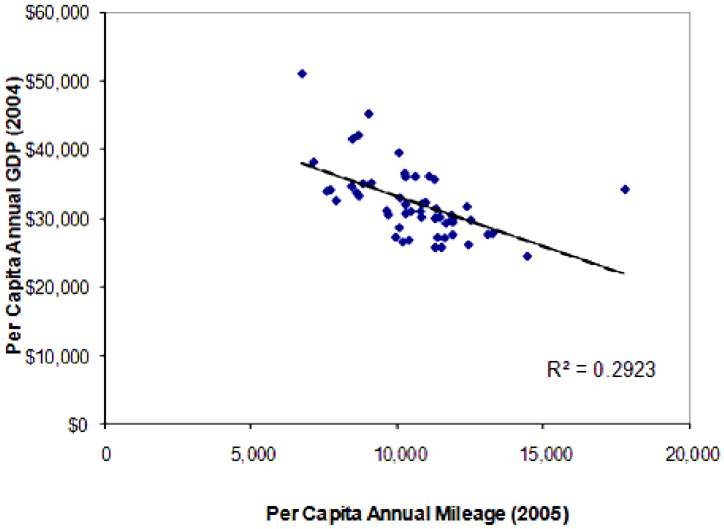
Motor vehicle travel is critical for many economic activities including deliveries, commuting, shopping and tourist activities, so congestion can reduce productivity (EDRG 2007). However, as previously discussed, vehicle travel speeds are only one factor in overall accessibility; for example, a business can generally access more goods, employees and customers if located in a dense, congested urban area than in a sprawled, less congested area (Levine, et al 2012; Levinson 2013; RPA 2014), and businesses use various techniques to minimize their congestion costs, for example, by shipping goods during off-peak periods and using traffic information services such as TomTom and INRIX to avoid congestion. Regional productivity tends to increase with congestion and declines with increased vehicle travel and road supply, as illustrated in figures 14 to 16.

***Figure 14*** **U.S. Metro Region Traffic Delay and GDP** (Dumbough 2012)



*Per capita Gross Domestic Product (GDP) tends to increase with per capita traffic congestion delay. This does not really prove that congestion increases productivity but indicates that congestion is not a major constraint to economic activities.*

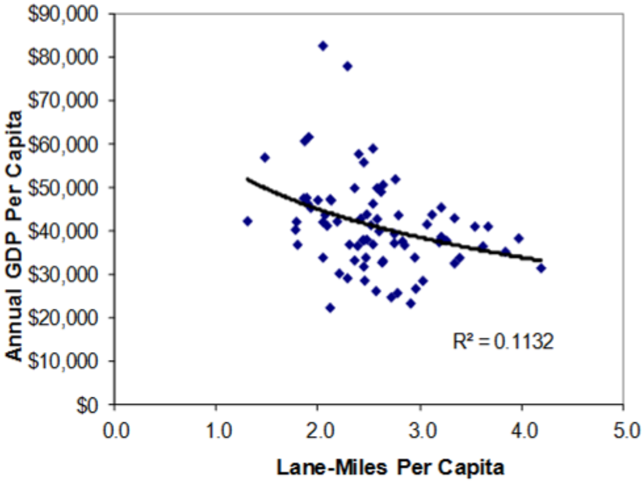
***Figure 15*** **Per Capita GDP and VMT For U.S. States** (VTPI 2009)



*Per capita economic productivity increases as vehicle travel declines. (Each dot is a U.S. state.)*

This does not really prove that traffic congestion is economically beneficial, but suggests that it is a minor constraint on productivity and its negative impacts are overwhelmed by other accessibility and cost factors (Sweet 2013). For example, the *Urban Mobility Report* estimates that traffic congestion increases trucking costs by $27 billion annually, or about 5% of the industry's total costs (TTI 2012). The trucking industry generally opposes congestion pricing despite its potential effectiveness at reducing their delays, suggesting that the industry considers congestion a modest problem (Boyce 2009).

***Figure 16*** **Per Capita GDP and Road Lane Miles** (VTPI 2009)



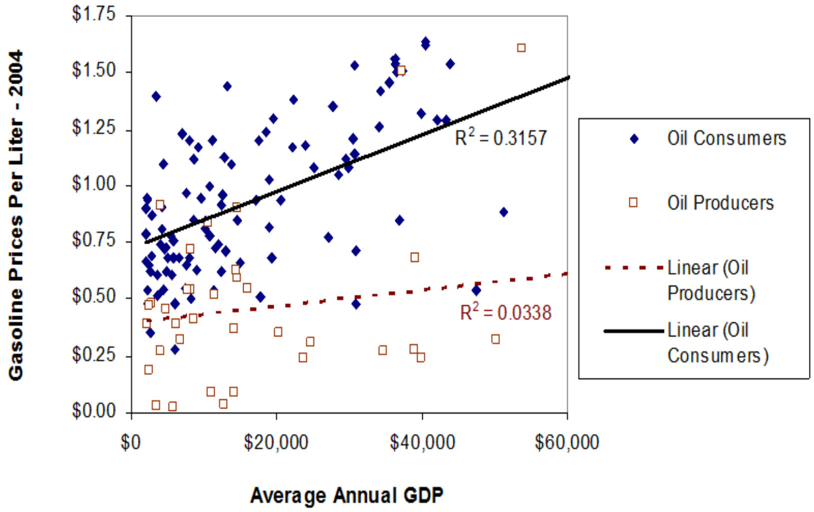
*Economic productivity declines with more roadway supply, an indicator of automobile-oriented transport and land use patterns. (Each dot is a U.S. urban region.)*

Congestion reduction strategies vary in their economic productivity impacts:

- Urban roadway expansions have mixed economic impacts. Although many economic activities depend on road transport, once a basic road network exists there is little evidence that expanding its capacity increases productivity (Nadri and Mamuneas 1996 and 2006). Urban roadway expansions tend to reduce congestion in the short-run, but as previously discussed, this benefit tends to decline over time as generated traffic fills the additional capacity. Most of the additional vehicle travel is personal travel, for example, allowing households more dispersed housing and shopping options; there is often little savings to commercial travelers. To the degree that roadway expansions reduce other forms of access, for example, by creating barriers to walking or stimulating sprawled development, they can increase congestion and other transport costs over the long run.
- Improving space-efficient modes, particularly grade-separated public transit, tends to reduce peak-period vehicle travel which reduces traffic congestion costs, expands labor pools, including for non-drivers, reduces parking costs and vehicle/fuel expenditures, and tends to stimulate more accessible development.
- Transportation pricing reforms (efficient road and parking fees, fuel tax increases and distance-based insurance) tend to reduce total vehicle travel and associated external costs, including congestion, facility costs, traffic accidents, fuel consumption and pollution emissions. Their impacts vary depending on the type of pricing and specific conditions. For example, congestion pricing (road tolls with higher fees during congested periods) is particularly effective at reducing congestion, while fuel tax increases are particularly effective at reducing the economic costs of importing and consuming vehicle fuel. Economic theory suggests that, to the degree that vehicle travel imposes external costs,

pricing reforms should increase economic efficiency and productivity. Available evidence indicates that, all else being equal, higher vehicle user fees are associated with increased per capita economic productivity, as indicated in Figure 17.

***Figure 17*** **GDP Versus Fuel Prices, Countries** (Litman 2014c)



*Economic productivity tends to increase with higher fuel prices, indicating that substantial increases in vehicle fees can be achieved without reducing overall economic productivity.*

- Smart growth development policies may increase congestion intensity (Steve, Parkhurst and Barton 2011), but by reducing travel distances and improving mobility options, tends to reduce per capita congestion costs (Kuzmyak 2012).
- Transportation demand management (TDM) programs, such as commute trip reduction programs, and mobility management marketing, tend to reduce peak-period vehicle travel which reduces traffic congestion, and often improves alternative modes, which tends to expand labor pools, including non-drivers, reduces parking costs and vehicle/fuel expenditures, and tends to support more accessible development.

As discussed earlier in this report, traffic congestion costs are modest compared with other transportation costs, so a congestion reduction strategy provides smaller net benefits and less productivity gains if it increases other economic costs, such as road and parking infrastructure costs, accident and pollution damages, or the economic costs of importing vehicles and fuel, and provides far greater benefits if it reduces these other costs.

Table 19 summarizes the economic development impacts of various congestion reduction strategies. Of course, these impacts can vary significantly depending on specific factors. In some situations, urban roadway expansions may support economic development, although often less than other congestion reduction strategies. These alternative strategies tend to have synergistic effects – their total impacts are greater than the sum of their individual impacts, and so they should generally be evaluated and implemented as an integrated program that includes appropriate improvements to space-efficient modes, pricing reforms, smart growth development policies and TDM programs.

This and other research suggests that urban roadway expansions provide less net benefits than other congestion reduction strategies such as improving space-efficient modes, more efficient transport pricing, and other TDM strategies (Cambridge Systematics 2012; Jiwattanakulpaisarn, Noland and Graham 2012).

***Table 19*** **Economic Impacts of Congestion Reduction Strategies**

| Economic Impacts | Roadway Expansion | Improve Alt. Modes | Efficient Pricing | Smart Growth | TDM Programs |
|---|---|---|---|---|---|
| **Traffic congestion** | Reduces short-run intensity, but increases long-run costs | Reduces congestion | Reduces congestion | Increases intensity, reduces total costs | Reduces congestion |
| **Labor pools** | Expands car commuters' work options | Expands all commuters' work options | Expands most commuters' work options | Improves worker accessibility | Can improve access |
| **Parking costs** | Increases parking costs | Reduces parking costs | Reduces parking costs | Increases unit costs but reduces total costs | Reduces parking costs |
| **Vehicle and fuel imports** | Increases | Reduces | Reduces | Reduces | Reduces |
| **Land use accessibility** | Causes sprawl, which reduces accessibility | Encourages compact development which improves accessibility | Encourages compact development which improves accessibility | Increases land use accessibility | Supports more accessible development |

*Roadway expansions can reduce congestion in the short-run, but do little to improve non-drivers' work options, and can have undesirable economic impacts including increased parking costs, vehicle and fuel imports, and sprawl. Other congestion reduction strategies often provide more economic benefits.*

## Evaluating Potential Congestion Reduction Strategies

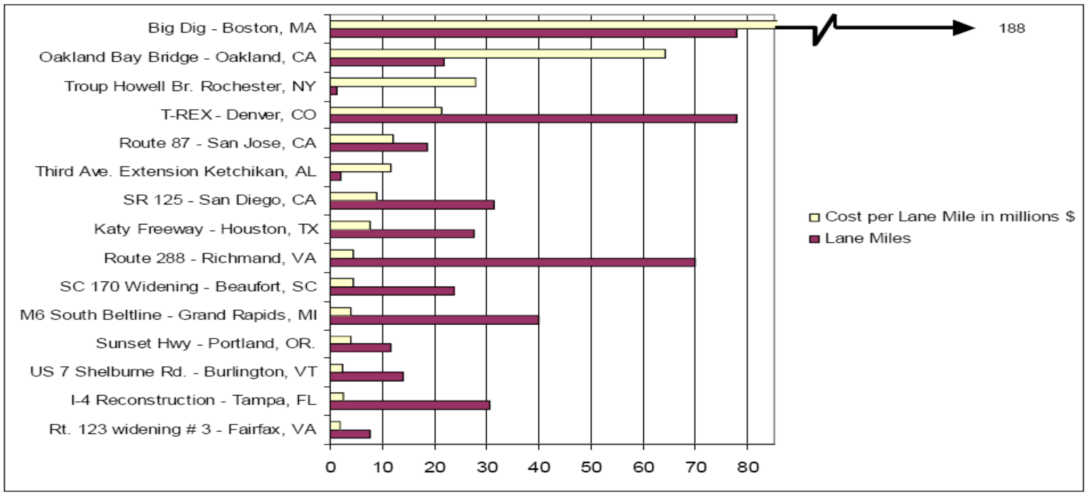
*This section describes and compares various congestion reduction strategies.*

### *Roadway Capacity Expansion*

Roadway capacity expansion can include new and expanded roads and bridges, wider and straighter lanes, intersection flyovers, traffic signal synchronization, reduced cross-streets and crosswalks on arterials, reversible lanes, conversions from two-way to one-way streets, automated highway technologies, half-width vehicles, improved incident response, and various transportation systems management (TSM) strategies. Automobile-oriented planning considers these the preferable solutions to traffic congestion (AHUA 2004).

Roadway expansion projects intended to reduce congestion are economically efficient if their costs can be paid by peak-period users (Hau 1998). Although some roadway capacity expansion strategies, such as signal synchronization, are relatively inexpensive, most are costly ("Roadway Costs," VTPI 2012). Urban roadway expansions often cost $10-20 million per lane-mile, including land acquisition, lane pavement and intersection reconstruction costs, as illustrated in Figure 18. This represents an annualized cost of $300,000-700,000 per lane-mile (assuming a 7% interest rate over 20 years). Dividing this by 4,000 to 8,000 additional peak-period vehicles for 250 annual commute days indicates costs of 15¢ to $1.00 per additional urban-peak vehicle-mile of travel, and sometimes more.

***Figure 18*** **Urban Highway Expansion Costs** (WSDOT 2005)

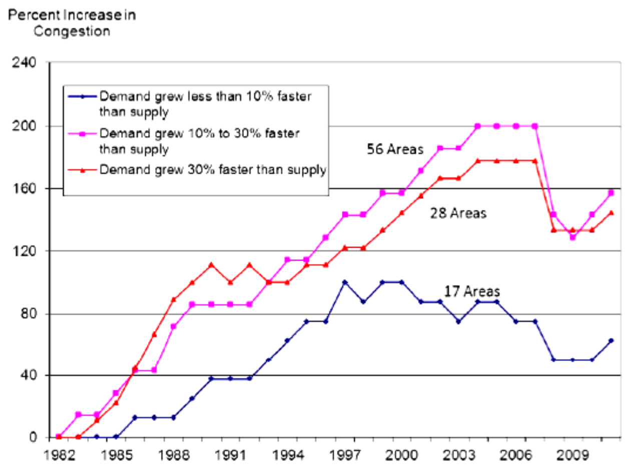


*Of 36 highway projects studied by the Washington State Department of Transportation, 13 had costs exceeding $10 million per lane-mile. Future projects are likely to have higher unit costs since most jurisdictions have already implemented the cheapest highway projects.*

Typical urban highways tolls of 20-30¢ per vehicle-mile will cause traffic volumes to decline 20-30%, and more if alternative routes and modes are good (Spears, Boarnet and Handy 2010). Many recent toll road projects have failed to achieve their traffic volumes and revenue targets (NCHRP 2006; Prozzi, et al. 2009). As a result, user fee revenue is seldom sufficient to fully finance urban roadway expansions. This indicates that roadway expansion is seldom economically efficient: users only want the additional capacity if it is subsidized.

There is debate concerning how much urban roadway expansion reduces congestion. Roadway expansion usually provides only modest and short-term congestion reductions on major urban corridors where congestion is most intense (Litman 2001). The *Urban Mobility Report* claims that expanding highways reduces congestion growth rates, as illustrated in Figure 19, but their analysis failed to account for differences in city size and growth rates that affect congestion growth, and measured congestion intensity instead of total congestion costs and so did not account for increased total delays caused by sprawl.

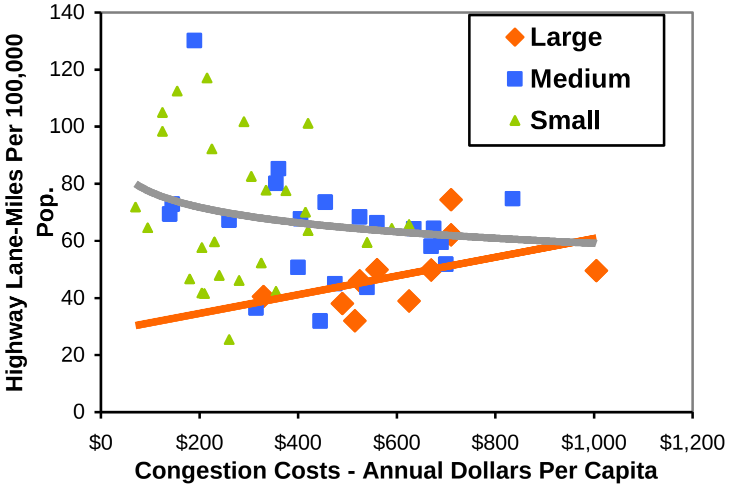
***Figure 19*** **Congestion Growth Versus Highway Expansion** (TTI 2012, p. 20)



*The Urban Mobility Report claims this graph proves that, "Urban areas where capacity increases matched the demand increase saw congestion grow much more slowly than regions where capacity lagged behind demand growth." However, this only measures congestion intensity not total congestion costs, and the analysis does not account for city size and growth rates; most of the cities where demand grew less than 10% faster than supply are smaller, slower-growing regions. This does not prove that roadway expansion is a cost effective way to reduce congestion in most cities.*

Figure 20 illustrates the relationship between urban highway lane-miles and congestion costs. Considering all cities, congestion decreases with more lane-miles but the relationship is weak (grey line). Among the ten largest cities (orange diamonds) the relationship is negative (orange line): those with more highways tend to have higher per capita congestion costs, probably because increased highway capacity increases automobile dependency and sprawl.

***Figure 20*** **Congestion Costs Versus Highway Supply** (TTI 2003; FHWA 2002)

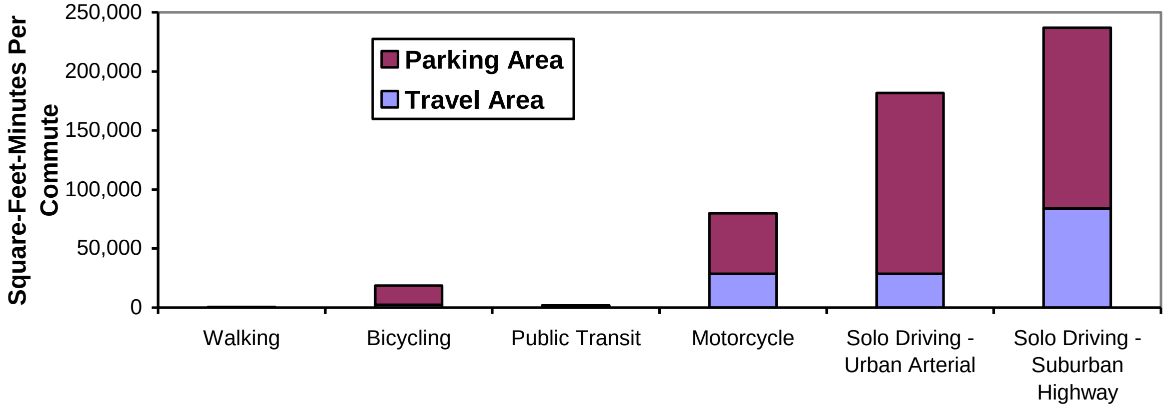


*This figure illustrates the relationship between highway supply and congestion costs. Overall, increased roadway supply provides a small reduction in per capita congestion costs (grey line), but among large cities, congestion increases with road supply (orange line), indicating that other factors have much more influence on congestion costs in large cities.*

### *Improving Space-Efficient Modes*

The space required to travel tends to increase with vehicle size and speed. For example, an automobile traveling at 30 miles-per-hour (mph) requires about 12 feet of lane width and 60 feet of lane length, or about 720 square feet in total, but at 60 mph this increases to 15 feet of lane width and 140 feet of length, or about 2,100 square feet in total. A bus requires about three times a much road space (measured as "passenger car equivalents") but typically carries 30-60 times as many passengers under urban-peak conditions. Figure 21 illustrates the road and parking space requirements of various modes: walking, cycling and public transit are space-efficient compared with automobiles.

**Figure 21** **Space Required By Travel Mode**



*Walking, cycling and public transit are space-efficient compared with automobile travel.*

If space-efficient modes are inconvenient, uncomfortable, dangerous, or unaffordable, travelers will drive even if congestion is severe, but as their service quality improves, travelers' are more likely to shift mode, reducing the point of congestion equilibrium. Even small shifts can provide significant benefits. For example, a 5% reduction from 2,000 to 1,900 vehicles per lane-hour typically increases traffic speeds by 5-15 miles per hour.

**Table 20** **Typical Alternative Mode Improvements**

| Walking | Bicycling | Public Transport |
|---|---|---|
| • More sidewalks and paths<br>• More crosswalks<br>• Traffic speed reductions<br>• Improved wayfinding<br>• More compact and mixed development so more services are within walking distance<br>• Improved safety and security<br>• *Universal design*, so pedestrian facilities accommodate pedestrians with disabilities<br>• Improved connectivity | • More paths<br>• More bike lanes<br>• Traffic speed reductions<br>• Improved wayfinding<br>• Bike parking<br>• Bike racks on buses and trains<br>• Improved safety and security<br>• Bicycle training and encouragement programs<br>• Loans and subsidies to purchase bicycles and safety equipment (lights and helmets) | • More routes<br>• More frequent service<br>• Faster service, grade separation<br>• Higher quality vehicles and stations<br>• Improved connections<br>• Improved user information<br>• Improved safety and security<br>• Reduced fares<br>• More convenient payment systems<br>• Improved stop/station access<br>• Better marketing<br>• *Universal design* |

*There are many possible ways to improve space-efficient modes.*

**How Improving Transport Options Can Reduce Traffic Congestion**
Urban traffic congestion tends to maintain equilibrium, it grows to the point that congestion delays discourage additional peak-period vehicle trips. If congestion increases, some travelers change route, destination, travel time and mode to avoid delay, and if it declines they take more peak-period trips. This is sometimes called the *Downs-Thompson Paradox* (Downs 1992). Reducing the point of equilibrium is the only way to reduce long-term congestion.

The quality of travel options influences the point of congestion equilibrium: If alternatives are inferior, fewer motorists will shift mode and the point of equilibrium will be high. If alternatives are attractive, motorists are more likely to shift modes, reducing the point of equilibrium. Improving travel options can therefore increase travel speeds for both travelers who shift modes and those who continue to drive.

To attract discretionary riders (travelers who have the option of driving), transit must be fast, comfortable, convenient and affordable. Grade-separated service (such as rail on separate right-of-way or busways) provides a speed advantage that can attract discretionary riders. When transit is faster than driving, a portion of travelers shift mode until the highway reaches a new equilibrium (that is, until congestion declines to the point that transit is no longer faster). As a result, the faster the transit service, the faster the traffic speeds on parallel highways. Several studies find that door-to-door travel times for motorists tend to converge with those of grade-separated transit (Mogridge 1990; Lewis and Williams 1999). The actual number of motorists who shift to transit may be relatively small, but is enough to reduce delays. Congestion does not disappear, but it never gets as bad as would occur if grade-separated transit service did not exist nearby. Comparisons between cities indicate that total congestion delay tends to be lower in areas with good transit service (STPP 2001; Litman 2004a).

Shifting traffic from automobile to transit on a particular highway not only reduces congestion on that facility, it also reduces vehicle traffic discharged onto surface streets, providing “downstream” congestion reduction benefits. For example, when comparing a highway widening with transit improvements, the analysis should account for the additional surface street traffic caused by the highway expansion that would be avoided if the same travelers arrive by public transit.

### Active Modes (Walking and Cycling)

Walking and cycling improvements can reduce traffic congestion in several ways. Poor walking and cycling conditions force people to drive for even short trips. A significant portion of urban vehicle traffic (typically 10-30%) consists of short trips suitable for active modes. Poor walking and cycling conditions also force motorists to chauffeur non-drivers to local destinations; such trips often include empty backhauls, so each passenger-mile generates two vehicle-miles of travel. Since most public transport trips include walking and cycling links, improving these modes tends to increase transit travel.

For example, consider how walking and cycling improvements can reduce traffic congestion around a 500-student primary school. If such improvements allow the portion of students driven by parents to decline 20-percentage points, this reduces 200 peak-period vehicle trips (including return trips), which could significantly reduce area traffic and parking congestion. Similarly, if walking and cycling improvements at a commercial district with 1,000 peak period customers reduces the average number of between store vehicle trips per shopper from 4 to 3, this reduces local circulation trips from 4,000 to 3,000, which can significantly reduce congestion in parking lots and on local roadways.

Non-motorized traffic can also contribute to congestion. Pedestrians primarily cause delays when crossing or walking on roads that lack sidewalks. To analyze the bicycling congestion impacts, road conditions are divided into four classes:

1. *Uncongested roads*. Bicycling in these conditions causes no congestion.
2. *Congested roads with space for bicyclists*. Bicycling on road shoulders (common rural roads), wide curb lanes (common in suburban and urban areas), or bike lanes causes little congestion except at intersections where turning vehicles may be delayed.
3. *Narrow, congested roads with low speed traffic.* Bicycling on low-speed streets where cyclists keep up with traffic (common on urban streets) ususlly causes less congestion than an average car due to bicycles' smaller size.
4. *Narrow, congested roads with moderate to high speed traffic*. Bicycling on a narrow, congested road where faster vehicles cannot easily pass can cause significant delay.

Congestion is reduced when travelers shift from driving to bicycling under the first three conditions. Only under condition 4 are shifts likely to increase congestion. This represents a small portion of total cycling because most bicyclists avoid such conditions.

### High Occupant Vehicles (HOVs)

High Occupant Vehicles (HOVs) include rideshare (car- and vanpool) vehicles and buses. Some roads have HOV lanes which may only be used by vehicles with a minimum number of occupants, which typically range from two (2+) to seven (7+). They can carry more people than general traffic lanes, which increases roadway efficiency (more passengers per lane-hour), and their higher speeds may attract some travelers who would otherwise drive, which can reduce traffic congestion. However, such mode shifting is usually modest, only a few percent of corridor travelers, since most HOV lanes only affect a minor portion of commuters' total trips; to be effective HOV priority lanes must be implemented with other mode shift incentives such as efficient road and parking pricing, and overall public transit service improvements (VTPI 2012).

**Mode Shifting Economics**

A ridesharing or public transit improvement or incentive often causes only modest mode shifting since it only affects a minor portion of total travel costs. For example, an HOV or bus lane might increase speeds by 30% on that roadway link, providing five minutes of travel time savings. However, for a typical 50-minute commute trip, that only represents a 10% savings, and assembling a rideshare or catching a bus often adds 10-20 minutes. A five-minute time savings may induce some mode shifting, but usually just a few percent of total trips.

To cause significant mode shifting and congestion reductions, HOV and bus lanes must be implemented with other service improvements and incentives, such as increased transit service, nicer vehicles and stations, amenities such as on-board Internet service (particularly for express commuter buses), financial incentives such as parking pricing or cash-out, and commute trip reduction and mobility management marketing programs (VTPI 2012). By providing a combination of incentives to shift mode these often have synergistic effects (their total impacts are greater than the sum of their individual impacts), and because ridesharing and public transit services have scale economies (unit costs decline as demand increases), such integrated policies and programs are often cost effective. Described differently, HOV and bus lanes become more cost-effective if implemented with ridership incentives, and ridership incentives become more cost effective if implemented with HOV and bus lanes.

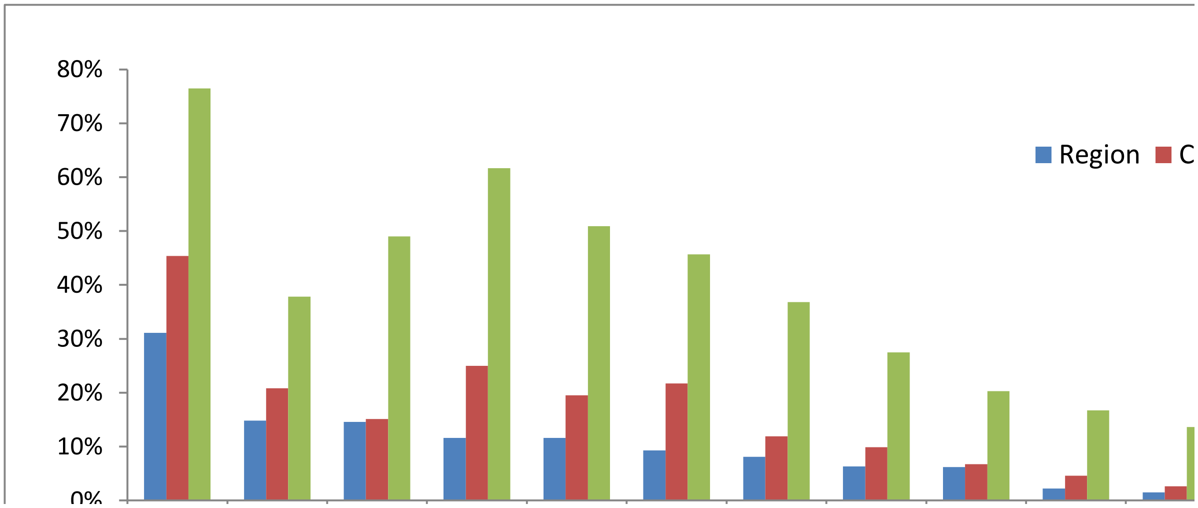
### Public Transport

High quality public transit which attracts discretionary travelers (people who would otherwise drive) can reduce the point of congestion equilibrium, although the benefits can be difficult to measure because of confounding factors: congestion and transit ridership both tend to increase with city size, density, transit service quality and employment rates (traffic congestion and transit ridership tend to increase with a business cycle). Studies that account for these factors generally indicate that public transit service improvements can reduce traffic congestion intensity and costs (Nelson\Nygaard 2006).

Studies indicate that peak-period highway travel times tend to converge with transit travel on a corridor. For example, if a suburb-to-city commute takes 30 minutes by transit, traffic congestion on parallel roadways will decline to the point that automobile commutes take a similar amount of time (Vuchic 1999). As a result, grade-separated services, such as bus-lanes and trains on their own rights-of-way, are particularly effective at reducing congestion. Other factors that attract discretionary transit travelers, such as improved convenience, comfort and affordability, are also likely to reduce congestion on parallel roadways.

Even if public transit only carries a minor portion of total regional travel, its mode share tends to be much higher on congested urban corridors and in central business districts (CBDs), and so can provide significant congestion reduction impacts (Figure 22). 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%, and when a strike halted transit service for five weeks, average highway congestion delay increased 47% (Anderson 2013), with particularly large speed reductions on rail transit corridors (Lo and Hall 2006), indicating that higher quality service is particularly effective at reducing congestion.

***Figure 22*** **Regional, Central City and CBD Mode Shares** (Pisarski 2006)



*Although transit is typically just 1-3% of total regional mode share, it represents a larger portion of urban commuting (typically 5-10%) and an even greater share (typically 10-50%) of peak-period travel to major activity centers such as central business districts (CBDs) and campuses.*

Bhattacharjee and Goetz (2012) found that Denver traffic volumes grew less on roads in light rail corridors than elsewhere: between 1992 and 2008 vehicle-miles traveled increased 41% outside the light rail zones but only 31% inside, despite rapid land development there. Similarly, Kim, Park and Sang (2008) found that after the Hiawatha LRT line was completed, peak-period traffic volumes on that corridor decreased while regional traffic grew. Aftabuzzaman, Currie and Sarvi (2010) estimate that in Australian cities, high quality public transit provides congestion cost reductions worth $0.044 to $1.51 per transit-vehicle kilometer, with higher values on the most congested corridors.

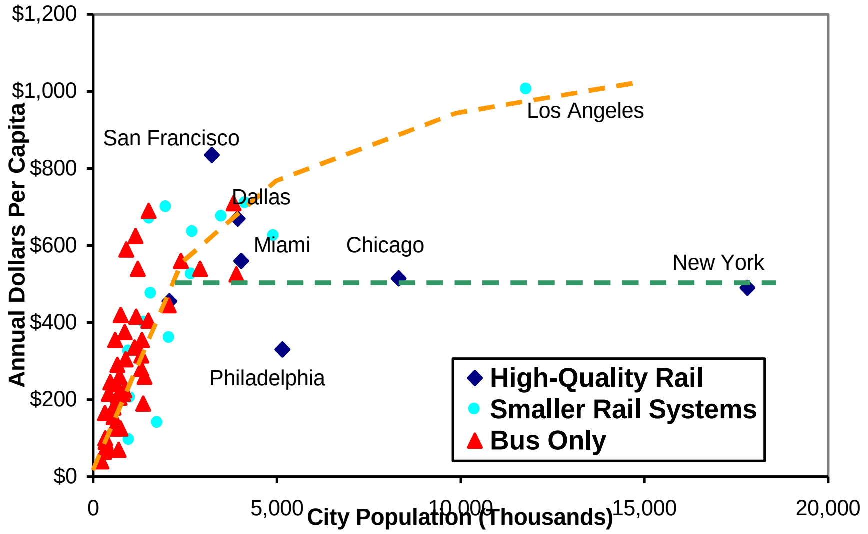
A major study by Jeihani, et al. (2013) evaluated the travel impacts of transit-oriented development (TOD) in the Washington, D.C. and Baltimore metropolitan regions. Out of 1,473 total transportation analysis zones in those regions they classified 107, occupied by approximately 11% of regional residents, as TODs. Their detailed analysis indicates that, all else being equal (accounting for various demographic and geographic factors), TOD residents drive about 20% fewer annual miles than residents of other areas, and rely significantly more on walking, cycling and public transport for both commute and non-commute trips. Since the vehicle travel reductions tend to be concentrated on major urban corridors, they provide proportionately larger reductions in traffic congestion delays.

Using a regional traffic model, they found that the TOD's 1.2% reductions in total regional vehicle travel reduces regional congestion delays by 2.8% and local delays by 20% , with similar air pollution emission reductions. During the PM peak period, TODs decreased 12,648 vehicle miles (0.41%), and 3,959 total hours of delay (4.0%).

Ewing, Tian and Spain (2014) investigated the effects that Salt Lake City's University TRAX light-rail system has on vehicle traffic on parallel roadways. This rail system began operating in 2001 and expanded over the following decades with new lines and stations. It currently carries about 53,000 average daily passengers. The study found significant declines in roadway traffic after the LRT line was completed, despite significant development in the area. The study estimates that the LRT line reduced daily vehicle traffic on the study corridor about 50%, from 44,000 (if the line did not exist) to 22,300 (what currently actually occurs).

Studies by Garrett (2004) and Winston and Langer (2004) indicate that regional traffic congestion often declines as rail transit mileage expands. Cities with extensive grade-separated transit systems have lower per capita congestion costs than comparable size cities with lower quality transit services, so New York and Chicago have lower per capita congestion costs than Dallas and Los Angeles, as illustrated in Figure 23.

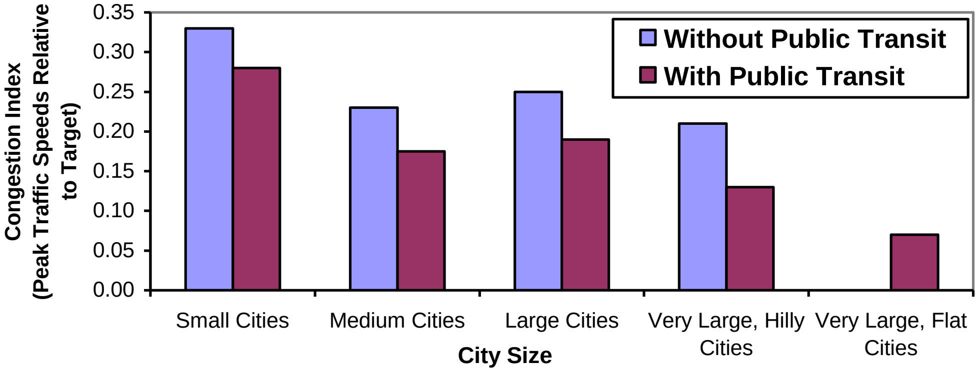
***Figure 23*** **Congestion Costs** (Litman 2004)



*Traffic congestion costs tend to increase with city size (orange dashed line), except for cities with high-quality rail systems (green dashed line).*

Similar patterns are found in developing countries. Figure 24 shows that Indian cities with rail transit have less intense roadway congestion.

***Figure 24*** **Traffic Congestion in India** (Wilbur Smith 2008)



*Traffic congestion is lower in Indian cities with higher quality public transit.*

The Texas Transportation Institute (TTI) *Urban Mobility Reports* estimate the congestion reductions provided by public transit, based on the estimated increase in urban-peak traffic volumes that would occur if current transit trips shifted to automobile travel. Harford (2006) used data from the TTI reports to estimate the monetized value of transit congestion reductions, plus pollution reductions and user consumer surplus gains; he estimated that these benefits provide a benefit–cost ratio of 1.34, with lower values in smaller urban areas and higher values in larger urban areas.

Some researchers claim that public transit fails to reduce traffic congestion, but their analyses do not reflect best practices. For example, Rubin and Mansour (2013) found a positive relationship between transit ridership and congestion, but they measure congestion *intensity* rather than *costs* (which ignores the congestion costs avoided by travelers who shift mode or have shorter trips), fail to account for confounding factors (city size and density, transit service quality, and employment rates), and aggregate all types of transit (Litman 2014b). Similarly, Duranton and Turner (2009) claim that transit fails to reduce congestion, based on regression analysis of regional transit supply (buses and light rail carriages per 10,000 population) and average annual daily traffic (AADT) on regional highways; their analysis fails to account for transit service quality (it does not differentiate between basic bus and grade-separated service), and since only a minor portion of total daily traffic occurs under congested conditions, the dependent variable is a poor indicators of congestion. These studies do not really prove that appropriate transit service improvements on major urban corridors are ineffective at reducing congestion.

Walking, cycling and public transit improvements can also help reduce congestion costs indirectly by providing a catalyst for more compact development, which leverages additional vehicle travel reductions (Cortright 2010). Where this occurs, each additional transit passenger-mile typically reduces two to ten motor vehicle-miles (ICF 2010; Litman 2007). High quality transit also complements congestion pricing: it reduces the toll required to achieve a given reduction in traffic volumes and congestion delays (Parsons Brinckerhoff 2013; PSRC 2008).

Critics sometimes argue that, because walking, cycling and public transit travel tends to be slower than automobile travel, travelers who shift from driving to space-efficient modes are worse off. However, travelers have diverse needs and preferences and travel decisions involve complex trade-offs between various benefits and costs: travelers sometimes prefer slower modes, for example, because they enjoy walking and cycling and appreciate the exercise benefits, or because they find public transit travel less stressful or more productive (they can rest or work) than driving on congested roads. If alternative mode improvements attract travelers out of automobiles, they must be directly better off (increased consumer surplus) or they would not shift.

How congestion is evaluated significantly affects the estimated congestion reductions of transit improvement projects. For example, if evaluated using roadway level-of-service or the Travel Time Index, a general-traffic-lane to bus-lane conversion is only justified if enough drivers would shift to transit that general traffic delay declines. If evaluated based on per capita congestion costs, such a conversion is justified if, after completed, the bus-lane would carry at least as many peak-period passengers as a traffic lane (e.g. 800 on an arterial or 2,000 on a limited access highway), since bus passengers' time savings will exceed incremental automobile occupant delays. This occurs because roadway level-of-service and the travel time index measure *vehicles*, while congestion cost indicators measure *people*, and so recognize the additional savings and benefits that result if higher-occupant vehicles are given priority in traffic.

### Transport Pricing Reforms

Various transportation pricing reforms, such as those listed in Table 21, can help reduce congestion by reducing vehicle traffic volumes and generating revenues for congestion reduction programs.

***Table 21*** **Transport Pricing Reforms** (Spears, Boarnet and Handy 2010; VTPI 2009)

| Type | Description | Travel Impacts | Congestion Impacts |
|---|---|---|---|
| **Congestion pricing** | Road tolls that are higher under congested conditions. | Reduces peak vehicle travel by shifting travel time, route, mode and destinations. | Tends to provide large congestion reductions. |
| **Flat tolls and vehicle travel fees** | Tolls and mileage-based vehicle fees intended to generate revenue. | Shifts automobile travel to other modes and destinations. Reduces total vehicle travel. | Effects are dispersed. Provides modest congestion reductions. |
| **Efficient parking pricing** | Parking fees with higher rates and times and places with high parking demands, and variations such as parking *cash out*. | Shifts driving to other modes and destinations. Reduces total vehicle travel. | Because this is implemented most in dense urban areas, it tends to provide large congestion reductions. |
| **Fuel tax increases** | Increase fuel prices to generate revenue and internalize external costs. | Shifts driving to other modes and destinations. Reduces total vehicle travel. Increases vehicle fuel efficiency. | Effects are dispersed. Provides modest congestion reductions. |
| **Distance-based pricing** | Prorate vehicle insurance premiums and registration fees by mileage. | Shifts automobile travel to other modes and destinations. Reduces total vehicle travel. | Impacts are potentially large but dispersed, so congestion reductions are modest. |

*This table summarizes major pricing reforms and their travel and congestion reduction impacts.*

*Congestion pricing* refers to road tolls with higher fees under congested conditions to reduce peak-period traffic volumes. This maximizes efficiency by allowing higher-value trips to outbid lower-value trips for roadspace (for example, it allows a commercial or high occupancy vehicle, or traveler running an urgent errand to avoid congestion delays), and by reducing traffic volumes to optimal levels tends to increase vehicle operating efficiency (more vehicles per lane hour). However, congestion pricing tends to have high implementation costs and raises privacy concerns, and is usually only suitable for a minor portion of total vehicle travel. Other pricing strategies (flat road user fees, efficient parking pricing, higher fuel prices and distance-based pricing) tend to apply to a larger portion of total travel and therefore tend to be more effective at achieving other planning objectives such as reducing parking costs, accidents, energy consumption and pollution emissions. Efficient parking pricing can be a particularly effective alternative to road pricing as a congestion reduction strategy.

Hybrid pricing strategies include *Value Pricing* (one highway lane is priced so motorists have an uncongested option) and *High Occupancy Vehicle* (HOT) lanes (lower-occupancy vehicles may use HOV lanes if they pay a toll).

Currently, road tolls are applied primarily to repay highway and bridge construction costs. Where automobile travel demand is sufficient it is possible to finance urban roadway expansions with tolls, but most recent experience indicates that vehicle travel is relatively price sensitive, particularly where there are good alternatives such as grade-separated public transit (Litman 2013; Williams-Derry 2011). As a result, many toll road projects have failed to achieve their traffic and revenue projections (Prozzi 2011). This indicates that road pricing is more effective as a congestion prevention strategy on existing urban roads rather than only to finance new highway capacity.

Transportation pricing reforms, particularly road tolls, are often criticized as excessive and unfair. There are various ways to define what road user fees are appropriate and fair:

- *What motorists normally pay.* Since most roads are untolled, any road toll can be considered unfair by this criteria.
- *The price needed to reduce traffic to optimal levels*. This usually justifies moderate to high fees, depending on demand. This can justify using a portion of road toll revenues to improve alternative modes (such as public transit) since this can reduce the price needed to achieve a given reduction in traffic volumes. For example, one major study found that the price elasticity of automobile commute trips is four times higher than average (-0.16 versus -0.04) on corridors with the best transit service (PSRC 2008), indicating that motorists would pay lower tolls to achieve a given congestion reduction target if public transit service is improved.
- *Cost recovery for roadway expansions.* This is often quite high since urban highway expansions are often quite costly.
- *The marginal external cost of vehicle travel.* This is often quite high under urban-peak conditions, since motor vehicle travel tends to impose a variety of external costs (costs of building and maintaining roads and parking facilities, plus congestion, accident and pollution costs imposed on other people).
- *Impacts on lower-income people.* Transportation pricing is often considered regressive (poor people pay more relative to their incomes) since a given fee represents a larger portion of income to lower-income motorists, but overall equity impacts depend on how prices are structured, the quality of travel options and how revenues are used. Lower-income residents tend to drive less than average, particularly on congested urban highways which reduces congestion pricing regressivity. Road tolls and parking fees are generally no more regressive than other funding options. For example, road tolls tend to be less regressive than financing highway expansions with general taxes (Schweitzer and Taylor 2008), and may be progressive overall if they fund improvements to alternative modes frequently used by lower-income traveler.

This indicates the importance of clearly defining the perspective used to evaluate pricing equity: a price structure that seems fair from one perspective may be considered unfair by another.

### *Improving Traveler Information*

Much of the cost of traffic congestion results from the variability and uncertainty it introduces: travelers cannot predict how much time they will need to make a particular trip and so must add “buffer” time (TTI 2012; Cambridge Systematics 2005). These costs can be reduced with traveler information such as predictions and real-time reports on roadway conditions provided by highway signs, radio congestion reports, and special commercial services such as TomTom (www.tomtom.com) and INRIX (www.inrix.com). Such services allow travelers to predict travel speeds and avoid congestion problems. Such information is particularly valuable for commercial travelers (freight and service vehicles, and other types of business travel) due to their relatively high travel time costs. Such services can significantly reduce congestion costs.

Although traffic condition information is already provided through various public and private services, additional improvements are possible which would further reduce congestion costs to individuals and businesses. For example, the European Commission’s real-time traffic information services aim to provide road users with useful, accurate and up-to-date information on the road network, traffic circulation plans, traffic regulations (such as speed limits and access restrictions), recommended driving routes and real-time traffic data including estimated travel times, information about congestion, accidents, road works and road closures, weather conditions, other relevant safety-related information, such as the presence of animals or debris on a road (EC 2013).

### *Smart Growth Development Policies*

*Smart growth* is a general term for various policies that create more compact, multi-modal communities where residents tend to own fewer vehicles, drive less and rely more on space-efficient modes. There is debate concerning how smart growth affects congestion. Some people assume that increasing density increases congestion (Melia, Parkhurst and Barton 2011), but smart growth includes other features that tend to reduce congestion. Table 22 summarizes how various smart growth features affect traffic congestion.

***Table 22*** **Smart Growth Congestion Impacts**

| Smart Growth Feature | Congestion Impacts |
|---|---|
| Increased development density | Increases vehicle trips within an area, but reduces trip distances and supports use of space-efficient modes |
| Increased development mix | Reduces trip distances and supports use of space-efficient modes |
| More connected road network | Reduces the amount of traffic concentrated on arterials. Reduces trip distances. Supports use of space-efficient modes. |
| Improved transport options | Reduces total vehicle trips. |
| Transport demand management | Reduces total vehicle trips, particularly under congested conditions. |
| Parking management | Can reduce vehicle trips and support more compact development |

*Smart growth includes many features that can reduce traffic congestion.*

Empirical studies indicate that smart growth policies can reduce congestion costs overall. For example, a major Phoenix, Arizona study found less intense congestion and reduced per capita travel times in older neighborhoods with more compact and mixed development, more connected streets, better walking conditions and better public transit services than in newer, lower-density, automobile-dependent suburbs (Kuzmyak 2012). Urban residents' commute trips averaged about 7 miles and shopping trips 3 miles, compared with almost 11 and 4 miles in suburban areas.

### *TDM Programs*

Various Transportation Demand Management (TDM) programs help reduce congestion, including employee transport management, transportation management associations and mobility management marketing (VTPI 2009). Such programs provide an institutional framework for implementing strategies such as rideshare matching and pricing reforms, and in various ways encourage travelers to try efficient alternatives. Such programs tend to increase the effectiveness of other congestion reduction strategies.

TDM includes improved traveler information, including dynamic signs, maps, websites and mobile communications that allow travelers to anticipate, avoid and respond to delays. For example, a commuter who normally drives might adjust their schedule, route or mode to avoid congestion, or when stuck in unexpected congestion send a message to family or colleagues to warn of delays. Improving transit information can also make it easier and more desirable for drivers to switch to public transit.

### *Summary of Congestion Evaluation Strategies*

Table 23 evaluates the impacts of five congestion reduction strategies and the degree they are considered in transport modeling and planning. Urban roadway expansions often provide only short-term congestion reductions, tend to increase other costs, and have few co-benefits. Conventional traffic models often exaggerate roadway expansion benefits and conventional planning tends to favor this solution. Other strategies tend to provide more long-term congestion reductions and more co-benefits, but are often overlooked or undervalued in conventional transport modeling and planning.

***Table 23*** **Congestion Reduction Strategies**

| | Roadway Expansion | Improve Alt. Modes | Pricing Reforms | Smart Growth | TDM Programs |
|---|---|---|---|---|---|
| **Congestion impacts** | Reduces short-run congestion, but this declines over time due to generated traffic. | Reduces but does not eliminate congestion. | Can significantly reduce congestion. | May increase local congestion intensity but reduces per capita congestion costs. | Can reduce congestion delays and the costs to users of those delays |
| **Additional costs and benefits** | High costs. By inducing additional vehicle travel and sprawl it tends to increase indirect costs. Minimal co-benefits. Small energy savings and emission reductions. | Moderate to high costs. Numerous co-benefits. Parking savings, safety and health, improved access for non-drivers, user savings, energy conservation, emission reductions, etc. | Low to high implementation costs. Costs users, creates revenue (economic transfers). Numerous co-benefits. Revenues, parking savings, traffic safety, energy conservation, emission reductions, improved public health, etc. | Low to high costs. Numerous co-benefits including infrastructure savings, safety and health, user savings, energy savings, emission reductions, improved non-drivers mobility, etc. | Generally low to moderate implementation costs. Numerous co-benefits. |
| **Consideration in traffic modeling** | Models often exaggerate benefits by underestimating generated traffic and induced travel | Models often underestimate the congestion reduction benefits of high quality space-efficient modes | Varies. Can generally evaluate congestion pricing but are less accurate for other reforms such as parking pricing | Models often underestimate smart growth's ability to reduce vehicle travel and therefore congestion | Sometimes considered |
| **Consideration in current planning** | Commonly considered and funded | Sometimes considered, particularly in large cities | Sometimes considered but seldom implemented | Not generally considered a congestion reduction strategy | Sometimes considered, particularly in large cities |

*Different congestion reduction strategies have different types of impacts and benefits. Current traffic models and planning practices tend to undervalue many of these impacts.*

Some strategies have synergistic effects; they are more effective if implemented together. For example, public transit improvements, efficient parking pricing and more compact development might individually only reduce vehicle travel 5%, but if implemented together provide 30% reductions because their effects are complementary. For this reason, impacts and benefits tend to be greatest if congestion reduction strategies are implemented as an integrated program.

## What Does Modeling Indicate?

Older four-step traffic models are not very accurate at predicting long-term traffic congestion effects because they use fixed trip tables which assume the same number of trips will be made between locations regardless of the level of congestion between them. As a result, they account for shifts in route and mode, and sometime in time, but not in destination or trip frequency ("Model Improvements," VTPI 2012).

Newer models incorporate more factors and so are more accurate at predicting impacts of specific transportation and land use policies. Johnston (2006) summarizes results from more than three dozen long-range modeling exercises performed in the U.S. and Europe using integrated transport, land use and economic models. These indicate that the most effective way to reduce congestion is to implement integrated programs that include a combination of public transit improvements, pricing reforms (fuel taxes, parking charges, or tolls) and smart growth development policies. These studies indicate that a reasonable set of policies can reduce total vehicle travel by 10% to 20% over two decades, maintain or improve highway levels-of-service ratings (i.e., they reduce congestion intensity), expand economic activity, increase transport system equity (by distributing benefits broadly), and reduce adverse environmental impacts compared to the base case. Expanding road capacity, along with transit capacity, but without changing market incentives to encourage more efficient use of existing roads and parking, results in expensive transit systems with low ridership.

Puget Sound region modeling reached similar conclusions (WSDOT 2006). It found that neither highway widening nor transit investments by themselves are cost effective congestion reduction strategies, although the model has fixed trip tables so it exaggerates highway expansion benefits and underestimates transit improvement benefits. The most effective congestion reduction program includes both transit service improvements and road pricing to give travelers better options and incentives. Table 24 summarizes estimated congestion reduction benefits and project costs. Both have costs that exceed congestion reduction benefits, but transit improvements are more cost effective overall since they provide many additional benefits including road and parking cost savings, consumer cost savings, crash reductions, improved mobility for non-drivers, energy conservation, emission reductions, and support for strategic land use.

***Table 24*** **Congestion Reduction Economic Analysis** (WSDOT 2006)

| | Congestion Reduction Benefits | | Direct Project Costs | |
|---|---|---|---|---|
| | Lower Estimate | Higher Estimate | Lower Estimate | Higher Estimate |
| Highway Expansion | $1,500 | $2,200 | $2,500 | $3,700 |
| Transit Improvements | $480 | $730 | $1,200 | $1,500 |

*This table indicates estimated highway and transit congestion reduction benefits and costs, in millions of annualized dollars. Neither approach provides congestion-reduction benefits that exceed costs, but transit provides many additional benefits.*

## Optimal Congestion Solutions

Comprehensive analysis, which considers various access factors, impacts, economic efficiency principles and social equity objectives, suggests that optimal congestion reduction involves the following steps:

1. Improve transport options (walking, cycling, public transit, ridesharing, carsharing and telecommuting) if there is demand. Target improvements on congested urban corridors, such as transit service improvements on congested roads, and commute trip reduction programs at major commercial centers. This reflects the principle of consumer sovereignty, and can help reduce external costs such as traffic and parking congestion.
2. On congested roadways, favor space-efficient modes. For example, provide bus lanes on urban arterials, if after all cost-effective transit service improvements and encouragement programs, they would carry more than about 600 passengers per peak hour, since those will carry more people than a general traffic lane. Similarly, provide High Occupant Vehicle (HOV) lanes on urban highways whenever they would carry more people than a general traffic lane. This increase efficiency.
3. If possible, apply congestion pricing (tolls or fees that are higher during congested periods), priced to reduce traffic volumes to optimal levels (level-of-service C or D). Apply system-wide if possible, but if not, apply on the most congested highways and bridges, provided that it does not cause significant spillover problems.
4. Implement other transport pricing reforms to the degree politically feasible, including revenue generating tolls, efficient parking pricing, fuel price increases, and distance-based insurance and registration fees. These reforms are justified on various efficiency and social equity grounds. Increased revenues can be used to improve space-efficient modes (particularly public transit service improvements and fare reductions that reduce traffic congestion), help finance roadways, or reduce local taxes (they can be considered compensation for the impacts that urban roadways impose on adjacent communities).
5. Implement commute trip reduction and mobility management marketing programs, particularly in conjunction with improvements to space-efficient modes.
6. Only consider urban roadway expansions if, after all of the previous strategies are implemented, congestion problems are significant and peak-period toll revenues would finance all associated costs, which tests users' willingness-to-pay for the additional capacity. For example, if a roadway expansion would have $5 million annualized costs, it should be implemented only if peak-period tolls on that road repay those costs. Off-peak tolls can be used to finance general roadway costs, such as maintenance and safety improvements, but not capacity expansion.

Some of these policies and investments, such as improvements to space-efficient modes and transportation demand management programs, might not be fully justified by congestion reduction benefits alone, but may be justified when all impacts are considered, including various savings and benefits, and social equity objectives since improving alternative modes insures that non-drivers receive a share of transport improvement benefits, and user fees reduce subsidies that non-drivers contribute toward roads and parking facilities.

## Examples

*Many cities around the world are implementing innovative win-win solutions that reduce traffic congestion and help achieve other planning objectives (CAI-Asia 2007; Grant, et al. 2011; Nelson/Nygaard 2006; Strompen, Litman and Bongardt 2012; VTPI 2012). Examples are described below.*

Pasadena, California commissioned a detailed study of potential traffic reduction strategies, which recommended the following strategies:

- Establish a target occupancy rate for on-street parking and develop a program to adjust meter prices to achieve that target.
- Develop Residential Parking Benefit Districts, with meter revenues dedicated to neighborhood benefits, including transportation demand management programs, transit pass subsidies, and local carsharing programs.
- Reduce or eliminate minimum parking requirements, and require parking unbundling (parking spaces are rented separately from building space, particularly for an apartment's second parking space) for new development in suitable locations.
- Encourage or require parking cash-out for new development and city employees (if parking is subsidized, employees can receive its cash equivalent if they do not drive).
- Establish funding for transit network improvement projects, and support efforts to establish a Bus Rapid Transit route.

Boulder, Colorado is a small city that has implemented a combination of transportation demand management strategies including improved walking, cycling and public transit services, campus transport management programs, and incentives to use these modes instead of driving when possible. Between 1995 and 2004 the drive-alone rate for downtown declined almost 36%, from 56% driving alone to 36%, while the transit mode share has more than doubled from 15% to 34%.

Vancouver, Canada's transportation plan is based on these principles (Brown 2012):

- Accommodate travel demand growth using the existing road network, by improving alternatives to the car: transit, walking and cycling. Support regional measures to manage travel demand, such as carpooling, parking limits, bridge tolls and electronic road charges.
- Accommodate automobile travel, particularly in areas not well served by transit.
- Maintain good truck access, and improve freight access where it can be achieved without unreasonable impacts on local neighborhoods.
- Support traffic calming to reduce traffic speeds and prevent neighbourhood short-cutting.
- Support local retailing, personal, business and community services so that residents can find more of the services and jobs they need closer to home.

Based on these principles, the plan identified 70 major transport improvement initiatives, and set mode share targets for walking, transit, biking, and automobile travel. The city increased downtown housing supply through its "living-first strategy." Walking and cycling mode shares increased, now representing more than a third of all downtown trips, and automobile trips declined. From 1996 to 2011, regional population grew 18% and employment 16%, but total vehicle trips to and within the city declined about 5%.

More than 150 cities have implemented Bus Rapid Transit (BRT) systems which provide convenient, fast, comfortable and affordable urban bus services that attract discretionary travelers (*BRT Global Database*). For example, Bogotá, Columbia's TransMilenio system has 1,500 buses on dedicated bus lanes, plus 410 feeder buses. Seventy-five percent of Bogota residents rate the system as good or very good. The city has also developed an extensive pedestrian and bicycle path network, and many TransMilenio stations have large bicycle parking facilities.

Since congestion pricing was introduced in central London in 2003, vehicle trips into the congestion pricing zone have declined by 17%, and congestion, measured as person-hours of delay per mile traveled, has fallen by 26%.

In 2002, Seoul, South Korea implemented various transport innovations including removal of a major downtown highway, development of a BRT system with more than 5,000 high-quality buses operating on 107 km of busways, and pedestrian and cycling improvements, plus a traffic control center which monitors traffic and parking problems on major arterials. This has greatly reduced congestion delay and accident risk.

The Marin County, California Safe Routes to School Program works to promote walking and biking to school. Using a multipronged approach, the program identifies and creates safe routes to schools and encourages community-wide involvement. By its second year, the program was serving 4,665 students in 15 schools. Participating public schools reported increases in walking trips (64%), biking trips (114%), and carpooling trips (91%), and a 39% decrease in trips by private vehicles carrying only one student.

In 1993, Kunming, China established its *Public Transport Masterplan* which gives priority to walking, cycling and public transport over private automobiles. The first bus lane opened in 1999, followed by a second in 2002, plus pedestrian and cycling improvements, and smart growth policies that focus new development around railway stations. Resident satisfaction increased from 79% in 1999 to 96% in 2001.

In 1975, Singapore first implemented an Area Licensing Scheme (ALS) which required motorists to purchase a paper license before entering the central area. In 1998 this was replaced by an automated Electronic Road Pricing (ERP) system which uses congestion pricing to maintain optimal traffic speeds of 45 to 65 km/h on expressways and 20 to 30 km/h on arterial roads.

Many Asian cities have relatively few parking spaces, so motorists must often pay for using a parking space, and in some cities motorists must show that they have an off-street parking space before they are allowed to register a vehicle (Barter 2010). This tends to reduce vehicle ownership and traffic, and encourages use of space-efficient modes.

## Conclusions

Traffic congestion increases user costs and causes frustration. How congestion is evaluated – the methods used to calculate congestion costs and the benefits of potential congestion reduction strategies – can significantly affect planning decisions. Congestion is a moderate cost overall, larger than some but smaller than others, so it is important to consider all impacts when evaluating potential congestion reduction strategies. It would not generally be efficient to implement a strategy that significantly increases other transportation costs, such as vehicle costs or accidents, but a strategy may be far more beneficial overall if it helps achieve other planning objectives.

Traffic congestion tends to maintain equilibrium: it increases to the point that congestion delays discourage some potential peak-period vehicle trips. As a result, traffic congestion seldom becomes as severe as predicted by extrapolating past growth trends, and urban roadway expansions seldom provide long-term congestion reductions because much of the additional capacity is eventually filled with latent demand. Long-term congestion reductions require changing the point of congestion equilibrium by improving alternative modes or more efficiently pricing road use.

Traffic congestion is an example of an external cost that road users impose on each other. As traffic volumes approach a roadway's capacity, each additional vehicle imposes large marginal costs. Travelers using space-efficient modes such as vanpools and buses impose much less congestion than travelers using space-intensive modes such as automobiles, and the costs of congestion vary widely from low for most personal travel, to very high for commercial and high-occupant vehicles, and for motorists on urgent errands. Basic economic principles can be used to help evaluate congestion reduction strategies: some strategies increase consumer welfare by improving travelers' mobility and accessibility options (for example, by improving public transit service quality, and housing options in more accessible locations), and some increase economic efficiency by favoring higher value trips and more efficient modes over lower-value trips and less efficient modes.

Experts recommend the following practices for comprehensive congestion evaluation.

- Evaluate transport system performance based on overall *accessibility* (people's overall ability to reach desired services and activities) rather than just *mobility* (vehicle travel).
- Measure per capita congestion *costs* rather than *intensity*. Congestion intensity indicators do not account for the amount residents drive during peak periods, and so undervalue strategies that improve transport options or reduce trip distances.
- Measure delays to *all travelers*, not just to *motorists*. Account for the travel time savings to transit passengers from bus lanes and priority systems, and for delays to pedestrians and cyclists caused by wider roads and increased vehicle traffic (called the *barrier effect*).
- Calculate the marginal congestion costs *imposed* by road users, rather than just the costs they bear. Use marginal congestion costing when calculating efficient road pricing and when comparing the congestion costs of different modes, and therefore the potential congestion cost savings of mode shifts.
- Use *efficiency-optimizing* baseline speeds (LOS C), rather than *freeflow* speeds. Freeflow speeds reduce roadway capacity, making them expensive to maintain at all times. Efficiency-optimizing speeds maximize roadway capacity and fuel economy, and so are more realistic.

- Use *travel time values* that reflect users' actual willingness-to-pay for incremental speed gains. For value priced lanes (lanes available for a fee) use consumer surplus analysis. For general travel time savings, willingness-to-pay is typically 30-50% of average wages for personal travel, and wages, benefits and equipment costs for commercial travel.
- Recognize *variations in travel time values*, and therefore the efficiency gains provided by policies that favor higher value trips over lower-value trips. Accounting for this impact tends to increase the value of priced, freight and high-occupant vehicle priority strategies.
- Use accurate *fuel efficiency* functions. Vehicle fuel efficiency generally peaks at about 50 miles per hour so reducing high congestion (LOS D-F) tends to conserve fuel, but reducing moderate congestion (LOS C) often increases fuel consumption and emissions, particularly if it induces additional vehicle travel.
- Recognize that congestion tends to *maintain self-limiting equilibrium*: it increases to the point that delays limit further peak-period vehicle travel. As a result, traffic volumes and congestion costs seldom increase as much as predicted by extrapolating past trends.
- Account for *generated and induced vehicle travel* when evaluating roadway capacity expansions. Induced travel tends to reduce predicted congestion reduction benefits, provides marginal consumer benefits, and increases external costs.
- Account for increased *crash costs* that result if congestion reductions lead to high traffic speeds.
- Account for *co-benefits* when evaluating potential congestion reduction strategies. In addition to reducing congestion some strategies also reduce parking costs, provide consumer savings and affordability, improve non-drivers' accessibility, increase safety and health, reduce pollution emissions, and support strategic land use objectives.
- Evaluate impacts on *specific corridors*. Although space-efficient modes, such as public transit, may serve a small portion of total regional travel, their mode share is often much higher on major urban corridors, so they can provide significant congestion reductions.
- Discuss potential sources of bias and variability, and apply sensitivity analysis to test alternative assumptions.

Failing to apply these practices tends to exaggerate congestion costs and roadway expansion benefits, and undervalues alternative congestion reduction strategies such as improvements to space-efficient modes, pricing reforms, smart growth policies, and transportation demand management programs. More comprehensive and multi-modal analysis can help identify truly optimal congestion reduction strategies. Many of these are *win-win* solutions: congestion reduction strategies that help achieve other important planning objectives. They are not necessarily the most cost effective strategy considering congestion reductions alone, but are best overall when all impacts are considered.

Many urban regions are implementing some innovative congestion reduction strategies, but few are implementing all that are economically justified. Recent experience indicates that vehicle travel is relatively price sensitive, particularly if travelers have good mobility options, which reduces the feasibility of financing urban roadway expansions with tolls but increases the effectiveness and benefits of transportation pricing reforms. The most effective congestion reduction programs usually include an integrated combination of improvements to space-efficient modes, pricing reforms, smart growth policies, and TDM programs.

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