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Factors to Consider When Estimating Congestion Costs and Evaluating Potential Congestion Reduction Strategies

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Abstract

Traffic congestion can be measured in various ways that result in very different conclusions about the nature of the problem and optimal solutions. This article describes various factors that affect congestion cost estimates and the evaluation of potential congestion reduction strategies. It discusses how these factors influence planning decisions, and describes best practices for comprehensive evaluation of congestion impacts.

Introduction

Traffic congestion refers to the incremental travel delay caused by interactions among vehicles on a roadway, particularly as traffic volumes approach a road's capacity.

Traffic congestion can be measured in various ways that result in very different conclusions about the nature of the problem and optimal solutions. Accurate analysis is important because planning decisions often involve trade-offs between congestion reduction and other planning objectives. Inaccurate estimates of congestion impacts can result in suboptimal planning decisions.

This article discusses various factors that affect congestion cost estimates and the evaluation of potential congestion reduction strategies, discusses how different methodologies and assumptions can influence planning decisions, and describes best practices for comprehensive and multi-modal congestion evaluation. It should be of interest to anybody involved in urban transportation planning.

Factors Affecting Congestion Evaluation

Numerous studies have quantified (measured) and *monetized* (measured in monetary units) congestion costs and the benefits of potential congestion reduction strategies.[1, 2, 3, 4, 5, 6] Various factors described below can influence analysis results.

Congestion Intensity Versus Costs

Table 1 summarizes various traffic congestion indicators. Some measure congestion *intensity* (the percentage reduction in vehicle traffic speeds on particular roads), while others are more comprehensive (they consider total traffic delay, taking into account travelers' exposure to congestion as well congestion intensity) and multi-modal (they consider delays to all travelers, not just motorists), and so measure total congestion *costs*.

Table 1 **Congestion Indicators**[7]

Indicator	Description	Comprehensive	Multi-Modal
Roadway Level-Of-Service (LOS)	Intensity of congestion on a road or intersection, rated from A (uncongested) to F (most congested)	No	No
Multi-modal Level-Of-Service (LOS)	Service quality of walking, cycling, public transport and automobile, rated from A to F	No	Yes
Travel Time Index	The ratio of peak to off-peak travel speeds	No	No
Avg. Traffic Speed	Average peak-period vehicle traffic speeds	No	No
Avg. Commute Time	The average time spent per commute trip	Yes	Yes
Congested Duration	Duration of "rush hour"	No	No
Delay Hours	Hours of extra travel time due to congestion	Yes	No if for vehicles, yes if for people
Congestion Costs	Monetized value of delay plus additional vehicle operating costs	Yes	No if for vehicles, yes if for people

Various indicators are used to evaluate congestion. Only a few are comprehensive and multi-modal.

Although intensity indicators are appropriate for some engineering analysis, economic evaluation should generally measure costs. For example, a compact city may have a 1.3 Travel Time Index (traffic speeds decline 30% during peak periods), 60% automobile commute mode share, and 6-mile average trip lengths, resulting in 34 average annual hours of delay per commuter; while a sprawled city has a 1.2 Travel Time Index, 90% automobile mode share, and 10-mile average trip lengths, resulting in a much higher 45 average annual hours of delay. Intensity indicators imply that the compact city has worse congestion since it has greater speed reductions, although its residents experience lower total congestion costs due to reduced exposure (they drive less during peak periods). Similarly, converting general traffic lanes into bus or High Occupant Vehicle (HOV) lanes may increase congestion intensity but reduce total congestion costs if incremental delays to low-occupant vehicle occupants are offset by reduced HOV passenger delays.

Described differently, intensity indicators reflect mobility while cost indicators reflect accessibility (people's ability to reach services and activities).[8] Recent research improves our understanding of the trade-offs between them. For example, a study by Levine, et al.

found that changes in development density affect the number of jobs and services available within a given travel time about ten times more than proportional changes in traffic speed.[9] Kuzmyak found that travelers in more compact neighborhoods experience less congestion than in more sprawled, suburban neighborhoods due to shorter trip distances, more connected streets, and better travel options, which more than offset higher trip generation rates per square mile.[10]

A study that measured the number of jobs accessible by automobile within certain time periods for the 51 largest US metropolitan areas found that the five cities with the most intense congestion (the highest Travel Time Index ratings) are among the *best* for automobile employment access because their lower traffic speeds are more than offset by higher employment densities which reduce commute distances.[11] Cortright found that roadway expansions that stimulate sprawl increase residents' total travel times, because their higher traffic speeds are more than offset by longer travel distances.[12] These studies indicate that transportation system changes intended to increase vehicle traffic speeds often reduce overall accessibility and increase total transportation costs by reducing the efficiency of other modes and stimulating sprawl.

Baseline Speeds

Baseline (also called *threshold*) speed is the speed below which congestion delays are calculated. For example, if the baseline speed is 60 miles per hour (mph), and peak-period traffic speeds are 50 mph, the 10 mph speed reduction is the basis for calculating congestion delay. Table 2 summaries ways to define and measure baseline speeds, and their equivalent roadway level-of-service (LOS) ratings.

Table 2 **Baseline Speed Definitions**

Name	Measurement Method	LOS Rating
Free-flow speeds	Measured off-peak speeds	A
Speed limits	Maximum legal speeds	A or B
Capacity-maximizing speeds	Speeds that maximizes traffic capacity	C or D
Economic efficiency-optimizing (also called *consumer-surplus maximizing*)	Users' willingness-to-pay for faster travel	C or D

There are several possible ways to define and measure baseline speeds. (LOS = Level-of-Service)

Roadway capacity tends to decline at speeds above 55 mph on limited access highways, and about 40 mph on urban arterials, so roads typically carry about twice as much traffic at LOS C than at LOS A.[13] As a result, traffic engineers generally recommend capacity-maximizing speeds, and economists generally recommend economic efficiency-optimizing speeds, both of which result in level-of-service C or D baseline speeds.[14]

For example, the Australian Bureau of Transport and Regional Economics calculates congestion costs based on estimates of motorists' willingness to pay for faster travel.[15] Using this method they estimate that congestion costs in major Australian cities totaled $5.6 billion in 2005, less than half the $11.1 billion calculated using freeflow speeds. Similarly, using capacity-maximizing baseline speeds, Wallis and Lupton estimate that in

2006 Auckland, New Zealand congestion costs totaled $250 million, a third of the $1,250 million cost estimate using a freeflow baseline.[16] Transport Canada calculates congestion costs uses 50%, 60% and 70% of free-flow speeds, which they consider a reasonable range of optimal urban-peak traffic speeds.[17] In contrast, traffic models often use speed limit baselines, and the *Urban Mobility Report* uses measured freeflow speed baselines although they often exceed legal speed limits.[18]

Travel Time Valuation

Another key factor is the cost assigned travel delay. There is extensive research on travel time valuation.[19, 20] Most studies conclude that on average motorists are willing to pay 25-50% of wages for reduced delay; a minority, including commercial travelers and travelers with urgent errands, would pay significantly more, but many motorists are price sensitive and would rather save money than time.[21, 22] The U.S. Department of Transportation recommends valuing personal travel time at 35% to 60% of prevailing incomes.[23]

The values used for analysis should reflect the motorists affected. A project that reduces delay for all motorists, such as a roadway expansion, should be evaluated based on overall average motorists' willingness to pay, while a project that reduces congestion for a particular group, such as value priced lanes, should be evaluated based on willingness to pay by those who would pay the fee.

Fuel Consumption and Emission Impacts

The function used to calculate how traffic speed changes affect fuel economy and pollution emissions affects congestion costs. Fuel economy usually peaks at 40-50 mph, so reducing extreme congestion (such as LOS E or F) conserves fuel and reduces emissions, but eliminating congestion (shifting from level-of-service C or D to A or B) tends to increase fuel consumption and emissions.[24, 25] Ignoring these effects tends to exaggerate congestion costs and roadway expansion benefits.

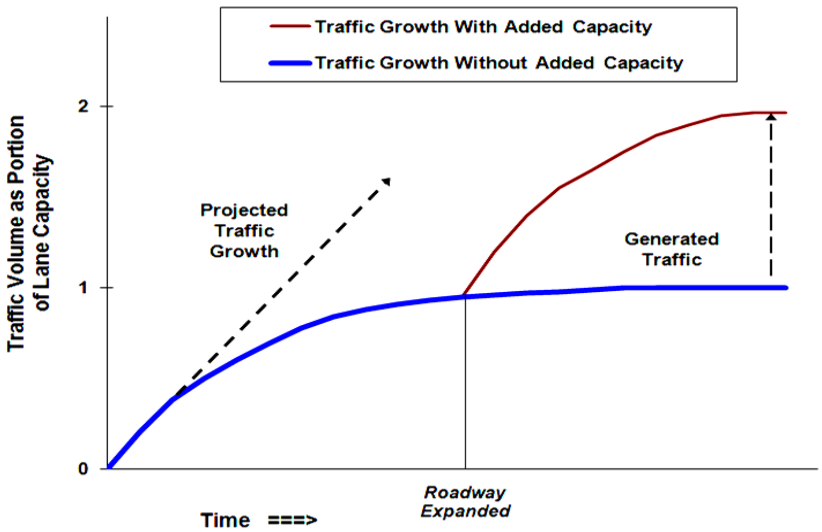
Safety Impacts

Total crash rates tend to be lowest on moderately congested roads (V/C=0.6), and increase at lower and higher congestion levels, while casualty rates (injuries and deaths) increase if congestion reductions lead to high traffic speeds.[26] Although some interventions, such as highway grade separation, can reduce both congestion and crash rates, many congestion reduction efforts increase total accident costs by increasing traffic speeds and inducing additional vehicle travel.[27, 28] These additional crash costs typically offset 5-10% of congestion reduction benefits.[29]

Generated Traffic and Induced Travel

Congestion tends to maintain equilibrium: it increases until delays cause some travelers to reduce peak-period trips by shifting travel times, routes, modes or destinations.[30, 31] Figure 1 illustrates this. When roads are expanded, increased peak-period vehicle travel is called *generated traffic*, and increases in total vehicle travel is called *induced travel*.

Figure 1 **How Road Capacity Expansion Generates Traffic**[32]



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

Generated and induced vehicle travel have these implications for congestion evaluation:

- Traffic congestion seldom becomes as severe as predicted if past traffic growth trends are simply extrapolated into the future. As congestion increases it discourages further peak-period trips, eventually reaching equilibrium.
- Roadway expansion provides less long-term congestion reduction benefits than predicted if generated traffic is ignored.
- Induced vehicle travel increases various external costs including downstream congestion, parking costs, total accidents, and pollution emissions, reducing net benefits.
- The induced vehicle travel provides direct user benefits (it increases consumer surplus), but these benefits tend to be modest because it consists of marginal-value vehicle travel that users are most willing to forego if their costs increase.

Barrier Effect

Wider roads and increased vehicle traffic tend to degrade walking and cycling access, and therefore public transit access since most transit trips include walking and cycling links. This is called the *barrier effect* or *severance*.[33, 34] This impact can be significant, particularly in urban areas. Conventional congestion evaluation only considers the delay that motor vehicles impose other motor vehicles, delay to other modes is often overlooked. New analysis tools provide guidance for measuring the barrier effect.[35]

Incorporating Economic Efficiency

Efficiency refers to the ratio of benefits (outputs) to costs (inputs). Engineers and economists both use this term but define and measure it differently.

Conventional transportation engineering often evaluates roadway efficiency based on vehicle traffic capacity and speed. A new approach evaluates roadway efficiency based on *mobility*, the capacity and speed of travel by people and goods. This recognizes that roads can become more efficient by increasing per vehicle occupancy or higher-occupant vehicle speeds. For example, a bus lane can carry far more passengers than a general traffic lane, and a minute saved by a bus often provides far more total time savings than a minute saved by a single-occupant vehicle.

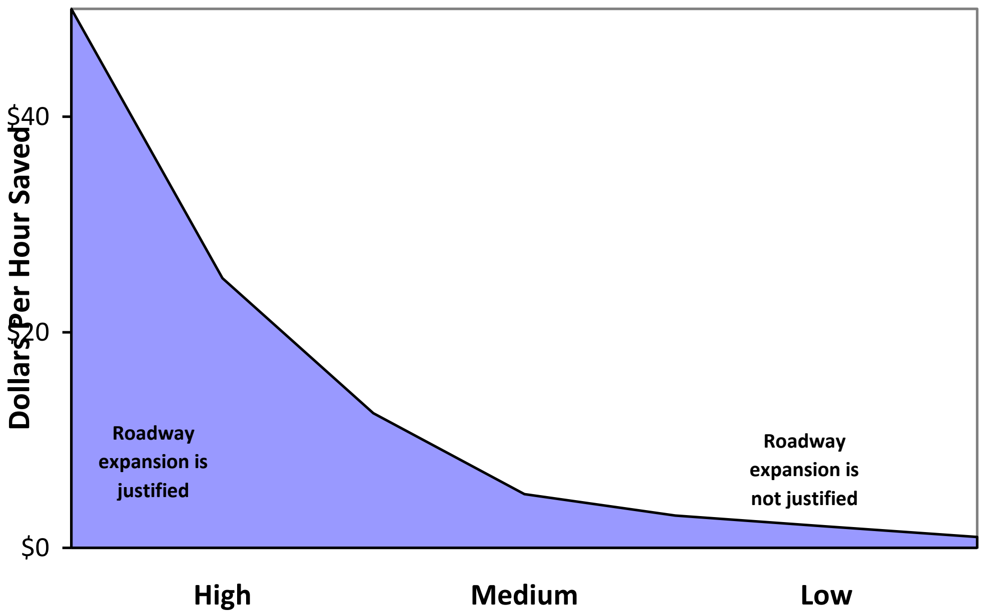
Economists consider variations in travel values and costs when evaluating transportation efficiency. Economic efficiency increases if vehicles with higher time values receive priority in traffic. For example, truck, High Occupancy Vehicle (HOV) and bus lanes tend to increase efficiency because these vehicles tend to have higher than average values of time. Congestion pricing (road tolls with higher fees during congested conditions) allow vehicles with higher travel time values to outbid lower-value vehicles for scarce road space, as illustrated in Figure 2. Roadway management strategies that favor higher occupancy vehicles can also provide *indirect* efficiency gains because these modes tend to experience scale economies; as their use increases so does their quality (more bus service and easier rideshare matching) and their cost per passenger-mile tends to decline.

Economically optimal road pricing applies peak period tolls to reduce traffic volumes to optimal levels (level-of-service C or D); toll revenues can be used to reduce traffic congestion by improving alternative modes or expanding urban roadways, depending on which is most cost effective overall. [36, 37, 38]

This has the following implications for congestion evaluation:

- Roadway efficiency increases if congestion pricing reduces traffic volumes to optimum levels (approximately level-of-service C).
- Economic efficiency increases if regulations or pricing favors higher value trips and more space-efficient modes.
- Value priced lanes tend to provide large economic efficiency gains by allowing motorists with higher travel time values to pay to save time, and motorists with lower time values to save money.
- It is economically efficient to expand congested roads if project costs can be recovered by peak-period tolls, which tests users' willingness to pay for such improvements.

Figure 2 **Travel Time Demand Curve**



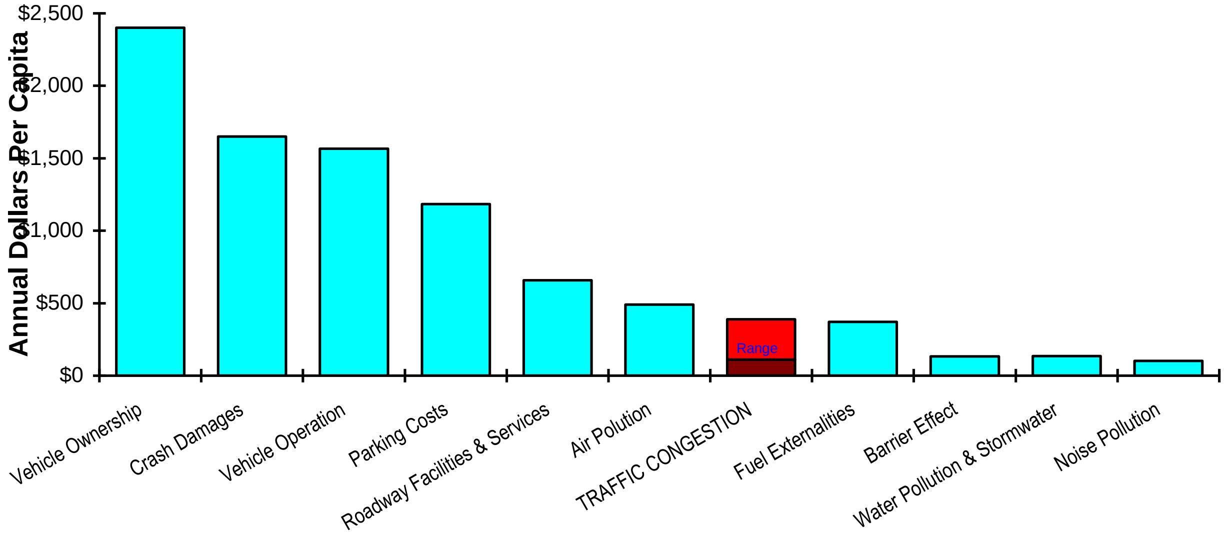
On a typical congested roadway, some vehicles (commercial vehicles, buses and motorists with urgent errands, etc.) have high travel time values: users would willingly pay relatively high prices for reduced delay. Roadway expansion is justified for these users. Other vehicles have low marginal values of travel time and so are price sensitive: users would rather save money than time, and would change their travel schedule, route, mode or destination than pay a modest fee for peak-period vehicle travel. It would be economically inefficient to expand urban roads for those vehicles. Economic efficiency increases if congestion pricing allows high travel time value motorists to outbid vehicles with lower time values for scarce urban road space. This tests users' willingness to pay for increased road capacity; roadway expansion is economically efficient if it can be financed by peak-period road tolls.

Congestion Compared With Other Transport Costs

Several studies have monetized transportation costs.[39, 40, 41] Figure 3 compares estimates of various motor vehicle costs, measured annual per capita. Congestion is estimated to cost between $112[42] to $388[43] annual per capita, compared with approximately $2,400 in vehicle ownership costs,[44, 45] $1,500 in crash damages,[46, 47] $1,200 in parking costs,[48] $658 in roadway costs,[49] and $500 in pollution damage costs.[50]

Comprehensive evaluation considers all of these impacts when evaluating potential congestion reduction strategies. A strategy can have much smaller net benefits if it increases other transportation costs, and greater total benefits if it provides additional benefits. For example, a roadway expansion may seem cost effective considering just congestion impacts, but not if, by inducing additional vehicle travel, it increases parking costs, accidents and pollution emissions. Conversely, a public transit improvement may not seem justified considering congestion reductions alone, but is cost effective overall when co-benefits (parking cost savings, increased safety, emission reductions, and improved mobility for non-drivers) are also considered.

Figure 3 **Costs Ranked by Magnitude**[51]



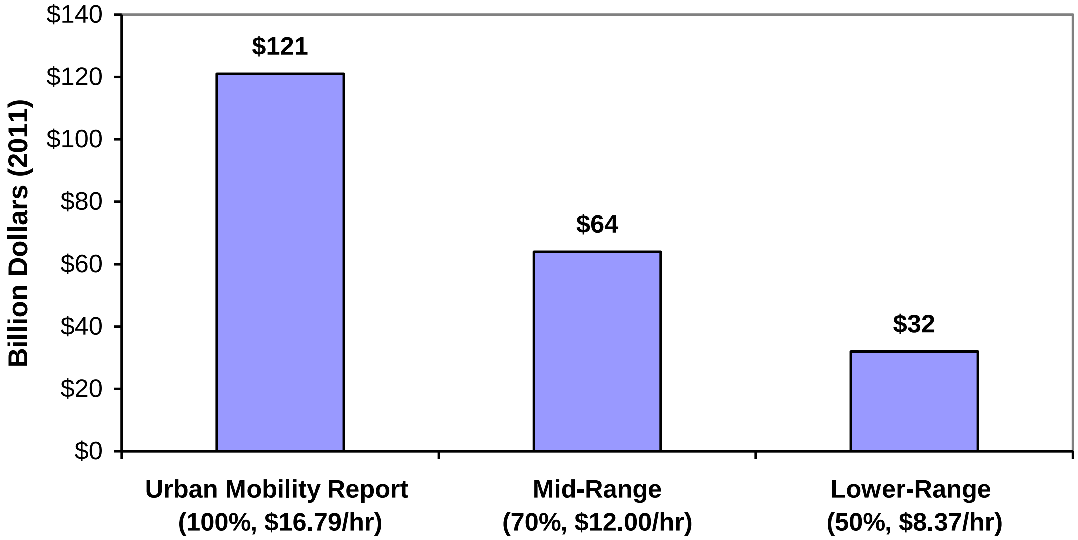
U.S. traffic congestion cost estimates range between about $112 and $388 annual per capita, depending on assumptions. These are modest compared with other transportation costs.

Addressing Uncertainty

When reporting congestion evaluation results it is important to identify possible sources of bias and uncertainty. Reports should discuss how alternative assumptions would change cost estimates and the predicted benefits of potential congestion reduction strategies. For example, if congestion costs are calculated using freeflow baseline speeds, these should be reported as upper-bound values, and the effects of using alternative baseline speeds should be discussed.

It is a good practice to perform sensitivity analysis to indicate how results would change with different input values. For example, Figure 4 illustrates sensitivity analysis applied to the *Urban Mobility Report*,[52] using alternative baseline and travel time values.

Figure 4 **Congestion Cost Estimate**[53]



The Urban Mobility Report's $121 billion cost estimate is based on higher baseline speeds and travel time unit costs than most economists recommend. The Mid-Range is based on 70% of baseline speeds and the U.S. Department of Transportation's recommended $12.00 per hour travel time unit costs; the lower-range estimate is based on 50% of baseline speed and the USDOT's lower travel time unit costs.

Summary of Congestion Costing Factors

Table 3 summarizes the factors and their impacts on congestion evaluation results.

Table 3 **Congestion Costing Factors**

Factor	Recommended Best Practices	Impacts on Evaluation
Intensity versus total costs	Evaluate and compare congestion based on total costs rather than intensity.	Intensity indicators ignore the influence of mode share and trip distance on total congestion costs.
Baseline speeds	Capacity-optimizing or user willingness-to-pay for reduced delay.	Freeflow baseline speeds tend to exaggerate congestion costs.
Travel time cost values	Use values reflecting affected motorists' willingness-to-pay for faster travel.	Excessive travel time values tend to exaggerate congestion costs.
Speed-fuel economy function	Account for the increased fuel consumption and emissions caused by traffic speeds over 50 mph.	Ignoring these effects exaggerates congestion costs and roadway expansion benefits.
Crash risk	Account for increased crash costs that may result from reduced congestion.	Ignoring this effect exaggerates congestion costs and roadway expansion benefits.
Generated and induced vehicle travel	Recognize the tendency of traffic to be self-limiting when projecting future congestion costs. Account for generated and induced vehicle travel impacts when evaluating roadway expansions.	Ignoring the tendency of congestion to be self-limiting tends to exaggerate future congestion costs. Ignoring generated and induced travel tends to exaggerate roadway expansion benefits.
Barrier effect	Account for the tendency of wider roads and increased traffic speeds to reduce walking, cycling and public transit accessibility.	Ignoring this impact exaggerates roadway expansion benefits.
Economic efficiency	Consider economic efficiency when evaluating potential congestion reduction strategies.	Ignoring this factor undervalues congestion pricing and HOV priority policies.
Additional costs and benefits	Consider other costs and benefits, besides congestion, when evaluating potential congestion reduction strategies.	Ignoring other impacts tends to exaggerate roadway expansion benefits and undervalues other congestion reduction strategies that provide co-benefits.
Addressing uncertainty	Document all assumptions, discuss potential biases, and perform sensitivity analysis indicating how results would change with different inputs.	Failing to identify possible biases and failing to apply sensitivity analysis creates unjustified confidence in results.

This table summarizes recommendations for comprehensive congestion evaluation.

Conclusions

It is important to accurately evaluate congestion costs: both under- and over-estimates can result in suboptimal planning decisions.

Various factors can affect traffic congestion cost estimates and the valuation of potential congestion reduction strategies. It is important that everybody involved in urban transportation planning understand how these factors can influence congestion impact evaluation.

The following practices are recommended for accurate congestion costing:

- Measure congestion costs rather than intensity.
- Use capacity- or efficiency-optimizing baseline speeds, such as level-of-service C or D.
- Use realistic travel time values that reflect users' willingness-to-pay for reduced delay. Recognize heterogeneity (some vehicles have higher time values than others).
- Use accurate speed-fuel economy functions which account for the increased fuel consumption and emissions that result when traffic speeds exceed 50 mph.
- Account for the increased crash costs that may result from increased traffic speeds.
- Recognize the tendency of congestion to be self-limiting when predicting future congestion costs, and account for generated traffic and induced vehicle travel impacts.
- Account for the increased barrier effect caused by wider roads and increased motor vehicle traffic speeds.
- Apply economic efficiency analysis which accounts for variations in travel time values and road space requirements, and therefore the efficiency gains provided by policies that favor higher value trips and space-efficient modes.
- Consider indirect costs and co-benefits when evaluating congestion reduction strategies.
- Document all assumptions, discuss possible biases, and perform sensitivity analysis.

These practices tend to provide the most accurate estimates of congestion impacts, and the full benefits of potential congestion reduction strategies. This can help practitioners identify truly optimal solutions to traffic congestion that best respond to user demands and community values.

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