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 Definitions

Traffic congestion costs consist of incremental delay, vehicle operating costs (fuel and wear), pollution emissions and stress that result from interference among vehicles in the traffic stream, particularly as traffic volumes approach a road's capacity.[1, 2] Reduced congestion is often described as increased *mobility*.[3]

This chapter focuses on the *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. Delay that motor vehicle traffic imposes on nonmotorized travel is discussed in the Barrier Effect chapter of this report.

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[1] 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.

[2] OECD/ECMT (2007), *Managing Urban Traffic Congestion*, Economic Co-operation and Development (OECD) and European Conference of Transport Ministers (ECMT); at www.internationaltransportforum.org/Pub/pdf/07Congestion.pdf

[3] Phil Goodwin (1997) *Solving Congestion*, Inaugural lecture for the professorship of transport policy, University College London; at www2.cege.ucl.ac.uk/cts/tsu/pbginau.htm.

5.5.3 Discussion

Traffic congestion is a widely recognized transport cost. It is a significant factor in transport system performance evaluation and affects transport planning decisions. As a road reaches its capacity, each additional vehicle imposes more total delay on others than they bear, resulting in economically excessive traffic volumes. Congestion tends to increase travel time, arrival unreliability, fuel consumption, pollution emissions and driver stress, and reduce life satisfaction (subjective wellbeing).[4]

Congestion can be *recurrent* (regular, occurring on a daily, weekly or annual cycle) or *non-recurrent* (*traffic incidents*, such as accidents and disabled vehicles). Some congestion costs only consider recurrent, others include both. Economist William Vickrey identified six types of congestion:[5]

1. Simple interaction on homogeneous roads: where two vehicles travelling close together delay one another.

2. Multiple interaction on homogeneous roads: where several vehicles interact.

3. Bottlenecks: where several vehicles are trying to pass through narrowed lanes.

4. "Trigger neck" congestion: when an initial narrowing generates a line of vehicles interfering with a flow of vehicles not seeking to follow the jammed itinerary.

5. Network control congestion: where traffic controls programmed for peak-hour traffic inevitably delay off-peak hour traffic.

6. Congestion due to network morphology, or polymodal polymorphous congestion: where traffic congestion reflects the state of traffic on all itineraries and for all modes. The cost of intervention for a given segment of roadway increases through possible interventions on other segments of the road, due to the effect of triggered congestion.

Most congestion cost analysis concentrates on the second and third types of congestion: congestion arising from interactions between multiple vehicles on a homogeneous road section, and bottleneck congestion. Others types are overlooked or assumed to be included in the types that are measured. Another often overlooked factor that complicates economic analysis is that congestion reduces some costs. Moderate highway congestion (LOS C) reduces traffic speeds to levels that maximize vehicle throughput and vehicle fuel efficiency, and although congestion tends to increase crash rates per vehicle-mile, the crashes that occur tend to be less severe, reducing injuries and deaths.[6]

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[4] Janet Choi, Joseph F. Coughlin and Lisa D'Ambrosio (2013), "Travel Time and Subjective Well-Being," *Transportation Research Record 2357*, Transportation Research Board (www.trb.org), pp. 100-108; at http://trb.metapress.com/content/gh2876h4x6p0n447.

[5] William S. Vickrey (1969), "Congestion Theory and Transport Investment," *American Economic Review*, Vol. 59/2, May, pp. 251-260; at http://ideas.repec.org/a/aea/aecrev/v59y1969i2p251-60.html.

[6] Min Zhou and Virginia Sisiopiku (1997), "On the Relationship Between Volume to Capacity Ratios in Accident Rates," *Transportation Research Record 1581*, TRB (www.trb.org), pp. 47-52

Measuring Congestion Impacts

Traffic congestion impacts can be measured based on roadway *volume to capacity ratios* (V/C). 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*. Congestion is a non-linear function, so as a road approaches its maximum capacity, small changes in traffic volumes can cause proportionately larger changes in congestion delays. Table 5.5.3-1 indicates units commonly used to measure traffic. Traffic volumes are often measured as *Annual Average Daily Traffic* (AADT). Speeds are generally measured for the 85th *percentile* (the speed below which 85% of vehicles travel).

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.

Roadway traffic conditions are categorized using *Level-of-Service* (LOS) ratings, a grade from *A* (best) to *F* (worst). Tables 5.5.3-2 and 5.5.3-3 show highway and intersection LOS ratings under favorable conditions. Weather, lighting, road surface conditions, cross street and turning volumes, can affect roadway capacity and therefore congestion.

Table 5.5.3-2   **Typical Highway Level-Of-Service (LOS) Ratings**[7]

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.	57-60	700-1,100	12-20
C	Ability to pass or change lanes constrained. Posted speeds 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 somewhat reduced, vehicle maneuverability limited. 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	1,850-2,200	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.

Tables 5.5.3-2 indicates that reducing traffic volume from 2,000 to 1,800 vehicles per hour (a 10% reduction) shifts a roadway from LOS E to LOS D, which increases traffic speeds about 15 mph (a 30% increase). This indicates that on a congested roadway, small reductions in traffic volumes can provide relatively large reductions in delays.

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[7] "Level of Service," *Wikipedia*, http://en.wikipedia.org/wiki/Level_of_service.

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.

Various factors can affect roadway capacity and therefore congestion costs, including vehicle type, traffic speeds, lane width and intersection design.[8] Congestion costs imposed by a vehicle tend to increase with size and weight by increasing its road space requirement and reducing its acceleration. The congestion impacts of different vehicles are 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 5.5.3-4, 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.[9] A large SUV imposes 1.4 PCEs, and a van 1.3 PCEs, when traveling through intersections.[10]

Table 5.5.3-4 **Passenger Car Equivalents** (PCEs)[11]

	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

As traffic speeds increase so does the space required between vehicles (called *shy distance*) for a given level of driver effort and safety. For example, a highway lane can efficiently carry more than 1,500 vehicles per hour at 45-54 mph, about twice the 700 vehicles accommodated at 60+ mph. Urban arterial capacity tends to peak at 35-45 mph.

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[8] AASHTO (2004), *A Policy on Geometric Design of Highways and Streets*, AASHTO (www.aashto.org).

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

[10] 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

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

Table 5.5.3-5 summarizes commonly-used congestion indicators, and indicates the scope of analysis (whether it considers impacts on some or all travelers). These are widely used to evaluate transport problems and solutions. For example, roadway level-of-service is often used as a primary indicator of transport system performance, and to determine whether and how much a developer must pay in transportation development fees.

*Table 5.5.3-5*   **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
Total 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
Planning Time Index	Earlier departure time required to insure timely arrival when traveling during peak periods	No
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.

Congestion delays can also be evaluated using travel reliability indicators:[12]

- The *90th or 95th percentile travel time* reflects the longest travel time during a ten or twenty day period.

- 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. For example, a 40% buffer index means that, for a 20-minute freeflow trip 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 *frequency that congestion exceeds a threshold* is typically expressed as the percent of days travel times exceed some standard, such as peak-period speeds slower than a target.

Figure 5.5.3-1   **Maximum Passengers Per Hour on Lane By Urban Mode[13]**
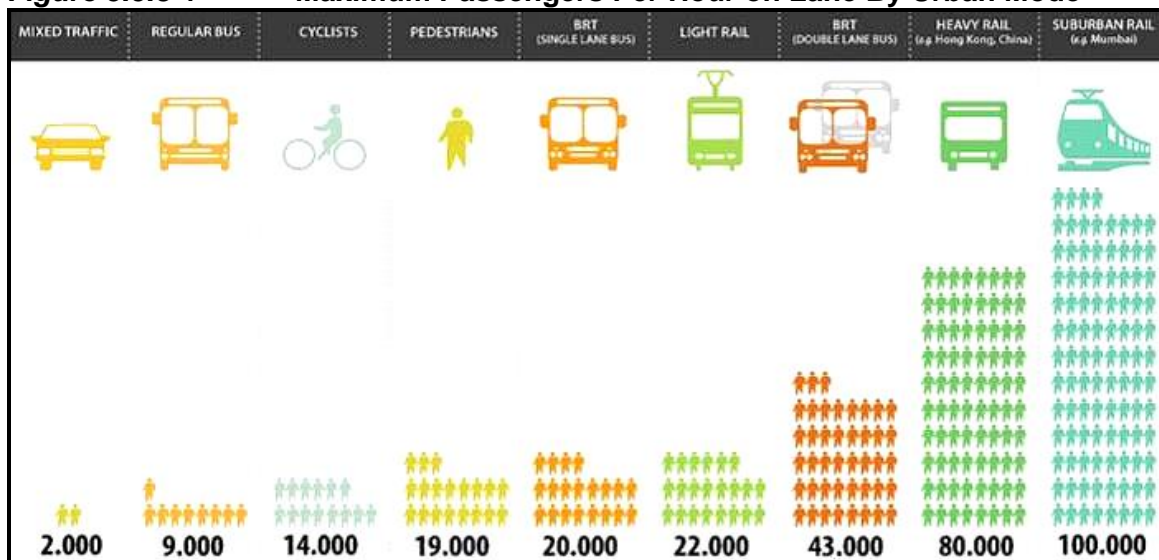
The maximum number of passengers that a 3.5-meter urban road lane can carry varies significantly by mode and load factor (number of passengers per vehicle). Automobiles are generally least space-efficient. This does not account for the additional space required for vehicle parking.

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[12] 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
[13] ADB (2012), *Solutions for Urban Transport*, Asian Development Bank (www.adb.org); at http://farm8.staticflickr.com/7228/7399658942_267b1ba9fc_b.jpg.

Congestion Costing Methods

Various methods are used to quantify congestion costs.[14] One approach is to determine the price needed to reduce traffic volumes to optimal roadway capacity, which indicates consumers' willingness-to-pay for increased mobility and therefore the actual cost they place on delay.[15] Another approach is to calculate the marginal impacts each vehicle entering the traffic stream imposes on other road users, taking into account the speed-flow relationship of each road segment.[16] However, the data needed for such analysis is seldom available so most estimates are based on simplified models that measure incremental delay, vehicle costs and emissions over some baseline. Monetized values are assigned to the additional time and emissions. Higher travel time unit costs (dollars per hour) are sometimes applied to congested conditions to reflect additional driver stress and unreliability, as discussed in the Travel Time Costs chapter.

Various methods are used to calculate congestion costs.[17] Most are based on the difference between peak and some baseline travel speed. A common baseline is free-flow speeds (LOS A), but this is criticized since it would be economically inefficient to provide sufficient road capacity to allow freeflow traffic under urban-peak conditions.

As one economist explains,[18]

> 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.

A more economically optimal baseline is LOS C/D (45-55 mph on highways), since this tends to maximize traffic throughput and fuel efficiency, and generally reflects user willingness-to-pay, assuming that most motorists would prefer slightly lower peak-period traffic speeds in exchange for much lower road user fees.

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[14] 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; Ian Wallis and David Lupton (2013), *The Costs Of Congestion Reappraised*, Report 489, New Zealand Transport Agency (www.nzta.govt.nz); at www.nzta.govt.nz/resources/research/reports/489/docs/489.pdf..

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

[16] Anthony Downs (1992), *Stuck in Traffic*, Brookings Institute (www.brookings.edu).

[17] Grant-Muller and Laird (2007).

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

Some roadways (mainly urban highways) have instruments that measure hourly traffic volumes and speeds.[19] GPS-equipped vehicles and mobile telephones can also provide traffic speed data.[20, 21] Where hourly traffic speed data are unavailable, peak-period congestion delay can be estimed using traffic volume data, as indicated in Table 5.5.3-6.

Table 5.5.3-6 **Roadway Congestion Categories**[22]

	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

These data are used to calculate calculate network congestion indicators such as the *Travel Time Rate* (TTR) and the *Travel Time Index* (TTI). For example, a 1.3 TTR indicates that trips which take 20 minutes off-peak take 26 minutes during peak periods. The *Travel Time Index* (TTI) is similar but also includes estimated non-recurring delays. These impacts are monetized by assigning unit costs to the additional travel time (see the "Travel Time Costs" chapter), fuel consumption and pollution emissions. How traffic data are collected and filtered can affect congestion cost results. For example, the Inrix and TomTom traffic indices are based on speed data collected by their subscribers, who tend to drive in congestion more than average (since they have the greatest need for roadway condition data), and so exaggerates the congestion costs for average motorists.[23]

The economic value of congestion reductions can be difficult to evaluate because congestion tends to maintain equilibrium: traffic volumes grow until delays discourage additional peak-period trips, as discussed in the next section. It also has indirect effects, such as land use development patterns and economic productivity that are difficult to measure. Dachis argues that conventional 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).[24] He concludes that including these impacts would increase monetized congestion costs by 25-85%.

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[19] Guillaume Leduc (2008), *Road Traffic Data: Collection Methods and Applications*, European Commission (http://ftp.jrc.es/EURdoc/JRC47967.TN.pdf).

[20] NAVTEQ (www.traffic.com/controller/home).

[21] TomTom (2013), *TomTom Congestion Index*, (www.tomtom.com), TomTom International; at www.tomtom.com/en_gb/congestionindex.

[22] David Schrank and Tim Lomax (2000), *Urban Mobility Study,* TTI (http://mobility.tamu.edu/ums).

[23] Felix Salmon (2012), *The Problems With Measuring Traffic Congestion*, Reuters (http://reuters.com); at http://blogs.reuters.com/felix-salmon/2012/10/17/the-problems-with-measuring-traffic-congestion.

[24] Benjamin Dachis (2013), *Cars, Congestion And Costs: A New Approach To Evaluating Government Infrastructure Investment*, C.D. Howe Institute (www.cdhowe.org); at www.cdhowe.org/pdf/Commentary_385.pdf.

Generated Traffic Impacts

Congestion reduction impact evaluation is complicated by the fact that urban congestion tends to maintain equilibrium: traffic volumes grow until delays discourage additional peak-period trips. Expanded roadway capacity tends to fill with *generated traffic*, some of which consists of *induced travel* (absolute increases in vehicle mileage).

Figure 5.5.3-1   **Generated Traffic**[25]
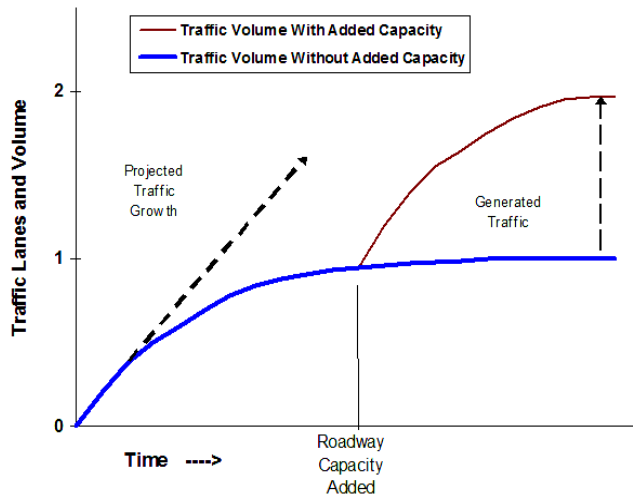
Traffic grows when roads are uncongested, but growth declines as congestion develops, reaching a self-limiting equilibrium (indicated by the curve becoming horizontal). If capacity increases, traffic volumes grow again until they reach a new equilibrium. This additional peak-period vehicle travel is 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 traffic has three economic impacts:

1. It reduces roadway expansion congestion recuction benefits.

2. It increases external costs, including parking costs, accidents, pollution and sprawl.

3. The additional peak-period travel provides user benefits, but these tend to be small because the additional travel consists to lower-value vehicle-miles that users are most willing to forego if their costs increase.

Not all congestion reduction strategies generate traffic, as indicated in Table 5.5.3-7. Analyses that ignore generated traffic impacts tend to exaggerate roadway expansion benefits and undervalue alternatives.

Table 5.5.3-7   **Generated Traffic Effects**

Causes Generated Traffic	Does Not Cause Generated Traffic
Increased road capacity (new lanes, grade-separated intersections, etc)	Congestion pricing
	Grade-separated HOV and public transit
Traffic signal synchronization	Comprehensive TDM that causes large mode shifts
Individual TDM programs that cause small mode shifts	Improved travel alternative and mobility substitutes.
Basic comfort and speed public transit	More accessible land use

Some congestion reduction strategies generate traffic, others do not, and so provide larger and more durable congestion reduction benefits.

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

Internal or External Cost?

Traffic congestion is generally considered a cost that motorists *bear*, but it is also a cost they *impose*. 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. Although some analysts consider congestion an internal impact, at least for equity analysis,[26] for most planning 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.[27] 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."[28]

- 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 vehicle user fees (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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[26] Mark Hanson (1992), "Automobile Subsidies and Land Use," *APA Journal*, Winter, pp. 60, 68; Per Kågeson (1993), *Getting the Prices Right*, European Federation for Transport and Environment (www.transportenvironment.org).

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

[28] 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).

Criticisms

Commonly-used congestion indicators such as roadway LOS and the TTI are criticized for the following omissions and biases.[29, 30, 31]

- They measure congestion *intensity* rather than congestion *costs*. As a result, they ignore the additional delay and transport costs caused by dispersed development and reduced transport options that increase per capita vehicle travel. Indicators such as the TTI imply that congestion declines if uncongested travel increases since congested travel is divided by more total vehicle-miles.

- They only consider impacts on motorists. They overlook the congestion avoided when travelers shift mode (for example, if grade separated bus or rail service allows some travelers to avoid driving on congested driving), and they ignore delays that wider roads and increased traffic imposes on to non-motorized travelers (see Barrier Effect chapter).

- They estimate delay relative to free flow conditions (LOS A) rather than more realistic urban-peak roadway conditions (LOS C) and apply relatively high travel time cost values (typically 35-60% of average wage rates for personal travel, and more for business travel), although lower values are often found when motorists' willingness-to-pay is tested with congestion tolls.

- They use outdated fuel and emission models that ignore new technologies such as fuel injection and variable valve timing, which exaggerates congestion reduction fuel savings and emission reductions. Although shifts from high to moderate congestion (LOS E/F to C/D) can save energy and reduce emissions, shifts from moderate congestion to free flow (LOS C/D to A/B) can increase costs since vehicles efficiency declines at higher speeds.

- They ignore the tendency of traffic congestion to maintain self-limiting equilibrium and the *generated travel* (additional peak-period trips) and *induced travel* (absolute increases in total vehicle travel) caused by roadway expansion.

As a result, conventional congestion indicators and costing methods tend to favor mobility over accessibility.[32] For example, more compact development tends to increase congestion intensity as measured by roadway LOS or the TTI, but increases accessibility and reduces total transport costs by reducing the distance between destinations and improving travel options. Similarly, bike and bus lanes can increase congestion intensity but reduce total transport costs. This helps explain why per capita congestion costs tend to be lower in compact, multi-modal cities such as New York and Chicago than in sprawled cities such as Los Angeles and Phoenix.[33]

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[29] Todd Litman (2013), *Congestion Costing Critique: Critical Evaluation of the 'Urban Mobility Report,'* VTPI (www.vtpi.org); at www.vtpi.org/UMR_critique.pdf.

[30] 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.

[31] Joe Cortright (2010), *Driven Apart: How Sprawl is Lengthening Our Commutes and Why Misleading Mobility Measures are Making Things Worse*, CEOs for Cities; at www.ceosforcities.org/work/driven-apart.

[32] CTS (2010), *Measuring What Matters: Access to Destinations*, Center for Transportation Studies (www.cts.umn.edu); at www.cts.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=1426.

[33] Todd Litman (2004), *Rail Transit In America: Comprehensive Evaluation of Benefits*, VTPI (www.vtpi.org); at www.vtpi.org/railben.pdf.

Congestion cost studies, such as the *Urban Mobility* reports, often argue that congestion signficiantly reduces economic productivity. In practice, however, congestion appears to impose only modest economic costs which can be more than offset by improved urban accessibility, which explains why GDP tends to increase with development density and congestion. [34] People and businesses find ways to minimize their congestion costs, for example, by shifting travel routes and times, and by using telecommunications, local shops and delivery services to avoid congested travel. As a result, congestion probably causes much smaller productivity costs than conventional estimates claim.

The table below summarizes common types of congestion costing biases, their impacts on transport policy and planning decisions, and ways to correct them.

Table 5.5.3-8 **Congestion Costing Biases, Impacts and Corrections**

Type of Bias	Planning Impacts	Corrections
Measures congestion *intensity* rather than total congestion costs	Favors roadway expansion over other transport improvements	Measure per capita congestion costs and overall accessibility
Assumes that compact development increases congestion	Encourage automobile-dependent sprawl over more compact, multi-modal infill development	Recognize that smart growth policies can increase accessibility and reduce congestion costs
Only considers impacts on motorists	Favors driving over other modes	Use multi-modal transport system performance indicators
Estimates delay relative to free flow conditions (LOS A)	Results in excessively high estimates of congestion costs	Use realistic baselines (e.g., LOS C) when calculating congestion costs
Applies relatively high travel time cost values	Favors roadway expansion beyond what is really optimal	Test willingness-to-pay for congestion reductions with road tolls
Uses outdated fuel and emission models that exaggerate fuel savings and emission reductions	Exaggerates roadway expansion economic and environmental benefits	Use more accurate models
Ignores congestion equilibrium and the additional costs of induced travel	Exaggerates future congestion problems and roadway expansion benefits	Recognize congestion equilibrium, and account for generated traffic and induced travel costs
Funding and planning biases such as dedicated road funding	Makes road improvements easier to implement than other types of transport improvements	Apply least-cost planning, so transport funds can be used for the most cost-effective solution.
Exaggerated roadway expansion economic productivity gains	Favors roadway expansion over other transport improvements	Use critical analysis of congestion reduction economic benefits
Considers congestion costs and congestion reduction objectives in isolation	Favors roadway expansion over other congestion reduction strategies	Use a comprehensive evaluation framework that considers all objectives and impacts

This table summarizes common congestion costing biases, their impacts on planning decisions, and corrections for more comprehensive and objective congestion costs.

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[34] Eric Dumbaugh (2012), "Rethinking the Economics of Traffic Congestion," *Atlantic Cities* (www.theatlanticcities.com); at www.theatlanticcities.com/commute/2012/06/defense-congestion/2118.

Guidelines for Comprehensive Congestion Costing

These guidelines can result in more comprehensive and objective congestion costing:

- Use indicators of total or per capita congestion costs, rather than congestion intensity (such as roadway *Level of Service* or a *Travel Time Index*).

- Measure impacts on non-motorized travel, such as delays caused by wider roads and increased traffic speeds.

- Calculate fuel savings and emission reductions using models that account for newer engine technologies, and recognize possible *increases* in fuel use and emissions that result if congestion reductions result in freeflow (LOS C/D shifting to LOS A/B).

- Use motorists' actual willingness to pay rather than estimates of aggregate travel time cost values.

- Account for *generated traffic* (additional peak-period vehicle trips) and *induced travel* (increases in total vehicle mileage). This should include:

    o The decline in congestion reduction benefits due to generated traffic.

    o Increases in external costs caused by induced vehicle travel, including downstream congestion, increased accidents, pollution emissions and sprawl.

    o Direct user benefits from the increased vehicle travel, taking into account that these are marginal value trips with small consumer surplus value.

- Do not add congestion costs to travel time and vehicle operating cost estimates when calculating total transport costs, since this would result in double-counting.

- Consider and compare various congestion reduction strategies. For example, roadway expansion should be compared with improvements to alternative modes (particularly grade-separated HOV and public transit), and demand management strategies.

- Put congestion costs in perspective with other transport costs (see the Cost Summary and Analysis chapter of this report). Evaluate transport system performance using indicators that reflect various modes and impacts, rather than focusing on roadway LOS.[35]

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[35] 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, pp. 17-21.

Congestion Pricing[36]

Congestion pricing (also called *value pricing*) refers to road tolls intended to reduce traffic volumes to optimal levels, which is typically LOS C or better. Such fees should reflect the congestion impacts each vehicle imposes on other road users and so should be greater for larger vehicles. The magnitude of fees needed to achieve optimal traffic flow 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.

Such fees indicate motorists' willingness-to-pay for reduced congestion delays and therefore reveal the true value users place on congestion reductions. This reflects the demand curve for reduced congestion, which usually varies from very high for a minority of vehicles (emergencies, deliver and service vehicle, buses with numerous occupants, business people traveling to meetings) to moderate and low for most vehicles.

Expanding unpriced roadways tends to be economically inefficient because there is no distinction between higher- and lower-value trips. Although such projects may be justified for the sake of higher value trips (freight travel and urgent trips), the added capacity is often filled by lower-value trips, reducing net benefits. Value pricing systems that allow motorists to choose between uncongested priced lanes and congested free lanes let travelers choose the option that reflects their value of time.

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[36] Parsons Brinckerhoff (2012), *Improving our Understanding of How Highway Congestion and Price Affect Travel Demand: Executive Summary and Technical Report*, SHRP 2 Capacity Project C04, Transportation Research Board (www.trb.org); at http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2prepubC04.pdf.

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[37]. * Indicates the currency year is assumed to be the same as the publication year.

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[37] 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).

General Estimates

- Aftabuzzaman, Currie and Sarvi (2010 and 2011) analyze public transit impacts on roadway traffic congestion. They identify and quantify three ways that high quality transit reduces congestion: (1) transit-oriented factor, (2) car-deterrence factor, and (3) urban-form factor. Regression analysis indicates that the car-deterrence factor provides the greatest congestion reductions, followed by transit-oriented and urban-form factors.[38] They conclude that high quality public transit provides congestion cost savings worth $0.044 to $1.51 (Aus$2008) per marginal transit-vehicle-km.[39]

- Bilbao-Ubillos proposes a methodology for quantifying congestion costs, including hours of passenger delay, additional fuel consumption, reduced business accessibility, accident costs and noise pollution.[40]

- The Australian Bureau of Transport and Regional Economics estimated current and projected congestion costs in major Australian cities, as indicated in the figure below.

Figure 5.5.4-1 **Average Australian City Congestion Costs – Current and Projected**[41]
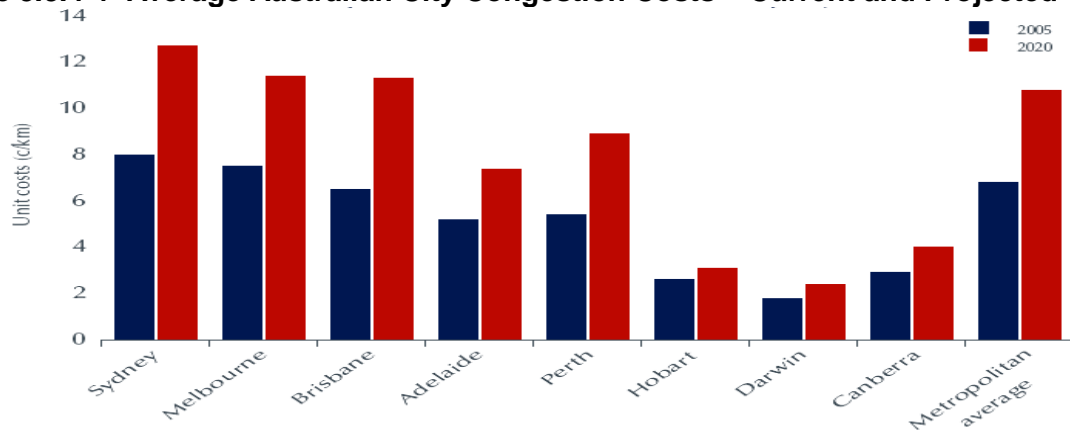
Note: Costs here refer to avoidable social costs, and are based on the deadweight losses associated with the congestion levels. That is, these unit social costs refer to the estimated aggregate costs of delay, trip variability, vehicle operating expenses and motor vehicle emissions—associated with traffic congestion above the economic optimum level for the relevant networks—divided by the total VKT (in PCU-km) on the network.

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[38] Md Aftabuzzaman, Graham Currie and Majid Sarvi (2011), "Exploring The Underlying Dimensions Of Elements Affecting Traffic Congestion Relief Impact Of Transit," *Cities*, Vol. 28, Is. 1 (www.sciencedirect.com/science/journal/02642751), February, Pages 36-44.

[39] Md Aftabuzzaman, Graham Currie and Majid Sarvi (2010), "Evaluating the Congestion Relief Impacts of Public Transport in Monetary Terms," *Journal of Public Transportation*, Vol. 13, No. 1, pp. 1-24; at www.nctr.usf.edu/jpt/pdf/JPT13-1.pdf.

[40] 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.

[41] BTRE (2007), *Estimating Urban Traffic And Congestion Cost Trends For Australian Cities*, Working Paper 71, Bureau of Transport and Regional Economics (www.btre.gov.au); at www.bitre.gov.au/publications/2007/files/wp_071.pdf.

- The American Association of Highway and Transportation Officials (AASHTO) *Bottom Line* report, estimates that if U.S. annual vehicle travel growths at 1.4% annually it must spend $144 billion for roadway expansion, repair and maintenance, but if vehicle travel only grows 1.0% annually required expenditures decline to $120 billion.[42] This suggests that a 0.4% growth in vehicle travel, which totals about 12 billion annual vehicle-miles, causes $24 billion in annual congestion and road maintenance costs, which translates into about $2 per avoided VMT.

- The study, *Economic And Environmental Costs Of Gridlock*, quantified the economic costs (incremental travel time, fuel and emissions) of vehicle idling caused by congestion on people and businesses in the UK, France and Germany.[43] It estimated annual congestion costs of €5.4bn in the UK, €5.9bn in France and €7.5bn in Germany, or €18.8bn in total. This averages €45 annual per household, although large city car commuters bear much higher costs, ranging from €981 in Stuttgart, Germany to €1,506 in London, UK.

- 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).[44]

- Grant-Muller and Laird (2007) provide a variety of estimates for congestion in the UK along with discussion of the possibility of decoupling growth in transportation demand and resulting congestion from economic growth.[45]

- 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.[46] 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.

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[42] AASHTO (2014), *The Bottom Line*, American Association of State Highway and Transportation Officials (www.aashto.org); at http://tinyurl.com/o5g23b9.

[43] CEBR (2013), *Economic and Environmental Costs of Gridlock: An Assessment Of The Direct And Indirect Economic And Environmental Costs Of Idling During Heavy Road Traffic Congestion To Households In The UK, France and Germany*, INRIX (www.inrix.com); at www.inrix.com/pdf/EconomicEnvironmentalCostsGridlockFINAL-REPORT.pdf.

[44] 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.

[45] 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.

[46] 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.

- Vehicle fuel consumption increases approximately 30% under heavily congestion.[47] Increased fuel consumption and air pollution costs represent about 17% the total external cost of congestion.[48]

- 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)[49]

	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, including detailed guidance on congestion cost analysis, monetization of congestion costs, and factors affecting congestion delay.[50]

- Hymel evaluated the impact of traffic congestion on employment growth in large U.S. metropolitan areas.[51] The study found that congestion dampens subsequent employment growth: particularly over the long run in highly congested places. The analysis suggests that in a highly congested city such as Los Angeles (50 annual hours of delay per capita) a 10% increase in congestion would reduce subsequent long-run employment growth by 4%, costs that can be reduced by highway expansion or efficient road pricing.

- Transport Canada research summarized in Table 5.5.4-3 calculates recurring and non-recurring congestion costs (including the value of excess delay, fuel use and greenhouse gas emissions) using various baselines which represent the point at which

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[47] 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.

[48] 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.

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

[50] 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.

[51] Kent Hymel (2009), "Does Traffic Congestion Reduce Employment Growth?," *Journal of Urban Economics*, Vol. 65, Issue 2, pp. 127-135; at https://webfiles.uci.edu/khymel/www/files/hymel_job_market.pdf.

urban-peak speed reductions considered unacceptable.[52] For example, a 50% baseline calculates congestion costs for traffic speeds below 50% of freeflow traffic speeds, and a 70% baseline calculates congestion costs below 70% of freeflow. The table below summarizes the results.

Table 5.5.4-3   **Congestion Costs In Various Canadian Cities** (2002 $m)[53]

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*

This analysis estimates congestion costs based on three baseline traffic speeds. A higher baseline speed indicates a higher expectation for urban-peak traffic speeds.

- 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)[54]   (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 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 Christchurch.[55]

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[52] TC (2006), *The Cost Of Urban Congestion In Canada*, Transport Canada (www.tc.gc.ca); at www.adec-inc.ca/pdf/02-rapport/cong-canada-ang.pdf.

[53] 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.

[54] 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.

[55] 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

- Professor Lee 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.[56]

- 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.[57]

- McDonald emphasizes that congestion prices should reflect network congestion costs, not just costs on the road that is tolled.[58] 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.[59]

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*

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[56] Gabriel Roth (2006), *Street Smart: Competition, Entrepreneurship, and the Future of Roads*, Transaction Publishers (www.transactionpub.com).

[57] Herbert Levinson (1995), "Freeway Congestion Pricing: Another Look," *Transportation Research Record 1450*, (www.trb.org) pp. 8-12.

[58] John McDonald (1995), "Urban Highway Congestion; An Analysis of Second-best Tolls," *Transportation*, Vol. 22, 1995, pp. 353-369.

[59] 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**[60]

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

- A study for the UK Department of Transport's Cycling England program estimates that a traveler shifting from driving to cycling 160 annual trips averaging 3.9 kms reduces congestion costs to other road users £137.28 (£0.22 per km) in urban areas and £68.64 (£0.11 per km) in rural environments.[61]

- 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.[62]

- 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¢.[63]

- 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*.[64] 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.[65]

- van Essen, et al., summarize various methods for calculating congestion costs and efficient road pricing, and provide typical values for various vehicles and traffic conditions.[66] Cost values range from zero (for off-peak travel) to more than one Euro

[60] Herbert Mohring and David Anderson (1994), *Congestion Pricing for the Twin Cities Metropolitan Area*, Dept. of Economics, University of Minnesota (www.econ.umn.edu). 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).

[61] SQW (2007), *Valuing the Benefits of Cycling: A Report to Cycling England*, Cycling England, Department for Transport (www.dft.gov.uk); at www.dft.gov.uk/cyclingengland/site/wp-content/uploads/2008/08/valuing-the-benefits-of-cycling-full.pdf.

[62] Transport Concepts (1994), *External Costs of Truck and Train*, Transport Concepts (Ottawa), p.23.

[63] TRB (1994), *Curbing Gridlock*, National Academy Press (www.trb.org), Appendix B.

[64] David Schrank and Tim Lomax (2007), *Urban Mobility Study,* Texas Transportation Institute (http://mobility.tamu.edu/ums).

[65] Cortright (2010) criticizes the methods used in this analysis and concludes that it overestimates true congestion costs by about 300%.

[66] van Essen, et al (2004), *Marginal Costs of Infrastructure Use – Towards a Simplified Approach*, CE Delft (www.ce.nl); at www.ce.nl/?go=home.downloadPub&id=456&file=04_4597_15.pdf.

per vehicle-kilometer under urban-peak conditions. Vermeulen, et al (2004) estimate that in European conditions, urban peak travel imposes congestion costs as high as €0.46 per vehicle-km for cars and €0.91 per vehicle-km for heavy vehicles.[67]

- Weisbrod, Vary and Treyz evaluate economic productivity congestion costs due to increased shipping costs, and reduced scale and agglomeration economies.[68] They estimate these costs range from $20 million to $1 billion annually in typical metropolitan regions. 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.[69]

- 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.[70]

- 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.[71] 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.[72] 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 if analyzed using more disaggregated analysis, such as corridors or roads.

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[67] Vermeulen, et al (2004), *The Price of Transport: Overview of the Social Costs of Transport*, CE Delft (www.ce.nl); at www.ce.nl/index.php?go=home.showPublicatie&id=181.

[68] 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*

[69] 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

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

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

[72] 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 congestion cost estimates for various vehicles.

Table 5.5.4-7   **Estimated Highway Congestion Costs** (Cents Per Vehicle Mile)[73]

	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)[74]

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

- 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.[75]

- Belgium researchers estimate that motorcycles typically have 0.5 Passenger Car Equivalents and use a traffic model to predict that a 10% shift from automobiles to motorcycles on a urban highway could reduce peak-period congestion delays 40%.[76]

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[73] 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

[74] M. Maibach, et al. (2008), *Handbook on Estimation of External Cost in the Transport Sector*, CE Delft (www.ce.nl), Table 7; at http://ec.europa.eu/transport/themes/sustainable/doc/2008_costs_handbook.pdf.

[75] 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.

- 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.[77]

Table 5.5.4-9 **Passenger-Car Equivalents (PCEs) for Bicycles by Lane Width**[78]

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

- Passenger Car Equivalents (PCEs) in developing country urban conditions (Bandung, Yogyakarta, Jakarta, and Semarang) are summarized below.[79]

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 external cost 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, but is inequitable when road users bear greater costs than they impose, for example, transit and rideshare passengers delayed in traffic although they use less road space than motorists, and since drivers tend to be wealthier than transit riders this tends to be regressive. Because it is an external cost at the individual level, traffic congestion is economically inefficient.

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[76] Isaak Yperman, Kristof Carlier (2011), *Commuting By Motorcycle: Impact Analysis Of An Increased Share Of Motorcycles In Commuting Traffic*, Transport and Mobility Leuven (www.tmleuven.be); at www.tmleuven.be/project/motorcyclesandcommuting/20110921_Motorfietsen_eindrapport_Eng.pdf.

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

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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,[80] 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[81]   Maximum
$0.02 $0.27

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