5.5 Congestion

This chapter examines traffic congestion costs, that is, delay and increased risk due to interference between road users. It describes how congestion is measured, factors that affect congestion, various estimates of congestion costs, and the benefits of congestion reductions.

5.5.1 Chapter Index

5.5.2 Definition

Traffic Congestion Costs consist of incremental delay, driver stress, vehicle costs, crash risk and pollution resulting from interference between vehicles in the traffic stream, particularly as a road system approaches its capacity,[1] or as defined by Pisarski (2006), congestion is "People with the economic means to act on their social and economic interests getting in the way of other people with the means to act on theirs." This chapter focuses on *external* costs a vehicle imposes on other motorists and transit riders, since the *internal* costs borne by a motorist are included in Vehicle Cost, Travel Time, and Crash Cost chapters. The Barrier Effect chapter discusses delays motor vehicle traffic impose on nonmotorized travel.

[1] Timothy Hau (1992). *Economic Fundamentals of Road Pricing*, Working Paper, World Bank (www.worldbank.org); at www.econ.hku.hk/~timhau/download.html.

5.5.3 Discussion

Traffic congestion is a widely recognized transportation cost. Several methods can be used to quantify and monetize this cost, which can provide different results.

Terms and Concepts

- *Traffic Congestion* consists of the incremental delay resulting from interference between vehicles in the traffic stream.
- Traffic congestion can be *recurrent* (occurring regularly on a daily, weekly or annual cycle, making it easier to manage) or *non-recurrent* (due to accidents, special events or road closures).
- *Capacity* refers to the number of people or vehicles that could be accommodated. *Load factor* refers to the portion of capacity that is actually used. For example, a load factor of 0.85 indicates that 85% of the maximum capacity is actually occupied.
- *Design vehicle* refers to the largest and heaviest vehicle a roadway is designed to accommodate.
- *Passenger Car Equivalents* (PCE) indicate the traffic impacts of larger vehicles compared with a typical car.
- A *queue* is a line of waiting vehicles (for example, at an intersection).
- A *platoon* is group of vehicles moving together (such as after traffic signals turn green).

Congestion intensity at a particular location is evaluated using *level-of-service* (LOS) ratings, a grade from *A* (best) to *F* (worst), based on the *volume-to-capacity ratio* (V/C) ratio. A V/C less than 0.85 is considered *under-capacity*, 0.85 to 0.95 is considered *near capacity*, 0.95 to 1.0 is considered *at capacity*, and over 1.0 is considered *over-capacity*. Roadway capacity depends on various design factors such as lane width and intersection configuration.[2] Table 5.5.3-1 indicates units commonly used to measure traffic, which are usually measured during *peak hours*. Speed are generally based on the *85th percentile* (the speed below which 85% of vehicles travel). Traffic volume is sometimes measured as *Annual Average Daily Traffic* (AADT), indicating volumes averaged over a year.

Table 5.5.3-1 **Parameters Used to Measure Traffic**

Parameter	Typical Units	Reciprocal	Typical Units
Flow	Vehicles per hour (Veh/h)	Headway	Seconds per vehicle (s/veh)
Speed	Kilometers per hour (Km/h)	Travel time	Seconds per km (s/km)
Density	Vehicles per lane-km (veh/lane-km)	Spacing	Meters per vehicle (m/veh)

This table summarizes units commonly used to measure vehicle traffic.

Tables 5.5.3-2 through 5.5.3-4 show typical highway and intersection Level-of-Service ratings and maximum volumes, assuming ideal conditions. Many factors can decrease this optimal performance. Urban street traffic speed and flow are determined primarily by intersection capacity which is affected by cross streets and turning volumes.

[2] AASHTO (1990), *A Policy on Geometric Design of Highways and Streets*, AASHTO (www.aashto.org).

Table 5.5.3-2 **Typical Highway Level-Of-Service (LOS) Ratings**[3]

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 impingement of maneuverability. Two motorists might be forced to drive side by side, limiting lane changes.	57-60	700-1,100	12-20
C	Ability to pass or change lanes is not assured. Most experienced drivers are comfortable and posted speed maintained but roads are close to capacity. This is the target LOS for most urban highways.	54-57	1,100-1,550	20-30
D	Speeds are somewhat reduced, motorists are hemmed in by other vehicles. Typical urban peak-period highway conditions.	46-54	1,550-1,850	30-42
E	Flow becomes irregular, speed vary and rarely reach the posted limit. This is considered a system failure.	30-46	1,850-2,000	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.

Congestion is a non-linear function: on congested roads a small reduction in traffic volumes can provide a relatively large reduction in delays. For example, Tables 5.5.3-3 and 5.5.3-4 indicate that reducing traffic volumes from 2,000 to 1,800 vehicles per hour (a 10% reduction) shifts a roadway from LOS E to LOS D, increasing traffic speeds by about 15 mph, a 30% increase. This indicates that a 5-10% reduction in traffic volumes on a congested highway typically causes a 10-30% reduction in delay.

Table 5.5.3-3 **Typical Intersection Level-Of-Service (LOS) Ratings**[3]

Level-Of-Service	Signalized Intersection	Unsignalized Intersection
A	≤10 sec	≤10 sec
B	10-20 sec	10-15 sec
C	20-35 sec	15-25 sec
D	35-55 sec	25-35 sec
E	55-80 sec	35-50 sec
F	≥80 sec	≥50 sec

This table summarizes intersection Level of Service (LOS) ratings.

Table 5.5.3-4 **Maximum Service Volumes** (Passenger Cars Per Hour Per Lane)[4]

	LOS A	LOS B	LOS C	LOS D	LOS E
4-lane Freeway	700	1,100	1,550	1,850	2,000
2-lane Highway	210	375	600	900	1,400
4-lane Highway	720	1,200	1,650	1,940	2,200

This table shows maximum traffic volume for various roadway types at various congestion levels.

[3] "Level of Service," *Wikipedia*, http://en.wikipedia.org/wiki/Level_of_service; Homburger, Kell and Perkins (1992), *Fundamentals of Traffic Engineering, 13th Edition*, ITS, UBC (www.its.berkeley.edu).
[4] Homburger, Kell and Perkins (1992), p. 8-3.

Specific factors that affect traffic capacity and congestion impacts are discussed below.

Vehicle Size

Larger and heavier vehicles cause more congestion than smaller, lighter vehicles because they require more road space and are slower to accelerate. The relative congestion impact of different vehicles is measured in terms of *Passenger Car Equivalents* or PCEs. Large trucks and buses tend to have 1.5-2.5 PCEs, depending on roadway conditions, as shown in Table 5.5.3-5, and even more through intersections, under stop-and-go driving conditions, or on steep inclines. Transit buses have 4.4 PCEs, when operating on city streets without bus bays where they must stop regularly at the curb for passengers.[5] A large SUV imposes 1.4 PCEs, and a van 1.3 PCEs, when traveling through intersections.[6]

Table 5.5.3-5 **Passenger Car Equivalents** (PCEs)[7]

	Traffic Flow	Level	Rolling	Mountainous
Two-Lane Highways	**PC/lane/hr**			
Trucks & Buses	0-300	1.7	2.5	N/A
Trucks & Buses	300-600	1.2	1.9	N/A
Trucks & Buses	> 600	1.1	1.5	N/A
Recreational Vehicles	0-300	1.0	1.1	N/A
Recreational Vehicles	300-600	1.0	1.1	N/A
Recreational Vehicles	> 600	1.0	1.1	N/A
Multi-Lane Highways	**PC/lane/hr**			
Trucks & Buses	Any	1.5	2.5	4.5
Recreational Vehicles	Any	1.2	2.0	4.0

PC=passenger cars

Vehicle Speed

Congestion costs per vehicle-mile increase with speed because faster vehicles require more "shy distance" between them and other objects. Traffic flow (the number of vehicles that can travel on a road over a particular time period) tends to be maximized at 30-55 mph on roads without intersections, and at lower speeds on roads with intersections. *Traffic incidents* (disabled vehicles and accidents) account for an estimated 60% of delay.[8] Although random events, they only cause significant delays where traffic volumes approach road capacity, and so are considered congestion costs. In uncongested conditions an incident causes little or no traffic delay, but a stalled car on the shoulder of a congested road can cause 100-200 vehicle hours of delay on adjacent lanes.

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5 TRB (1985) *Highway Capacity Manual*, Transportation Research Board (www.trb.org).

6 Raheel Shabih and Kara M. Kockelman (1999), *Effect of Vehicle Type on the Capacity of Signalized Intersections: The Case of Light-Duty Trucks*, UT Austin (www.ce.utexas.edu); at www.ce.utexas.edu/prof/kockelman/public_html/ASCELDTShabih.pdf

7 TRB (2000), *Highway Capacity Manual*, TRB (www.trb.org), exhibits 20-9 and 21-8.

8 G. Giuliano (1989), "Incident Characteristics, Frequency, and Duration on a High Volume Urban Freeway," *Transportation Research A* (www.elsevier.com), Vol. 23, 1989, pp. 387-396.

Calculating Congestion Costs and Congestion Reduction Benefits

Various methods are used to quantify congestion costs.[9] The most appropriate approach for many applications, although difficult to perform, is to calculate the marginal delay caused by an additional vehicle entering the traffic stream, taking into account the speed-flow relationship of each road segment.[10] Another approach is to determine the user fee needed to reduce demand to design capacity, based on travelers' willingness-to-pay for road use. A third approach is to calculate unit costs of current expenditures on congestion reduction projects. In theory these three methods should produce similar values, assuming that roadway capacity is expanded based on vehicle delay costs as reflected in vehicle users' willingness to pay, but in practice they often provide different results.[11] In addition, necessary data is often limited, making accurate congestion costing difficult.

The Travel Rate Index

The *Travel Rate Index* (TRI) calculates the additional travel time over free-flowing conditions caused by congestion. It involves the following steps.[12]

1. Estimate peak period vehicle mileage.
2. Assign each road segment to the five congestion levels summarized below.

Table 5.5.3-6 **Roadway Congestion Categories**

	Extreme	Severe	Heavy	Moderate	Freeflow
Highway					
Avg. Daily Traffic Per Lane	>25,000	20,001-25,000	17,501-20,000	15,001-17,500	< 15,000
Avg. Vehicle Speed (mph)	32	35	38	45	60
Arterial					
Avg. Daily Traffic Per Lane	> 10,000	8,501-10,000	7,001-8,500	5,001-7,000	< 5,500
Avg. Vehicle Speed (mph)	21	23	27	30	35

3. Calculate vehicle travel delay, based on the difference between average and freeflow traffic speeds on each segment, times vehicle mileage on that segment.
4. Calculate average passenger-speed for each road section based on vehicle occupancy.

The results indicate the ratio of peak to free-flow travel speeds. For example, a 1.3 TRI indicates that trips which take 20 minutes during off-peak periods take 26 minutes during peak periods. This is used to calculate indicators such as *annual hours of delay* and *portion of travel under congested conditions*. This delay can be monetized based on the vehicles, people and goods delayed, the increased travel time unit costs due to the additional stress and unreliability of driving in congestion (see the "Travel Time Costs"

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[9] Miller and Li (1994), *Investigation of the Costs of Roadway Traffic Congestion*, California PATH, 1994; David Schrank and Tim Lomax (1999), *Mobility Measures*, TTI (http://mobility.tamu.edu); Francois Schneider, Axel Nordmann and Friedrich Hinterberger (2002), "Road Traffic Congestion: The Extent of the Problem," *World Transport Policy & Practice*, Vol. 8, No. 1 (http://ecoplan.org/wtpp), pp. 34-41.
[10] Anthony Downs (1992), *Stuck in Traffic*, Brookings Institute (www.brookings.edu).
[11] Terry Moore and Paul Thorsnes (1993), *The Transportation/Land Use Connection*, Report 448/449 American Planning Association (www.planning.org).
[12] David Schrank and Tim Lomax (2000), *Urban Mobility Study*, TTI (http://mobility.tamu.edu/ums).

chapter of this report), the additional fuel consumed and pollution emitted, and additional crashes, since congestion tends to increase crash frequency, although this may be offset by the reduction in crash severity, due to lower speeds, so total crash costs do not necessarily increase (see the "Safety and Health Impacts" chapter of this report).

The Travel Rate Index only reflects recurring congestion (congestion resulting from traffic volumes that approach or exceed roadway capacity). A significant portion of congestion is caused by incident delays (e.g., traffic crashes and special events). The *Travel Time Index* (TTI) is similar to the Travel Rate Index but also includes these non-recurring delays and so can be considered a more comprehensive congestion indicator.

Travel conditions and congestion delays can now be measured using the *Smart Dust Network*, which uses billions of discrete reports from GPS-enabled probe vehicles that provide traffic speed data for specific times and locations.[13] This information is used to calculate Travel Time Indices and Bottleneck factors (the number of congested hours for a particular intersection or link) for major U.S. urban highways, and regional road system conditions are averaged to calculate a Metropolitan Travel Time Index.

Criticisms of Congestion Costing Methods

The Travel Rate Index and Travel Time Index costing methods use free-flow travel speeds as a reference because it is easy to understand and calculate. However, free-flow conditions are an unrealistic goal for urban transport systems, and so overestimates congestion costs compared with what is economically efficient. As described by one leading transport economist,[14]

> 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 all 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. Such huge, but non-achievable, benefits inflate the currency of debate and distract attention from the value for money of real policies. However, among the many estimates there were a few which take an entirely different approach. In these, the idea of a totally congestion-free target is ignored, and emphasis is put on the *change* in congestion that would be realistically achievable as a result of implementing specific more or less ambitious transport policies, such as road building, public transport improvements, and transport prices. The most useful applications of this approach have been developed in connection with congestion charging. The figures are of course typically smaller than the unrealistic estimates produced by comparing against zero congestion, though typically much larger than the benefits which are produced, in urban conditions, by road construction projects. They are also much easier to interpret and much more relevant for real policy purposes. Thus it would be better to shift the focus from the '*total* economic cost of congestion' to 'the economic value of the savings in congestion that could be achieved with congestion charging'.

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[13] INRIX (2008), *National Traffic Scorecard*, INRIX (http://scorecard.inrix.com/scorecard).

[14] Phil Goodwin (2003), *The Economic Cost of Congestion when Road Capacity is Constrained*, 6th International Symposium on Theory and Practice in Transport Economics (www.internationaltransportforum.org).

Another researcher states,[15]

> We can no longer simply evaluate the effects of road widening projects on vehicles using limited, aggregate measures such as traffic counts, VKT, the volume/capacity ratio and LOS, nor is it helpful to apply arbitrary speed or volume thresholds across all facility types. These limited measures are usually derived from simple, limited data (e.g., average volumes, number of lanes) extrapolated over large segments of the network and do not consider the impacts on different types of users. The current poor measurements may also be clouding our thinking and leading to irrational policy actions. These factors limit the specificity of performance reporting to large areas and generalized effects. Given new developments that allow for more robust data collection and demands for reporting actual system performance, we can no longer rely on the old way of system performance measurement.

Congestion Costs Tend to Increase With Wealth
Traffic congestion problems tend to increase with wealth because consumers purchase more vehicles, which greatly increases the amount of space needed for travel (a car trip typically requires an order of magnitude more space than the same trip made by walking, cycling or transit). Although increased wealth allows greater facility construction expenditures, the supply of land does not increase. Road and parking facilities must compete for land that is increasingly expensive due to competition for other uses, so land costs become an increasing portion of project costs and a limiting factor in roadway and parking capacity expansion. Although sprawl may seem to overcome this problem by shifting travel to the urban fringe where land costs are lower, dispersed development increases per-capita vehicle mileage, requiring more lane-miles and parking spaces per capita, so land costs continue to be a major constraint. As a result, congestion costs tend to increase and alternative modes and demand management tend to become more important with increased wealth.

15 Robert L. Bertini (2005), *You Are the Traffic Jam: An Examination of Congestion Measures*, Transportation Research Board Annual Meeting (www.trb.org); at www.its.pdx.edu/pdf/congestion_trb.pdf.

Congestion Indicators Compared

Different congestion indicators represent different perspectives and assumptions, which can favor certain solutions over others. For example, roadway *LOS* and the *Travel Time Index* only consider motorists' delays. *Percent Travel Time* declines if uncongested vehicle travel increases, for example, due to increased sprawl. These indicators ignore congestion cost reductions to travelers who shift modes (such as to grade-separated transit) and reduced travel distances, and so are unsuited for evaluating the congestion reduction benefits of alternative modes, mobility management strategies and smart growth policies. Indicators that reflect *per capita* rather than *per vehicle* impacts are more suitable for evaluating total congestion costs. Table 5.5.3-7 summarizes commonly used congestion indicators.

Table 5.5.3-7 **Roadway Congestion Indicators**

Indicator	Description	Comprehensive?
Roadway Level Of Service (LOS)	Intensity of congestion at a particular roadway or intersection, rated from A (uncongested) to F (most congested).	No
Travel Time Rate	Ratio of peak period to free-flow travel times, considering only recurring congestion delays.	No
Travel Time Index	The ratio of peak period to free-flow travel times, considering both recurring and incident delays (e.g., traffic crashes).	No
Percent Travel Time In Congestion	Portion of peak-period vehicle or person travel that occurs under congested conditions.	No if for vehicles, yes if for people.
Congested Road Miles	Portion of roadway miles congested during peak periods.	No
Congested Time	Estimate of how long congested "rush hour" conditions exist	No
Congested Lane Miles	The number of peak-period lane miles with congested travel.	No
Annual Hours Of Delay	Hours of extra travel time due to congestion.	No if for vehicles, yes if for people.
Annual Delay Per Capita	Hours of extra travel time divided by area population.	Yes
Annual Delay Per Road User	Extra travel time hours divided by peak period road users.	No
Excess Fuel Consumption	Total additional fuel consumption due to congestion.	Yes
Fuel Per Capita	Additional fuel consumption divided by area population	Yes
Annual Congestion Costs	Hours of extra travel time multiplied times additional monetized travel time and fuel costs.	Yes
Congestion Cost Per Capita	Additional travel time costs divided by area population	Yes
Congestion Burden Index (CBI)	Travel rate index multiplied by the proportion of commuters subject to congestion by driving to work.	Yes
Avg. Traffic Speed	Average peak-period vehicle travel speeds.	No
Avg. Commute Travel Time	Average commute trip time.	Yes for commuting
Avg. Per Capita Travel Time	Average total time devoted to travel.	Yes

This table summarizes various congestion cost indicators. Some only consider impacts on motorists and so are unsuited for evaluating congestion reduction benefits of mode shifts or more accessible land use.

Reliability

A U.S. Federal Highway Administration publication identifies various travel reliability indicators, which can be considered indicators of congestion:[16]

- The *90th or 95th percentile travel times*, which reflects the longest travel time during a ten or twenty day period. This is reported in minutes and seconds
- The *buffer index* reflects the extra time travelers must add to their travel schedule to ensure on-time arrival, computed as the difference between the 95th percentile and average travel times, divided by the average travel time. It is expressed as a percentage. For example, a 40% buffer index means that, for a trip that averages 20 minutes travelers should budget an additional 8 minutes (20 minutes × 40% = 8 minutes) to ensure on-time arrival. The extra minutes are called the *buffer time*.
- The *planning time index* reflects the total travel time required to provide an adequate buffer time, including both typical and unexpected delay. The planning time index compares near-worst case travel time to a travel time in light or free-flow traffic. For example, a planning time index of 1.60 means that a 20-minute trip in light traffic requires 32 minutes of total time planned (20 minutes × 1.60 = 32 minutes).
- The *frequency that congestion exceeds some threshold* reflects the degree to which congestion exceeds a performance standard. It is typically expressed as the percent of days or periods travel times exceed X minutes or travel speeds fall below Y mph. This is relatively easy to compute if continuous traffic data are available, and it is typically reported for weekdays during peak traffic periods.

Improved Techniques

Most roadway performance indicators such as Level-of-Service ratings primarily reflect traffic speed and delay, ignoring qualitative factors important to users, such as the number of modes and route options available, traffic mix (number of trucks and buses), speed differentials, number of stops, number of signals, lane widths, lane changing frequency, driveway frequency, presence of sidewalks and bike lanes (reducing conflicts with nonmotorized modes), traveler information quality, and aesthetic conditions.[17]

Alternative techniques have been proposed that better account for non-automobile transportation options. For example, a *Congestion Burden Index* (CBI) was proposed, which is defined as the travel rate index multiplied by the proportion of commuters who are subject to congestion by driving to work.[18] The 1999 Portland travel rate index was 1.36 (rank 8), and the transit share was 0.14, so the CBI was 1.36 x (1-0.143) = 1.16 (rank 14). Similarly, the *Transportation Choice Ratio* is calculated by dividing the hourly km of transit service per capita by the lane km of interstates, freeways, expressways and principal arterials for each metro area.

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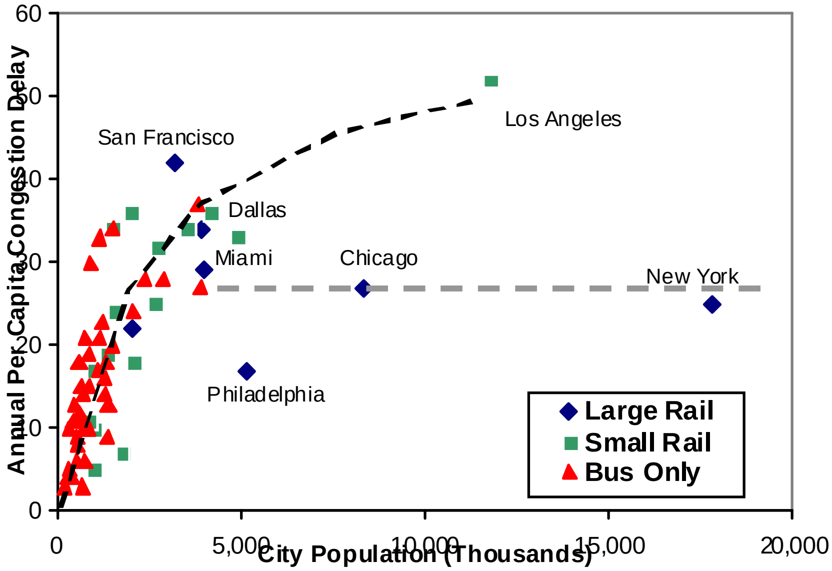
[16] FHWA (2006), *Travel Time Reliability: Making It There On Time, All The Time*, Federal Highway Administration (http://ops.fhwa.dot.gov); at http://ops.fhwa.dot.gov/publications/tt_reliability/index.htm
[17] Aimee Flannery, Douglas McLeod and Neil J. Pedersen (2006), "Customer-Based Measures of Level of Service," *ITE Journal*, Vol. 76, No. 5 (www.ite.org), May 2006, pp. 17-21.
[18] STPP (2001), *Easing the Burden: a Companion Analysis of the Texas Transportation Institute's Congestion Study*, Surface Transportation Policy Project (www.transact.org).

Congestion Indicators, Density & Transit

When measured in terms of roadway LOS or delay per vehicle trip, higher development densities tend to increase congestion, since more trips are generated per acre. From this perspective, infill development is harmful and sprawl is helpful for reducing congestion problems.[19] However, density tends to increase land use accessibility and transport diversity, resulting in shorter trip distances and shifts to other modes such as walking and transit. *Although streets in higher density urban areas may experience more LOS E or F, implying serious congestion problems by some measures, per capita congestion costs are actually lower because residents have better travel options and closer destinations.*

As a result, *per capita* (rather than *per-vehicle trip*) congestion delay tends to be greater in lower-density, automobile-dependent areas such as Los Angeles and Houston than in higher-density areas such as New York and San Francisco, because low-density areas have more per capita vehicle mileage.[20] Figure 5.5.3-1 compares per capita congestion delays in various U.S. cities with differing levels of transit service. Similarly, strategies such as HOV Priority and walking improvements may increase congestion when measured as roadway LOS but reduce it when measured as per capita congestion delay, by improving travel options and reducing per capita driving.

Figure 5.5.3-1 **Traffic Congestion**[21]



Cities with large, well-established rapid transit systems (indicated by large rail systems) tend to have less per capita traffic congestion than comparable size cities that lack such systems. This benefit is not reflected in roadway LOS or Travel Time Index ratings.

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[19] Brian D. Taylor (2002), "Rethinking Traffic Congestion", *Access*, Number 21, University of California Transportation Center (www.uctc.net), Fall 2002, p. 8-16.

[20] STPP (2001), *Easing the Burden: A Companion Analysis of the Texas Transportation Institute's Congestion Study*, Surface Transportation Policy Project (www.transact.org).

[21] Todd Litman (2004), *Critique of 'Great Rail Disasters'*, VTPI (www.vtpi.org).

Some congestion reduction strategies, such as HOV priority and transit improvements are most effective under congested conditions, when automobile traffic experiences the greatest delay. Such strategies do not eliminate congestion, since it is automobile traffic delays that make these alternatives relatively attractive, but they can significantly reduce congestion delays both to people who shift mode and those who continue driving. For example, they may improve a roadway from LOS E to LOS D, which is a significant improvement, but by themselves will never provide LOS B. Extreme congestion tends to impose high travel time costs (see Travel Time Cost chapter), which increases the justification for such strategies.

The economic value of congestion reduction strategies are difficult to evaluate because urban traffic tends to maintain equilibrium: traffic volumes grow until congestion delays discourage additional peak-period trips. Efforts to reduce congestion by increasing urban roadway capacity or convincing a few individuals to shift mode causes *generated traffic* (additional peak period traffic that would not otherwise occur), which over the long term fills a significant portion (50-90%) of the added capacity.[22]

This changes the nature of benefits that result: roadway expansion tend to provide only temporary congestion reductions, benefits consist largely of increased mobility and urban fringe property values, and reduced congestion during shoulder periods (just before or after peaks). It also means that increasing highway capacity can exacerbate problems such as downstream congestion, crashes, pollution and sprawl. On the other hand, strategies that reduce the point of equilibrium by raising the price of driving, improving travel alternatives, or reducing the need for travel can reduce congestion over longer periods of time, although they might never eliminate it. These strategies include HOV priority, transit and rideshare improvements, telecommunications that substitute for travel and land use changes, as indicated in Table 5.5.3-8.[23]

Table 5.5.3-8 **Effects of Generated Traffic on Congestion Reduction**

Affected by Generated Traffic	Not Affected by Generated Traffic
Increased road capacity (new lanes, grade-separated intersections, etc). Traffic signal synchronization. Small, individual TDM programs that cause small mode shifts. Transit without transit priority measures.	Congestion pricing. HOV and transit priority and grade-separated service. Large, comprehensive TDM programs that cause significant mode shifts. Improved travel alternative and mobility substitutes. More accessible land use.

Some congestion reduction strategies generate traffic (additional peak period vehicle traffic that would not otherwise occur), which reduces their congestion reduction benefits. Other strategies generate little or no traffic and so provide more congestion reduction benefits.

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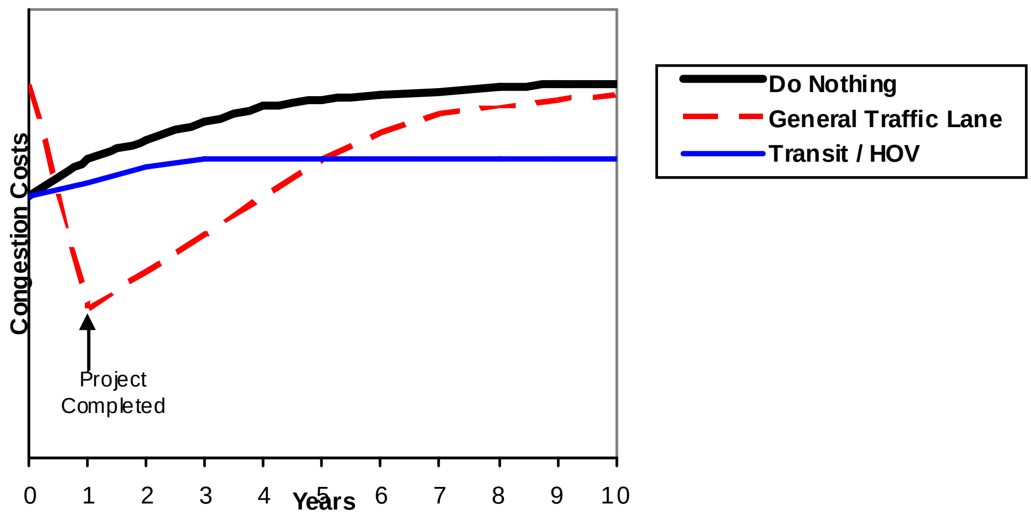
[22] Todd Litman (2001), "Generated Traffic; Implications for Transport Planning," *ITE Journal*, Vol. 71, No. 4, Institute of Transport. Engineers (www.ite.org), April 2001, pp. 38-47; at www.vtpi.org/gentraf.pdf

[23] Todd Litman (2002), *Evaluating Public Transit Benefits and Costs*, VTPI (www.vtpi.org); at www.vtpi.org/tranben.pdf

The analysis time frame affects congestion reduction evaluation. Shorter-term analysis tends to favor roadway expansion while longer-term analysis tends to favor transit and HOV improvements, as illustrated in Figure 5.5.3-2. With no intervention congestion achieves equilibrium because delays discourage further peak-period vehicle trips. Adding general traffic lanes reduces congestion in the short term but traffic volumes grow over time until it reaches the same equilibrium. Transit improvements, such as grade separated rail or HOV lanes, provide little short-term congestion reduction, but benefits increase over time as delays on parallel highways make alternative modes increasingly attractive. Although congestion continues, it never becomes as bad as would otherwise occur.

Figure 5.5.3- 2 **Road Widening and Transit/HOV Improvement Congestion Impacts**



Adding general traffic lanes increases congestion during the construction period and reduces it on completion, but generated traffic fills much of the added capacity within a few years, reducing long-term congestion reduction benefits. Grade separated transit or HOV facilities provide modest short-term congestion reductions but these benefits increase over time as transit and ridesharing become relatively attractive to peak-period travelers.

Optimal Congestion Fees

Congestion pricing (also called *value pricing*) is intended to reduce traffic volumes to optimal levels on each roadway, which typically means LOS C, or about 1,500 vehicles-per-hour on grade-separated highways and 800 vehicles-per-hour on urban arterials. The magnitude of fees needed to achieve this depends on many factors, including total travel demand on the corridor and the quality of travel options (such as alternative roads, and grade-separated transit services and HOV lanes), and varies significantly over time, from zero during off-peak periods to more than 20¢ per vehicle-mile on major congested corridors. Fees should reflect the congestion impacts each vehicle imposes on other road users, with higher fees for larger and slower accelerating vehicles. However, fees can also be set using pragmatic objectives such as reducing automobile traffic enough to allow a lane to be re-allocated for transit. Note that there is no reason that total congestion fees should equal the total estimated congestion costs described below.

Internal or External Cost?

Traffic congestion is an example of a cost that is external to individual motorists but largely internal to motorists as a group: each vehicle user both imposes and bears this cost. As a result, some analysts consider congestion an internal impact, at least for equity analysis.[24] However, for most planning, evaluation and pricing applications congestion should be treated as an external cost, for the following reasons:

- The incremental congestion delay an individual traveler imposes when making an urban-peak vehicle trip is often much greater than the incremental cost they bear. This violates the principle that prices (consumers' internal costs, in this case including both financial and time costs) should reflect the marginal costs they impose.[25] As a result, congestion is economically inefficient. As Poldy states,

  > "While it is true that road users bear congestion costs collectively, they make their decisions to travel individually. For each individual, a decision to travel requires only that the benefits exceed the delay costs that each traveller would expect to face on the congested road network...By deciding to join the congested traffic flow, the marginal traveller adds to the congestion, and causes a small increase in the delay experienced by each of the other users. The sum (over all road users) of these additional delays can be very much greater than the average delay (experienced by each individual) which formed the basis of the decision to travel. It is because cost bearing and decision making are separated that these costs are appropriately considered external."[26]

- Congestion is inequitable because the costs imposed and borne vary significantly between modes. Congestion costs imposed per passenger-mile are lower for bus and rideshare passengers, but they bear the same congestion delay costs as single occupant drivers (except on HOV and transit priority facilities). This is unfair and inefficient because travelers have no incentive to choose space efficient modes.

- Congestion is also an externality because it delays nonmotorized travel (discussed in Chapter 5.13), and increases pollution emissions. The external nature of congestion costs is also indicated by the considerable resources society spends to increase road capacity, only part of which are paid by automobile user fees (as discussed in Chapter 5.6).

For these reasons, even non-drivers are negatively impacted by traffic congestion, and can benefit from reduced congestion.

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24 Mark Hanson (1992), "Automobile Subsidies and Land Use," *APA Journal*, Winter 1992, pp. 60, 68; Per Kågeson (1993), *Getting the Prices Right*, European Federation for Transport and Environment (www.transportenvironment.org).

25 VTPI (2002), "Market Principles," *Online TDM Encyclopedia*, VTPI, (www.vtpi.org); at www.vtpi.org/tdm/tdm60.htm

26 EPA Victoria (1994), "The Costing and Costs of Transport Externalities: A Review," *Victorian Transport Externalities Study*, Vol. 1, Environment Protection Authority, Victoria (www.epa.vic.gov.au).

5.5.4 Estimates

Note: all monetary units in U.S. dollars unless indicated otherwise.

Summary Table of Congestion Cost Estimates

Table 5.5.4-1 **Congestion Cost Estimate Summary Table – Selected Studies**

Publication	Costs	Cost Value	2007 USD
Delucchi (1997)	Total US in 1991	$34-146 billion (1991)	$52-222 billion
	Per urban peak mile	$0.07-0.32	$0.11-0.49/mile
Lee (2006)	U.S. traffic congestion delay costs, relative to free flowing traffic	$108 billion (2002)	$124 billion
	Delay costs based on willingness to pay	$12 billion	$14 billion
TRB (1994)	Congested urban roads per vehicle mile	average of $0.10 to 0.15*	$0.14-0.21/mile
Texas Transportation Institute (2007)	Total USA in 2005	$78.2 billion (2005)	$83 billion
Winston and Langer (2004)	Total US congestion costs	$37.5 billion (2004)	$41 billion
Land Transport New Zealand (2005).	Benefits of TDM mode shift per Km	$1.27 - Auckland, $0.98 - Wellington, $0.09 - Cristchurch (NZ$ 2002 / Km.)	$1.09 / mile $0.84 $0.08
FHWA (1997)	Urban Highway Car	$0.062 / VMT*	$0.08 / mile
	Bus	$0.128	$0.17
M. Maibach, et al (2008)	Urban collectors in European centres over 2 million - Car	0.5 €/vkm 2000	$0.89 / mile
	Truck	1.25 €	$2.23

*This table summarizes key congestion cost studies. These estimates range widely since they have been produced using different methods for different purposes. More detailed descriptions of these studies are found below. Values are converted to 2007 U.S. dollars using the Consumer Price Index[27]. * Indicates the currency year is assumed to be the same as the publication year.*

General Estimates

- Bilbao-Ubillos proposes a methodology for quantifying congestion costs, including hours of passenger delay, additional fuel consuymption, reduced business accessibility, accident costs and noise pollution.[28]

- Delucchi estimates U.S. congestion external costs, including delay and increased fuel consumption, totaled $34-146 billion in 1991 ($52-222 billion in 2007 dollars), which averages 7-32¢ per urban-peak vehicle-mile (11-49¢ in 2007 dollars).[29]

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[27] Note that CPI is not the only way to adjust for inflation and results can vary significantly with different methods, see: Samuel H. Williamson (2008), "Six Ways to Compute the Relative Value of a U.S. Dollar Amount, 1790 to Present," MeasuringWorth (www.measuringworth.com).

[28] Javier Bilbao-Ubillos (2008), "The Costs of Urban Congestion: Estimation of Welfare Losses Arising From Congestion On Cross-Town Link Roads," *Transportation Research A*, Vol. 42, pp. 1098-1108.

- Grant-Muller and Laird (2007) provide a variety of estimates for congestion in the UK along with discussion of the possibility of decoupleing growth in transportation demand and resulting congestion from economic growth[30].

- A study for the Chicago Metropolitan Planning Council estimates that regional congestion costs total $7.3 billion annually, ranging from $824 to $3,014 per automobile commuter.[31] The analysis applied a value of $14.75 per hour of delay to automobile users and $66.83 per hour of truck delay for driver time and cargo. It estimated the reduction in regional employment caused by congestion by assuming half of the additional commuting costs are passed on to employers, and the elasticity of labor demand at the metropolitan area level, with a sensitivity of labor demand to changes in labor cost of 1.35, resulting in an estimated loss of 87,000 jobs.

- Vehicle fuel consumption increases approximately 30% under heavily congestion.[32] Increased fuel consumption and air pollution costs represent about 17% the total external cost of congestion.[33]

- Table 5.5.4-2 shows marginal congestion costs for various Australian cities.

Table 5.5.4-2 **Marginal External Congestion Costs** (Aus. Cents per Veh. Km)[34]

	Melbourne	Sydney	Brisbane	Adelaide	Perth
Freeways	14¢	13¢	14¢	0	14¢
CBD Streets	57¢	62¢	40¢	40¢	40¢
Inner Arterials	20¢	21¢	16¢	16¢	16¢
Outer Arterials	7¢	7¢	5¢	5¢	5¢

- The *Highway Economic Requirements System* developed by the U.S. Federal Highway Administration to evaluate highway improvement needs and benefits,

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29 Mark Delucchi (1997), *Annualized Social Cost of Motor-Vehicle Use in the U.S., 1990-1991*, University of California Institute of Transportation Studies, (www.engr.ucdavis.edu/~its), UCD-ITS-RR-96-3.

30 Susan Grant-Muller and James Laird (2007), *International Literature Review Of The Costs Of Road Traffic Congestion*, Scottish Executive (www.scotland.gov.uk); at www.scotland.gov.uk/Publications/2006/11/01103351/0.

31 HDR (2008), *Moving at the Speed of Congestion - The True Costs of Traffic in the Chicago Metropolitan Area*, Metropolitan Planning Council (www.metroplanning.org), at www.metroplanning.org/resource.asp?objectID=4476&keyword=figures+and+finding.

32 I.D. Greenwood and C.R. Bennett (1996), “The Effects of Traffic Congestion on Fuel Consumption,” *Road & Transport Research*, Vol. 5, No. 2, June 1996, pp. 18-31.

33 Olof Johansson (1997), “Optimal Road Pricing: Simultaneous Treatment of Time Losses, Increased Fuel Consumption, and Emissions,” *Transportation Research D*, Vol. 2, No. 2, June 1997, pp. 77-87.

34 BTCE (1996), *Traffic Congestion and Road User Charges in Australian Capital Cities*, Australian Gov. Publishing Service (Canberra), Table 5.1.

including detailed guidance on congestion cost analysis, monetization of congestion costs, and factors affecting congestion delay.[35]

- A Transport Canada study summarized in Table 5.5.4-3 calculated monetized costs of recurring and non-recurring congestion (including the value of excess delay, fuel use and greenhouse gas emissions) using various thresholds (traffic speeds relative to freeflow travel speeds) which represent the point at which congestion becomes apparent and is deemed unacceptable. The table below summarizes the results.

Table 5.5.4-3 **Congestion Costs In Various Canadian Cities** (2000 $m)[36]

Location	50%	60%	70%
Vancouver	$737	$927	$1,087
Edmonton	$96	$116	$135
Calgary	$185	$211	$222
Winnipeg	$121	$169	$216
Hamilton	$20	$33	$48
Toronto	$1,858	$2,474	$3,072
Ottawa-Gatineau	$100	$172	$246
Montréal	$1,179	$1,390	$1,580
Québec City	$73	$104	$138
Total	*$4,370*	*$5,596*	*$6,745*

- Keeler, et al's marginal congestion cost estimates for San Francisco area highways in the early 1970s are summarized in the table below, presented in 1994 dollars.

Table 5.5.4-4 **Marginal Highway Congestion Costs** (¢/mile)[37] (Travel time = $13.50)

	Interest	Peak	Near Peak	Day Avg.	Night Avg.	Weekend
Rural-Suburban	6%	8.1	3.3	1.8	1.2	0.3
	12%	15.6	4.5	2.4	1.5	0.3
Urban-Suburban	6%	9.9	3.6	2.1	1.5	0.3
	12%	21.0	4.8	2.4	1.5	0.3
Central City	6%	45.6	5.4	2.7	1.8	0.6
	12%	80.1	5.4	2.7	1.8	0.6

- Land Transport NZ's *Economic Evaluation Manual* provides guidelines for transportation project benefit analysis. Congestion reduction benefits of peak-period

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35 FHWA (2002), *Highway Economic Requirements System: Technical Report*, Federal Highway Administration, U.S. Department of Transportation (www.fhwa.dot.gov); at http://isddc.dot.gov/OLPFiles/FHWA/010945.pdf

36 iTrans (2006), *Costs of Non-Recurrent Congestion in Canada*, Transport Canada (www.tc.gc.ca); at www.tc.gc.ca/pol/en/Report/FullCostInvestigation/Road/tp14664/tp14664.pdf.

37 Theodore Keeler, et al. (1975), *The Full Costs of Urban Transport: Part III Automobile Costs and Final Intermodal Cost Comparisons*, Institute of Urban and Regional Dev. (http://iurd.berkeley.edu), p. 47.

shifts from automobile to another mode are valued at $1.27 per kilometer (NZ 2002) in Auckland, $0.98 in Wellington, and $0.09 in Cristchurch.[38]

- Professor Douglass Lee of the Volpe National Transportation Systems Center updating his previously published analysis ("Net Benefits from Efficient Highway User Charges," *Transportation Research Record 858*), estimates U.S. traffic congestion delay costs, relative to free flowing traffic, totaled about $108 billion in 2002, but the economic losses are a much smaller $12 billion, based on his estimate of what road users would willingly pay for increased traffic speed.[39]

- Levinson calculates that marginal peak period congestion costs for urban freeway average 6-9¢ when traffic flows faster than 50 mph, and 37¢ when traffic flows at less than 40 mph, based on *Highway Capacity Manual* speed-flow curves.[40]

- John McDonald emphasizes that congestion prices should reflect network congestion costs, not just costs on the road that is tolled.[41] He concludes that prices should be *higher* if a road is complementary to other congested roads (such as a tolled bridge or highway that adds traffic to congested surface streets), and *lower* if a road substitutes for other congested roads (such as a tolled highway with parallel untolled roads).

- Estimated marginal congestion costs in the U.K. are summarized in Table 5.5.4-5.[42]

Table 5.5.4-5 **Marginal External Costs of Congestion in the U.K.**

	1990 Pence Per Vehicle Km	1996 US$ Per Vehicle Mile
Motorway	0.26	$0.009
Urban Central Peak	36.37	$1.25
Urban Central Off Peak	29.23	$1.00
Non-central Peak	15.86	$0.55
Non-central Off Peak	8.74	$0.30
Small Town Peak	6.89	$0.034
Small Town Off Peak	4.2	$0.144
Other Urban	0.08	$0.003
Rural Dual Carriageway	0.07	$0.003
Other Trunk and Principal	0.19	$0.007
Other Rural	0.05	$0.002
Weighted Average	*3.4*	*$0.117*

[38] Land Transport New Zealand (2006 / 2005) *Economic Evaluation Manual (EEM) – volumes 1 & 2* (www.landtransport.govt.nz); at www.landtransport.govt.nz/funding/manuals.html
[39] Gabriel Roth (2006), *Street Smart: Competition, Entrepreneurship, and the Future of Roads*, Transaction Publishers (www.transactionpub.com).
[40] Herbert Levinson (1995), "Freeway Congestion Pricing: Another Look," *Transportation Research Record 1450*, (www.trb.org) pp. 8-12.
[41] John McDonald (1995), "Urban Highway Congestion; An Analysis of Second-best Tolls," *Transportation*, Vol. 22, 1995, pp. 353-369.
[42] David Morrison, et al. (1996), *True Costs of Road Transport*, Earthscan (www.earthscan.co.uk), p. 111.

- Mohring and Anderson estimate average congestion costs for Twin City roads shown in the table below.

***Table 5.5.4-6* Average Marginal Congestion Costs**[43]

	Morning Peak	Afternoon Peak
All Road Links	20.7¢	17.0¢
Expressways	23.6¢	20.1¢

- Transport Concepts estimates truck congestion costs at 62¢ per ton-mile for intercity semi-trailer trucks and 79¢ per ton-mile for B-Train trucks.[44]

- A Transportation Research Board special report indicates that optimal congestion prices (which are considered to represent congestion costs) ranging from about 5¢ to 36¢ per vehicle mile on congested urban roads, with averages of 10¢ to 15¢.[45]

- The Texas Transportation Institute has developed a congestion index, which is used to calculate congestion costs in major U.S. cities, the results of which are published in their annual *Urban Mobility Study*.[46] These costs are widely cited and used for comparing and evaluating urban congestion problems. The 2007 report estimates that congestion costs $78 billion in 2005 (2005 dollars) in the form of 4.2 billion lost hours and 2.9 billion gallons of wasted fuel.

- van Essen, et al, summarize various methods for calculating congestion costs and efficient congestion pricing, and provide typical values for various vehicles and traffic conditions.[47] Cost values range from zero (for off-peak travel) to more than one Euro per vehicle-kilometer under urban-peak conditions. Vermeulen, et al (2004) apply these methods and estimate that in European conditions, urban peak car travel imposes congestion costs as high as €0.46 per vehicle-km, and heavy vehicle travel imposes congestion costs averaging €0.91 per vehicle-km.[48]

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[43] Herbert Mohring and David Anderson (1994), *Congestion Pricing for the Twin Cities Metropolitan Area*, Dept. of Economics, University of Minnesota (www.econ.umn.edu), January 1994. Also see their (1996) "Congestion Costs and Congestion Pricing," in *Buying Time; Research and Policy Symposium on the Land Use and Equity Impacts of Congestion Pricing*, Humphrey Institute (Minneapolis; www.hhh.umn.edu).
[44] Transport Concepts (1994), *External Costs of Truck and Train*, Transport Concepts (Ottawa), p.23.
[45] TRB (1994), *Curbing Gridlock*, National Academy Press (www.trb.org), Appendix B.
[46] David Schrank and Tim Lomax (2007), *Urban Mobility Study,* Texas Transportation Institute (http://mobility.tamu.edu/ums/).
[47] van Essen, et al (2004), *Marginal Costs of Infrastructure Use – Towards a Simplified Approach*, CE Delft (www.ce.nl).
[48] Vermeulen, et al (2004), *The Price of Transport: Overview of the Social Costs of Transport*, CE Delft (www.ce.nl).

- Weisbrod, Vary and Treyz evaluate economic productivity congestion costs due to increased shipping costs, and reduced scale and agglomeration economies.[49] They estimate these costs range from $20 million to $1 billion annually in typical metropolitan regions. These costs are higher in industries that rely significantly on distribution systems or specialized employees. Applying this analysis framework using the Transportation Economic Development Impact System (TREDIS), the researchers find that traffic delays are a major hindrance to the Oregon state economy, projected to cost $1.7 billion and 16,000 jobs annually by 2025.[50]

- Wang, Feng and Liang estimate that on urban arterials in Chinese cities, bicycles impose 0.28 Passenger Car Equivalents overall, with values of 0.22 on separate paths and 0.33 when making left turns at mixed intersections.[51]

- Winston and Langer review congestion costing methods, and using their own model estimate that U.S. congestion costs total $37.5 billion annually (2004 dollars), a third of which consists of freight vehicle delays.[52] They find that highway spending is not a cost effective way of reducing congestion costs.

- Zupan estimates that each 1% increase in VMT in an U.S. urban region was associated with a 3.5% increase in congestion delays in that region during the 1980's, but this relationship disappeared during the 1990s.[53] This may reflect increased ability of travelers to avoid peak-period driving through flextime, telework and suburbanization, allowing VMT growth without comparable increases in congestion delay. The relationship between vehicle travel and congestion is probably stronger when evaluated at more disaggregated levels, such as on individual corridors or roads.

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[49] Glen Weisbrod, Donald Vary and George Treyz (2001), *Economic Implications of Congestion*, NCHRP Report 463, TRB (www.trb.org); at *http://gulliver.trb.org/publications/nchrp/nchrp_rpt_463-a.pdf*

[50] EDRG (2007), *The Cost of Highway Limitations and Traffic Delay to Oregon's Economy*, Oregon Business Council and Portland Business Alliance (www.orbusinesscouncil.org); at www.portofportland.com/PDFPOP/Trade_Trans_Studies_CostHwy_Lmtns.pdf

[51] Dianhai Wang, Tianjun Feng and Chunyan Liang (2008), "Research On Bicycle Conversion Factors," *Transportation Research A*, Vol. 42, pp. 1129-1139.

[52] Clifford Winston and Ashley Langer (2004), *The Effect of Government Highway Spending on Road Users' Congestion Costs*, Brookings Institute (www.brookings.edu).

[53] Jeffrey Zupan (2001), *Vehicle Miles Traveled in the United States: Do Recent Trends Signal More Fundamental Changes?*, Surdna Foundation (www.surdna.org).

Vehicle Type Comparisons

- The table below summarizes FHWA marginal highway congestion cost estimates for various vehicles.

Table 5.5.4-7 **Estimated Highway Congestion Costs** (Cents Per Vehicle Mile)[54]

	Rural Highways			Urban Highways			All Highways		
	High	Med.	Low	High	Med.	Low	High	Med.	Low
Automobile	3.76	1.28	0.34	18.27	6.21	1.64	13.17	4.48	1.19
Pickup & Van	3.80	1.29	0.34	17.78	6.04	1.60	11.75	4.00	1.06
Buses	6.96	2.37	0.63	37.59	12.78	3.38	24.79	8.43	2.23
Single Unit Trucks	7.43	2.53	0.67	42.65	14.50	3.84	26.81	9.11	2.41
Combination Trucks	10.87	3.70	0.98	49.34	16.78	4.44	25.81	8.78	2.32
All Vehicles	4.40	1.50	0.40	19.72	6.71	1.78	13.81	4.70	1.24

- M. Maibach, et al. *Handbook on Estimation of External Cost in the Transport Sector* provides a comprehensive overview of external costs estimation and internalization methods. The central values of congestion cost estimates are shown in the table below, minimum and maximum values are included in the source table.

Table 5.5.4-8 **Marginal social costs of congestion by road class** (€/vkm 2000)[55]

Area & Road Type	Passenger Cars	Goods Vehicles
Large urban areas (> 2,000,000)		
Urban motorways	0.50	1.75
Urban collectors	0.50	1.25
Local streets centre	2.00	4.00
Local streets cordon	0.75	1.50
Small and medium urban areas (< 2,000,000)		
Urban motorways	0.25	0.88
Urban collectors	0.30	0.75
Local streets cordon	0.30	0.60

- Table 5.5.4-9 summarizes congestion factors for bicycles. "Opposed" means that a bicycle encounters interference from other road users, such as when making a left turn. Bicyclists probably contribute relatively little congestion overall because they avoid high traffic roads.[56]

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[54] FHWA (1997), *1997 Federal Highway Cost Allocation Study*, USDOT (www.fhwa.dot.gov) Table V-23; at www.fhwa.dot.gov/policy/hcas/summary/index.htm

[55] M. Maibach, et al. (2008), *Handbook on Estimation of External Cost in the Transport Sector: Produced within the study Internalisation Measures and Policies for All external Cost of Transport (IMPACT)*, CE Delft (www.ce.nl), Table 7, p 34; at http://ec.europa.eu/transport/costs/handbook/doc/2008_01_15_handbook_external_cost_en.pdf

[56] Todd Litman (1994), "Bicycling and Transportation Demand Management," *Transportation Research Record 1441* (www.trb.org), pp. 134-140.

Table 5.5.4-9 **Passenger-Car Equivalents (PCEs) for Bicycles by Lane Width**[57]

Riding Condition	< 11 ft. Lane	11-14 ft. Lane	> 14 ft. Lane
Unopposed	1.0	0.2	0.0
Opposed	1.2	0.5	0.0

- Large SUVs impose about 1.41 PCEs (Passenger Car Equivalents) and vans 1.34 PCEs when traveling through an intersection, due to their slower acceleration and large size, which reduces traffic flow and increases traffic congestion problems.[58]

- Passenger Car Equivalents (PCEs) in developing country urban conditions (Bandung, Yogyakarta, Jakarta, and Semarang) are summarized below.[59]

Bicycle 0.19	Motorcycle 0.27
Trishaw 0.89	Medium vehicle 1.53
Heavy vehicle 2.33	Trailer 2.98

5.5.5 Variability

Congestion varies by location, time, and, to a lesser extent, vehicle type. Of particular note is the extreme variation between large metropolitan areas and smaller centers. This cost occurs primarily during Urban Peak travel.

5.5.6 Equity and Efficiency Issues

As described earlier, traffic congestion is an example of a cost that is external to individuals, but largely internal to road users as a group. To the degree that an individual bears the same amount of delay that they impose, it can be considered an equitable cost. It is inequitable when road users bear greater costs than they impose, for example, transit and rideshare passengers who are delayed in traffic the same as single occupant vehicle drivers. Since drivers tend to be wealthier than transit riders, low income people disproportionately bear congestion costs imposed by wealthier people when transit vehicles travel in general purpose lanes. Because it is an external cost at the individual level, traffic congestion is economically inefficient.

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[57] AASHTO (1990), *Policy on Geometric Design for Streets and Highways*, AASHTO (www.aashto.org).
[58] Kara M. Kockelman (2000), "Effects of Light-Duty Trucks on the Capacity of Signalized Intersections," *Journal of Transportation Engineering*, Vol. 126, No. 6, 2000, pp. 506-512; at www.ce.utexas.edu/prof/kockelman/home.html.
[59] Heru Sutomo (1992), PhD Thesis, Institute for Transport Studies, Leeds University (www.its.leeds.ac.uk).

5.5.7 Conclusions

Congestion is a significant cost and an externality in terms of economic efficiency, and to some degree in terms of equity due to differences in congestion imposed by different modes. Because it is largely internal to road users as a group, it is inappropriate to add congestion with other costs when calculating total costs. This framework incorporates congestion costs borne by individuals in travel time and vehicle operating costs, and nets out congestion costs when all costs are aggregated to avoid double counting.

Viable U.S. congestion cost estimates range from $14 to $200 billion annually. $100 billion is used here as a base. Assuming 20% of all driving and 80% of congestion costs occur under Urban Peak conditions, and 3,000 billion miles are driven annually,[60] this averages about 13¢ per Urban Peak mile ([$100 x 80%] / [3000 x 20%]). Urban Off-Peak driving represents 40% of driving and is estimated to have 20% of congestion costs, for an estimate of 2¢ ([$100 x 20%] / [3000 x 40%]). Rural driving is considered to have no significant congestion costs. Compact and electric cars, vans, light trucks and motorcycles impose about the same congestion costs as an average car. Rideshare passengers cause no incremental congestion. Buses and trolleys are considered to impose twice, and bicycles 5% the congestion of an average car. Walking can impose congestion costs if pedestrians delay traffic while crossing streets but this impact is small since pedestrians seldom cross major highways, and usually cross during regular signal cycles or breaks in traffic flow. Telework imposes no congestion costs.

Estimate **Congestion Costs (2007 U.S. Dollars per Vehicle Mile)**

Vehicle Class	Urban Peak	Urban Off-Peak	Rural	Average
Average Car	0.130	0.020	0.000	0.035
Compact Car	0.130	0.020	0.000	0.035
Electric Car	0.130	0.020	0.000	0.035
Van/Light Truck	0.130	0.020	0.000	0.035
Rideshare Passenger	0.000	0.000	0.000	0.000
Diesel Bus	0.270	0.040	0.000	0.069
Electric Bus/Trolley	0.270	0.040	0.000	0.069
Motorcycle	0.130	0.020	0.000	0.035
Bicycle	0.010	0.001	0.000	0.002
Walk	0.003	0.001	0.000	0.001
Telework	0.000	0.000	0.000	0.000

Automobile (Urban Peak) Cost Range

Minimum and Maximum estimates are based on the literature cited, discounting the highest values for reason discussed in section 5.5.3.

Minimum[61]	Maximum
$0.02	$0.27

[60] FHWA (2008), *April 2008 Traffic Volume Trends*, (www.fhwa.dot.gov); at www.fhwa.dot.gov/ohim/tvtw/tvtpage.htm

[61] Based on Lee's (2006) willingness to pay value of $14 billion (2007 dollars): (14 X 0.8) /(3000 X 0.2)

5.5.8 Information Resources

Information sources on congestion costing are described below.

Jim Beamguard (1999), "Packing Pavement," *Tampa Tribune* (www.tampatrib.com); at www.swt.org/share/bguard.html . Compares road space requirements by mode.

Robert L. Bertini (2005), *You Are the Traffic Jam: An Examination of Congestion Measures*, TRB Annual Meeting (www.trb.org); at www.its.pdx.edu/pdf/congestion_trb.pdf.

BTS (2003), *Improving Measurements of Road Congestion*, BTS (www.bts.gov).

Cambridge Systematics (2004), *Traffic Congestion and Reliability: Linking Solutions to Problems*, FHWA (www.fhwa.dot.gov); at www.ops.fhwa.dot.gov/congestion_report/index.htm

Cordis (2000), *TransPriceProject* (http://cordis.europa.eu/en/home.html); at www.cordis.lu/transport/src/transpricerep.htm. A European study of various pricing strategies for reducing urban traffic congestion and air pollution emissions.

DFT (2006), *Transport Analysis Guidance*, Integrated Transport Economics and Appraisal, Department for Transport (www.dft.gov.uk); at www.webtag.org.uk/index.htm

EDRG (2007), *The Cost of Highway Limitations and Traffic Delay to Oregon's Economy*, Oregon Business Council and Portland Business Alliance (www.orbusinesscouncil.org); at www.portofportland.com/PDFPOP/Trade_Trans_Studies_CostHwy_Lmtns.pdf

FHWA, *Management and Operations Toolbox*, (www.fhwa.dot.gov); at http://ops.fhwa.dot.gov/tdm/toolbox.htm, provides information and techniques for evaluating transportation systems management strategies.

FHWA (2006), *Travel Time Reliability: Making It There On Time, All The Time*, Federal Highway Administration (www.fhwa.dot.gov); at http://ops.fhwa.dot.gov/publications/tt_reliability/index.htm

Susan Grant-Muller and James Laird (2007), *International Literature Review of the Costs of Road Traffic Congestion*, Scottish Executive (www.scotland.gov.uk); at www.scotland.gov.uk/Publications/2006/11/01103351/0.

David T. Hartgen and M. Gregory Fields (2006), *Building Roads to Reduce Traffic Congestion in America's Cities: How Much and at What Cost?*, Reason Foundation (www.reason.org).

INRIX (2008), *National Traffic Scorecard*, INRIX (http://scorecard.inrix.com/scorecard).

iTrans (2006), *Costs of Non-Recurrent Congestion in Canada*, Transport Canada (www.tc.gc.ca); at www.tc.gc.ca/pol/en/Report/FullCostInvestigation/Road/tp14664/tp14664.pdf.

Todd Litman (2001), "Generated Traffic; Implications for Transport Planning," *ITE Journal*, Vol. 71, No. 4, ITE (www.ite.org), April, pp. 38-47; at www.vtpi.org/gentraf.pdf.

Todd Litman (2006), *Smart Congestion Reductions: Reevaluating the Role of Highway Expansion for Improving Urban Transportation* (www.vtpi.org/cong_relief.pdf), and *Smart Congestion Reductions II: Reevaluating the Role of Public Transit for Improving Urban Transportation* (www.vtpi.org/cong_reliefII.pdf), VTPI (www.vtpi.org)

Herbert Mohring (1999), "Congestion," in *Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer*, Brooking Institution (www.brookings.edu), pp. 181-222.

Alan Pisarksi (2006), *Commuting In Amercia III*, Transportation Research Board (www.trb.org); summarized in *Issues in Science and Technology* (www.issues.org/23.2/realnumbers.html)

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