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Generated Traffic and Induced Travel

Implications for Transport Planning

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Abstract

Traffic congestion tends to maintain equilibrium; traffic volumes increase until congestion delays discourage additional peak-period trips. If road capacity expands, peak-period trips increase until congestion again limits further traffic growth. The additional travel is called "generated traffic." Generated traffic consists of diverted traffic (trips shifted in time, route and destination), and induced vehicle travel (shifts from other modes, longer trips and new vehicle trips). Generated traffic often fills a significant portion of capacity added to congested urban road.

Generated traffic has three implications for transport planning. First, it reduces the congestion reduction benefits of road capacity expansion. Second, it increases many external costs. Third, it provides relatively small user benefits because it consists of vehicle travel that consumers are most willing to forego when their costs increase. It is important to account for these factors in analysis. This paper defines types of generated traffic, discusses generated traffic impacts, recommends ways to incorporate generated traffic into evaluation, and describes alternatives to roadway capacity expansion.

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Introduction

Traffic engineers often compare traffic to a fluid, assuming that a certain volume must flow through the road system, but it is more appropriate to compare urban traffic to a gas that expands to fill available space (Jacobsen 1997). Traffic congestion tends to maintain equilibrium: traffic volumes increase to the point that congestion delays discourage additional peak-period vehicle trips. Expanding congested roads attracts *latent demand*, trips from other routes, times and modes, and encourages longer and more frequent travel. This is called *generated traffic*, referring to additional peak-period vehicle traffic on a particular road. This consists in part of *induced travel*, which refers to absolute increases in vehicle miles travel (VMT) compared with what would otherwise occur (Hills 1996; Schneider 2018).

Generated traffic reflects the economic "law of demand," which states that a good's consumption increases as its price declines. Roadway improvements that reduce the user costs of driving (i.e., the price) encourage more vehicle travel. In the short-run generated traffic represents a shift along the demand curve; reduced congestion reduces travel time and vehicle operating costs. Over the long run it represents an outward shift in the demand curve as transport systems and land use patterns become more automobile dependent, so people must drive more to maintain a given level of accessibility to goods, services and activities (Lee 1999).

This is not to suggest that increasing road capacity provides no benefits, but generated traffic affects the nature of these benefits. It means that road capacity expansion benefits consist more of increased peak-period mobility and less of reduced traffic congestion. Accurate transport planning and project appraisal must consider these three impacts:

1. Generated traffic reduces the predicted congestion reduction benefits of road capacity expansion (a type of *rebound* effect).
2. Induced travel imposes costs, including downstream congestion, accidents, parking costs, pollution, and other environmental impacts.
3. The additional travel that is generated provides relatively modest user benefits, since it consists of marginal value trips (travel that consumers are most willing to forego).

Ignoring these factors distorts planning decisions. Experts conclude, "*…the economic value of a scheme can be overestimated by the omission of even a small amount of induced traffic. We consider this matter of profound importance to the value-for-money assessment of the road programme*" (SACTRA 1994). "*…quite small absolute changes in traffic volumes have a significant impact on the benefit measures. Of course, the proportional effect on scheme Net Present Value will be greater still*" (Mackie, 1996) and "*The induced travel effects of changes in land use and trip distribution may be critical to accurate evaluation of transit and highway alternatives*" (Johnston, et al. 2001)

This paper describes how generated traffic can be incorporated into transport planning. It defines different types of generated traffic, discusses their impacts, and describes ways to incorporate generated traffic into transport modeling and planning, and provides information on strategies for using existing roadway capacity more efficiently.

Defining Generated Traffic

Generated traffic is the additional peak-period vehicle traffic that results from a road improvement, particularly urban roadway expansions. Congested roads cause people to defer trips that are not urgent, choose alternative destinations and modes, and forego avoidable trips. Generated traffic consists of *diverted travel* (shifts in time and route) and *induced travel* (increased total motor vehicle travel). Highway expansion can stimulate sprawl (dispersed, automobile-dependent development) which further increasing per capita vehicle travel.

Below are examples of decisions that generate traffic:

- Consumers choose closer destinations when roads are congested and further destinations when traffic flows more freely. "*I want to try the new downtown restaurant but traffic is a mess now. Let's just pick up something at the local deli.*" This also affects long-term decisions. "*We're looking for a house within 40-minute commute time of downtown. With the new highway open, we'll considering anything as far as Midvalley.*"
- Travelers shift modes to avoid driving in congestion. "*The post office is only five blocks away and with congestion so bad this time of day, I may as well walk there.*"
- Longer trips may seem cost effective when congestion is light but not when congestion is heavy. "*We'd save $5 on that purchase at the Wal-Mart across town, but it's not worth fighting traffic so let's shop nearby.*"

Travel time budget research indicates that increased travel speeds often results in more mobility rather than saving time (Marchetti 1994; Zahavi and Ryan 1980). People tend to average about 75 minutes of daily travel time regardless of transport conditions (Ahmed and Stopher 2014; Lawton 2001). National data indicate that as freeway travel increases, average commute trip distances and speeds increase, but trip time stays about constant (Levinson and Kumar 1997). As a result, traffic congestion tends to maintain a self-limiting equilibrium: once congestion becomes a problem it discourages further growth in peak-period travel. Road expansion that reduces congestion in the short term attracts additional peak-period trips until congestion once again reaches a level that limits further growth (Krol 2020). It may therefore be incorrect to claim that congestion reductions save travel time.

Definitions

Generated Traffic: Additional peak-period vehicle trips on a particular roadway that occur when capacity is increased. This may consist of shifts in travel time, route, mode, destination and frequency.

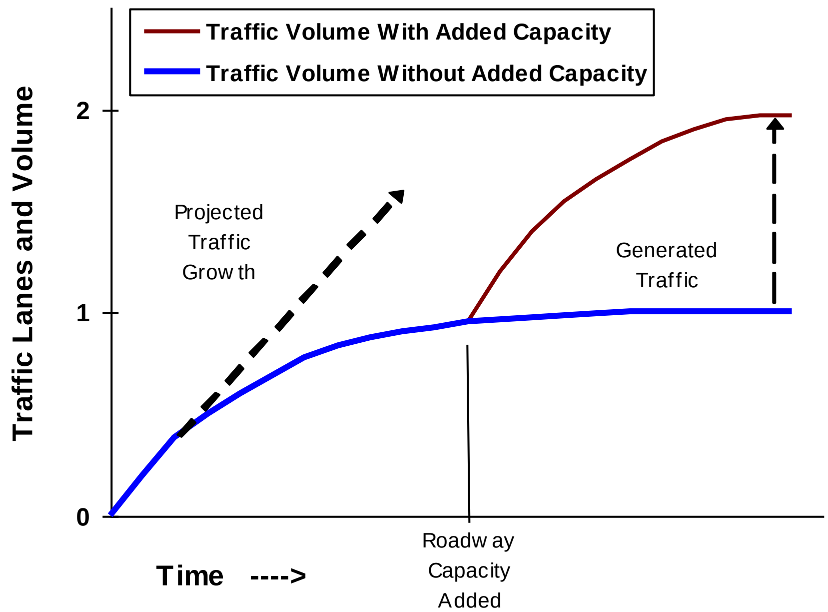
Induced travel: An increase in total vehicle mileage due to roadway improvements that increase vehicle trip frequency and distance, but exclude travel shifted from other times and routes.

Latent demand: Additional trips that would be made if travel conditions improved (less congested, higher design speeds, lower vehicle costs or tolls).

Triple Convergence: Increased peak-period vehicle traffic volumes that result when roadway capacity increases, due to shifts from other routes, times and modes.

Figure 1 illustrates this pattern. Traffic volumes grow until congestion develops, then the growth rate declines and achieves equilibrium, indicated by the curve becoming horizontal. A demand projection made during this growth period will indicate that more capacity is needed, ignoring the tendency of traffic volumes to eventually level off. If additional lanes are added there will be another period of traffic growth as predicted.

Figure 1 **How Road Capacity Expansion Generates Traffic**



Traffic grows when roads are uncongested, but the growth rate declines as congestion develops, reaching a self-limiting equilibrium (indicated by the curve becoming horizontal). If capacity increases, traffic grows until it reaches 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 can be considered from two perspectives. Project planners are primarily concerned with the traffic generated *on the expanded road segment*, since this affects the project's congestion reduction benefits. Others may be concerned with changes in *total vehicle travel* (induced travel) which affects overall benefits and costs. Table 1 describes various types of generated traffic. In the short term, most generated traffic consists of trips diverted from other routes, times and modes, called *Triple Convergence* (Downs 1992). Over the long term an increasing portion is induced travel. In some situations, adding roadway capacity can reduce overall network efficiency, called *Braess's Paradox* (Youn, Jeong and Gastner 2008).

Highway capacity expansion can induce additional vehicle travel on adjacent roads (Hansen, et al. 1993) by stimulating more dispersed, automobile-dependent development. Although these indirect impacts are difficult to quantify they are potentially large and should be considered in transport policy and planning analysis (Byun, Park and Jang 2017).

Table 1 **Types of Generated Traffic**

Type of Generated Traffic	Category	Time Frame	Travel Impacts	Cost Impacts
Shorter Route – Improved road allows drivers to use more direct route.	Diverted trip	Short term	Small reduction	Reduction
Longer Route – Improved road attracts traffic from more direct routes.	Diverted trip	Short term	Small increase	Slight increase
Time Change – Reduced peak period congestion reduces the need to defer trips to off-peak periods.	Diverted trip.	Short term	None	Slight increase
Mode Shift; Existing Travel Choices – Improved traffic flow makes driving relatively more attractive than other modes.	Induced vehicle trip	Short term	Increased driving	Moderate to large increase
Mode Shift; Changes in Travel Choice – Less demand leads to reduced rail and bus service, less suitable conditions for walking and cycling, and more automobile ownership.	Induced vehicle trip	Long term	Increased driving, reduced alternatives	Large increase, reduced equity
Destination Change; Existing Land Use – Reduced travel costs allow drivers to choose farther destinations. No change in land use patterns.	Longer trip	Short term	Increase	Moderate to large increase
Destination Change; Land Use Changes – Improved access allows land use changes, especially urban fringe development.	Longer trip	Long term	More driving and auto dependency	Moderate to large increase, equity costs
New Trip; No Land Use Changes – Improved travel time allows driving to substitute for non-travel activities.	Induced trip	Short term	Increase	Large increase
Automobile Dependency – Synergetic effects of increased automobile oriented land use and transportation system.	Induced trip	Long term	Increased driving, fewer alternatives	Large increase, reduced equity

Some types of generated traffic represent diverted trips (trips shifted from other times or routes) while others increase total vehicle travel, reduce travel choices, and affect land use patterns.

What constitutes *short-* and *long-term* impacts can vary. Some short term effects, such as mode shifts, may accumulate over several years, and some long term effects, such as changes in development patterns, can begin almost immediately after a project is announced if market conditions are suitable. Roadway expansion impacts tend to include:

- *First order.* Reduced congestion delay, increased traffic speeds.
- *Second order.* Changes in time, route, destination and mode.
- *Third order.* Land use changes. More dispersed, automobile-oriented development.
- *Fourth order*. Overall increase in automobile dependency. Degraded walking and cycling conditions (due to wider roads and increased traffic volumes), reduced public transit service (due to reduced demand and associated scale economies, sometimes called the *Downs-Thomson paradox*), and social stigma associated with alternative modes (Noland and Hanson 2013, p. 75).

Such impacts can also occur in reverse: reducing urban roadway capacity often reduces total vehicle travel (Cairns, Hass-Klau and Goodwin 1998; Cervero 2006; CNU 2011; ITDP 2012; Miller 2006) which is sometimes called *traffic evaporation* (EC 2004).

Measuring Generated Traffic

Numerous studies using various analysis methods have quantified generated traffic and induced travel impacts (WSP 2018). Their findings are summarized below:

- The National Center for Sustainable Transportation's [Induced Travel Calculator](#) (NCST 2019) estimates the incremental vehicle travel induced by adding general-purpose or high-occupancy-vehicle (HOV) lane miles to roadways. It is calibrated for California's urbanized counties, but the methodology is transferable to other geographic areas.

- Sophisticated analysis of 545 European cities indicates that urban highway expansion tends to increase vehicle traffic and so fails to solve congestion (Garcia-López, Pasidis, and Viladecans-Marsal 2020). The study indicates that each 1% increase in highway lane-kilometers typically increases total vehicle kilometers by 1.2%. The analysis found significantly less congestion (indicated by vehicle-kms relative to the log of lane-kms) in cities with road pricing and high quality rail transit. A 1% increase in lane kilometers increases congestion by 1.9% in cities without highway tolls but only 0.3% in cities with tolls. A 1% increase in railroad network length decreases congestion by 0.6% in a city without subways, 0.8% in a city with the average share of subways, and 1.3% in a city where the majority of the railroad network consists of subways.

- Detailed analysis by Hymel (2019) found that U.S. vehicle miles traveled increase in proportion with lane-mileage, and congestion relief from capacity expansion generally vanishes within five years of expansion.

- Graham, McCoy and Stephens (2014) quantify roadway capacity expansion effects on aggregate urban traffic volume and density in U.S. cities using a mixed model propensity score (PS) estimator which accounts for confounding unobserved characteristics. They found that a 10% increase in lane miles increases average VMT 9% beyond 'natural growth.' They conclude that even major urban highway expansions can lead to little or no reduction long-term reduction in traffic densities and congestion.

- A critical review by Handy and Boarnet (2014) concluded that the *short-run* elasticity highway expansions generally range from 0.3 to 0.6, and *long-run* effects are considerably higher, mostly falling into the range from 0.6 to just over 1.0, meaning that each 10% increase in road capacity increases traffic volumes by 3-6% within two years, and 6-10% within about five years. More recent studies using more sophisticated methodologies produced higher elasticities. They therefore conclude that in congested urban areas, expanding highway capacity is unlikely to reduce congestion or associated GHG in the long-run.

- Duranton and Turner (2008) found that in U.S. urban regions, vehicle travel increases proportionately to highway capacity due to four effects: increased driving by current residents, an inflow of new residents, and more transport intensive production activity. They conclude that, without congestion pricing, increasing road or public transit supply is unlikely to relieve congestion, and current roadway supply exceeds optimums.

- Cervero (2003a & 2003b) used data on freeway capacity, traffic volumes, demographic and geographic factors in California between 1980 and 1994. He estimated a 0.64 long-term elasticity of VMT with respect to traffic speed, meaning that a 10% speed increases VMT 6.4%, about a quarter of which results from land use changes (e.g., additional urban fringe development). He

estimated that about 80% of additional roadway capacity is filled with additional peak-period travel, about half of which (39%) can be considered the direct result of the added capacity.

- Noland (2001) and (Noland and Lem 2002) used time-series travel data for various roadway types to evaluate induced travel. They found an elasticity of vehicle travel with respect to lane miles of 0.5 in the short run, and 0.8 in the long run. This means that half of increased roadway capacity is filled with added travel within about 5 years, and that 80% of the increased roadway capacity will be filled eventually.

- Leading U.K. transportation economists concludes that the elasticity of travel volume with respect to travel time is -0.5 in the short term and -1.0 over the long term (SACTRA 1994). This means that reducing travel time on a roadway by 20% typically increases traffic volumes by 10% in the short term and 20% over the long term. The following are elasticity values for vehicle travel with respect to travel time: urban roads, short-term -0.27, long term –0.57; rural roads, short term –0.67, long term –1.33 (Goodwin 1996).

- Noland and Quddus (2006) found that increases in road space or traffic signal control systems that smooth traffic flow tend to induce additional vehicle traffic which quickly diminish any initial emission reduction benefits.

- Tennøy, Tønnesen and Gundersen (2019) found that Norwegian highway expansions provide only short-term congestion relief, and by increasing sprawled development, increase total traffic growth. They find that road authorities generally overlooked these effects.

- Cervero and Hanson (2000) found the elasticity of VMT with respect to lane-miles to be 0.56, and an elasticity of lane-miles with respect to VMT of 0.33, indicating that roadway capacity expansion results in part from anticipated traffic growth.

- A comprehensive study found that in the U.S., a 10% increase in urban road density (lane-miles per square mile) increases per capita annual VMT by 0.7% (Barr 2000).

- Yao and Morikawa (2005) develop a model of induced demand resulting from high speed rail service improvements between major Japanese cities. They calculate elasticities of induced travel (trips and VMT) with respect to fares, travel time, access time and service frequency for business and nonbusiness travel.

- Modeling analysis indicates that adding an urban beltway can increase regional VMT by 0.8-1.1% for each 1.0% increase in lane capacity, as indicated in the following table.

Table 2 **Portion of New Capacity Absorbed by Induced Traffic** (Rodier, et al. 2001)

Author	Short-term	Long-term (3+ years)
SACTRA		50 - 100%
Goodwin	28%	57%
Johnson and Ceerla		60 - 90%
Hansen and Huang		90%
Fulton, et al.	10 - 40%	50 - 80%
Marshall		76 - 85%
Noland	20 - 50%	70 - 100%

- Odgers (2009) found that Melbourne, Australia freeway traffic speeds did not increase as predicted following highway construction, apparently due to induced traffic. He concludes that, "major road infrastructure initiatives and the consequent economic investments have not yet delivered a net economic benefit to either Melbourne's motorists or the Victorian community."

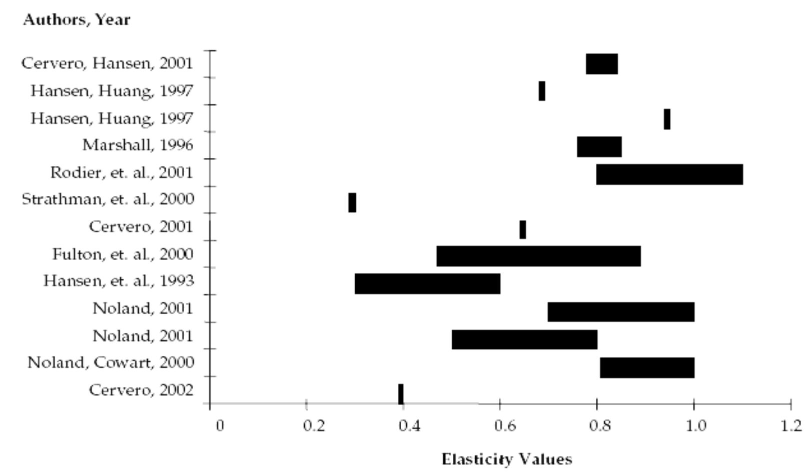
- Burt and Hoover (2006) found that each 1% increase in road lane-kilometres per driving-age person increases per capita light truck travel 0.49% and car travel 0.27%, although they report that these relationships are not statistically significant, falling just outside the 80% confidence interval for cars and the 90% confidence interval for light trucks.

- Hymel, Small and Van Dender (2010) used 1966-2004 U.S. state-level cross-sectional time series data to evaluate how income, fuel price, road supply and traffic congestion affect vehicle miles travel (VMT). They find the elasticity of VMT with respect to statewide road density is 0.019 in the short run and 0.093 in the long run (a 10% increase in total lane-miles per square mile increases state vehicle mileage by 0.19% in the short run and 0.93% in the long run); with respect to total road miles is 0.037 in the short run and 0.186 in the long run (a 10% increase in lane-miles causes state VMT to increase 0.37% in the short run and 1.86% over the long run); and vehicle use with respect to congestion is -0.045 (a 10% increase in total regional congestion reduces regional VMT 0.45% over the long run), but this increases with income, assumedly because the opportunity cost of time increases with wealth. Their analysis indicates that long-run travel elasticities are typically 3.4–9.4 times short-run elasticities.

- The *Handbook of Transportation Engineering* finds that urban highway capacity expansion often fails to significantly increase travel speeds due to latent demand (Kockelman 2010). They conclude that the long-run elasticities of VMT with respect to roadspace is generally 0.5 to 1.0 after controlling for population growth and income, with values of almost 1.0, suggesting that new roadspace is totally filled by generated traffic where congestion is relatively severe.

- A meta analysis by Schiffer, Steinvorth and Milam (2005) reached the following conclusions:
    - *Induced travel effects exist* **–** The elasticity of VMT with respect to added lane-miles or reductions in travel time is generally greater than zero and the effects increase over time. Figure 3 summarizes their results.
    - *Short-term induced travel effects are smaller than long-term effects* **–** As measured by the increase in VMT with respect to an increase in lane-miles, short-term effects have an elasticity range from near zero to about 0.40, while long-term elasticities range from about 0.50 to 1.00. This means that a 10% increase in lane-miles can cause up to a 4% increase in VMT in the short term and a 10% increase in the long term.
    - *Induced travel effects generally decrease with the size of the unit of study* **–** Larger effects are measured for single facilities while smaller effects are measured for regions and subareas. This is mainly due to diverted trips (drivers changing routes) causing more of the change on a single facility, whereas, at the regional level, diverted trips between routes within the region are not considered induced travel unless the trips become longer as a result.
    - *Traditional four-step travel demand models do not fully address induced travel or induced growth* **–** Land use allocation methods overlook accessibility effects, trip generation often fails to account for latent trips (potential trips constrained by congestion), many models overlook time-of-day shifts, and static traffic assignment algorithms may not account for queuing impacts on route shifts; all of which underestimate generated traffic effects.

Figure 3 **VMT With Respect to Road Capacity** (Schiffer, Steinvorth and Milam 2005)



This figure summarizes long term vehicle travel elasticities with respect to roadway capacity.

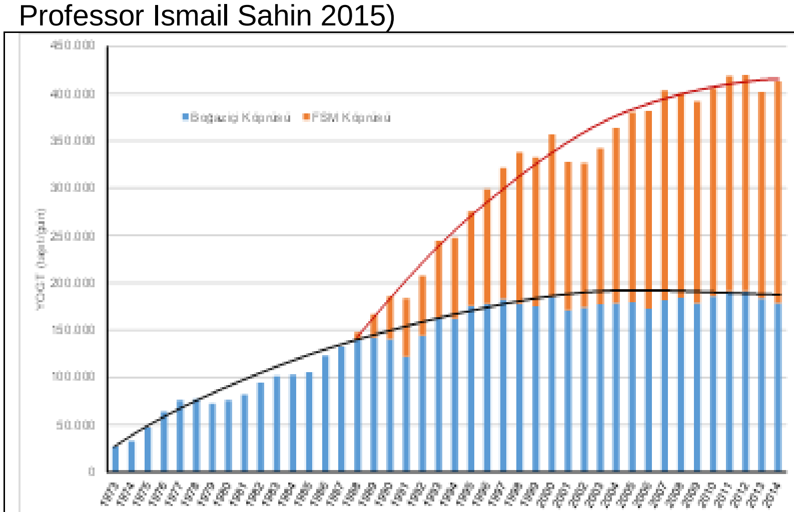
- Melo, Graham and Canavan (2012) found a positive relationship between urban highway expansion and vehicle travel in the U.S. between 1982 and 2009.

- Rahmana, Bakerb and Rahmanc (2020) found that in Dhaka, Bangladesh, urban intersection flyovers typically provide a one-minute time savings, which increased affected vehicle trip generation by 35%.

- Özuysal and Tanyel (2008) found the elasticity of travel per vehicle relative to Turkish state highway supply is 2.0 for private vehicles and 3.5 for commercial vehicles over 3-5 year periods.

- Analysis by Professor Ismail Sahin of Turkey's Yildiz Technical University shows that after new bridges were built in Istanbul, traffic volumes increased, representing induced vehicle trips, resulting in a new, higher level of congestion equilibrium.

Figure 4 **Istanbul Bridge Traffic Volumes** (Personal correspondence with Professor Ismail Sahin 2015)



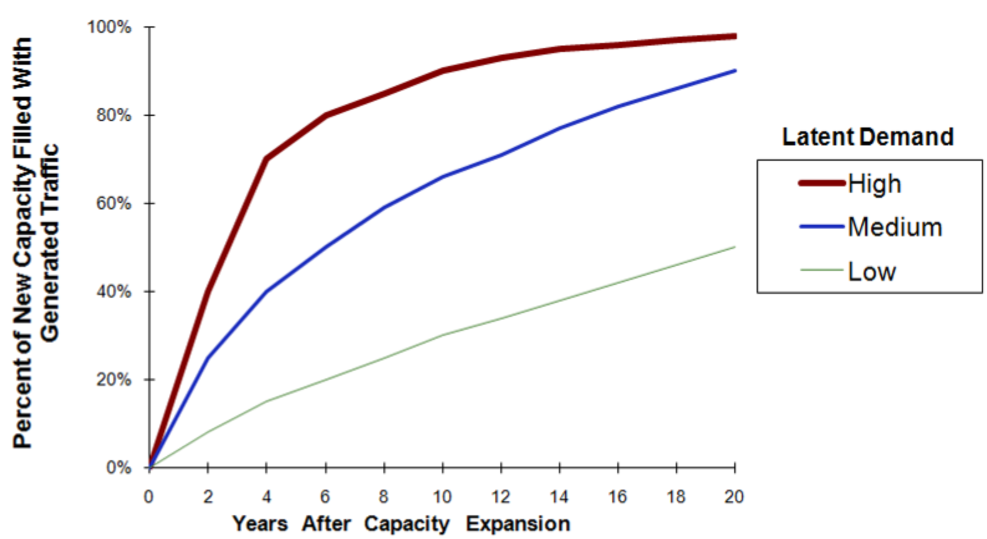
This graph shows Average Annual Daily Trips (AADTs) on Bosporus Bridge (blue bars) opened in 1973 and Fatih Sultan Mehmet (FSM) Bridge (orange bars) opened in 1988. This shows the tendency of traffic volumes to fill the new capacity and then reach equilibrium as congestion becomes self-limiting.

The amount of traffic generated by a road project varies depending on conditions. It is not capacity expansion itself that generates travel, it is the reduction in delay and therefore per-mile travel costs (Milam, et al. 2017). Expanding uncongested roads generates no traffic, although paving a dirt road or significantly raising roadway design speeds may induce more vehicle travel. In general, the more congested a road, the more traffic is generated by expansions. Increased capacity on highly congested roads often generates considerable traffic (Marshall 2000). Older studies of the elasticity of VMT growth with respect to increased roadway lane-miles performed during the early years of highway building (during the 1950s through 1970s) have little relevance for evaluating current urban highway capacity expansion. In developed countries, where most highway expansion now occurs on congested links, such projects are likely to generate considerable amounts of traffic, providing only temporary congestion reduction benefits.

Gridlock?
People sometimes warn of roadway *gridlock* without some recommended action, such as roadway expansion. Such claims are usually exaggerated because they ignore traffic congestion's tendency toward equilibrium. Gridlock is a specific condition that occurs when backups in a street network block intersections, stopping traffic flow. Gridlock can be avoided with proper intersection design and traffic law enforcement. Increasing regional highway capacity can increase this risk by adding more traffic to surface streets where gridlock occurs.

Generated traffic usually accumulates over several years. Under typical urban conditions, more than half of added capacity is filled within five years of project completion by additional vehicle trips that would not otherwise occur, with continued but slower growth in later years (Goodwin 1998). Figure 5 shows typical generated traffic growth based on various studies. Techniques for modeling these impacts are described in the next section.

Figure 5 **Elasticity of Traffic Volume With Respect to Road Capacity**



This illustrates traffic growth on a road after its capacity increases. About half of added capacity is typically filled with new traffic within a decade of construction. (Based on cited studies)

Modeling Generated Traffic

To predict generated traffic, transport models must incorporate "feedback," which reflects the impacts congestion has on travel behavior, and long-term changes in transport and land use patterns. This recognizes that congestion diverts traffic to other routes, times and modes, and reduces trip length and frequency, while reduced congestion has the opposite effects. Because of non-linear speed flow relationships, and typically small net differences between large costs and large benefits, a small amount of induced traffic can have a disproportionately large effect on the cost effectiveness of a roadway project.

All current traffic models can predict route and mode shifts, and some can predict changes in trip frequency, scheduling and destination, but few incorporate feedback on long-term effects, such as the tendency of highway expansions to increase automobile-dependent urban fringe development where households own more vehicles and drive more annual miles than they would if located in more central, multimodal areas (Milam, et al. 2017; Næss, Nicolaisen and Strand 2012; Volker, Lee, and Handy 2020). As a result, current models overestimate highway expansion costs and underestimate long-term induced vehicle travel, and associated costs, including downstream traffic and parking congestion, crashes and pollution emissions.

Volker, Lee, and Handy (2020) examined the evaluation methods used in five recent highway project. They found that conventional analyses frequently fail to account for induced travel effects, which exaggerated their benefits and underestimated their environmental costs. The authors used this information to develop the National Center for Sustainable Transportation's **Induced Travel Calculator**, which estimates the incremental vehicle travel induced by adding general-purpose or high-occupancy-vehicle (HOV) lane miles to roadways. It is calibrated for California's urbanized counties but the methodology is transferable to other areas. The Rocky Mountain Institute used this information to develop a **Colorado Induced Travel Calculator**.

Ramsey (2005) found that a suburban highway expansion project's net benefits declined by 50% if the project caused just 2% of the regional population to move from urban to suburban locations. In a case study of a proposed roadway expansion in Copenhagen, Denmark, Næss, Nicolaisen and Strand (2012) found that ignoring a portion of induced traffic effects significantly affected cost-benefit results: results show lower travel time savings, more adverse environmental impacts and a considerably lower benefit-cost ratio when induced traffic is partly accounted for than when it is ignored. They conclude that, "By exaggerating the economic benefits of road capacity increase and underestimating its negative effects, omission of induced traffic can result in over-allocation of public money on road construction and correspondingly less focus on other ways of dealing with congestion and environmental problems in urban areas." Analysis of urban highway expansion impacts on total emissions by Williams-Derry (2007) indicates that construction and induced vehicle travel emission quickly exceed any emission reductions from less congestion.

Transportation modelers have developed techniques for incorporating full feedback (Henk 1989; SACTRA 1994; Loudon, Parameswaran and Gardner 1997; Schiffer, Steinvorth and Milam 2005). This recognizes that expanding the capacity of congested roads increases the number and length of trips in a corridor (DeCorla-Souza and Cohen 1999). Federal clean air rules require that these techniques be used in metropolitan transportation models to evaluate the effects transport system changes have on vehicle emissions, but many metropolitan planning organizations have yet to comply, and few models used in medium and small cities have full feedback. Full feedback

is necessary to accurately predict future congestion and traffic speeds, and the incremental costs and benefits of alternatives. Models that lack feedback tend to overestimate future congestion problems and overestimate capacity expansion benefits.

Models that fail to consider generated traffic were found to overvalue roadway capacity expansion benefits by 50% or more (Williams and Yamashita 1992). Another study found that the ranking of preferred projects changed significantly when feedback is incorporated into project assessment (Johnston and Ceerla 1996). Ignoring generated traffic tends to skew planning decisions toward highway projects and away from No Build and transportation demand management alternatives such as road pricing, transit improvements and commute trip reduction programs (Boarnet 1995). UK Department for Transport's *Transport Analysis Guidance* (DfT 2007), includes a section on *Variable Demand Modelling* (www.dft.gov.uk/webtag/documents/expert/unit3.10.1.php) which describes methods for incorporating induced travel demand into project appraisal.

Short Cut Methods of Incorporating Induced Demand
Based on comments by Phil Goodwin, 2001.

The easiest way to incorporate induced demand into conventional traffic models is to apply an overall demand elasticity to forecasted changes in travel speed, calculated either:

- Elasticities applied to generalized costs (travel time and financial costs) using a price elasticity (about -0.3 for equilibrium, less for short term), with monetized travel time costs. The time elasticity is generally about -0.5 to -0.8 or so, though this is highly dependent on context. Where to apply it depends on the model used. With a fixed trip matrix altered only by reassignment, apply elasticities to each separate cell, or the row and column totals, or the overall control total - depending on how short the short cut has to be. Or add a separate test at the end.

or

- Direct application of a 'capacity elasticity,' i.e. percent change in vehicle miles resulting from a 1% change in highway capacity, for which lane miles is sometimes used as a proxy, the elasticity in that case usually coming out at about -0.1. This will tend to underestimate the effect if the capacity increase is concentrating on bottlenecks.

Care is needed if the basic model has cost-sensitive distribution and mode split, as this will already account for some induced traffic. Induced traffic consists of several types of travel changes that make vehicle miles "with" a scheme different from "without," including re-assignment to longer routes and increased trip generation. Although time-shifting is not induced traffic, it has similar effects on congestion reduction benefits and is often a large response. Ideally you iterate on speed and allow for the effect from retiming of journeys, and separate the various behavioural responses which make up induced traffic. These short cuts are subject to bias, but less than the bias introduced by assuming zero induced traffic.

Land Use Impacts

An important issue related to generated and induced travel is the degree to which roadway improvements affect land use patterns, and in particular, whether highway capacity expansion stimulates lower-density, urban fringe development (i.e., urban sprawl), and the costs to society that result (Louis Berger & Assoc. 1998; USEPA 2001; ICF Consulting 2005). Land use changes are one category of induced travel. Such changes take a relatively long time to occur, and are influenced by additional factors, but they are durable effects with a variety of economic, social and environmental impacts.

Urban economists have long realized that transportation can have a major impact on land use development patterns, and in many situations improved accessibility can stimulate development location and type. Different types of transportation improvements tend to cause different types of land use development patters: highway improvements tend to encourage lower-density, automobile-oriented development at the urban fringe, while transit improvements tend to encourage higher-density, multi-modal, urban redevelopment, although the exact types of impacts vary depending on specific conditions and the type of transportation improvements implemented (Rodier, Abraham, Johnston and Hunt 2001; Boarnet and Chalermpong 2002).

Some researchers claim that investing in road construction does not lead to the sprawl (Sen, et al. 1999; Hartgen 2003), although the evidence indicates otherwise. Even in relatively slow-growth regions with modest congestion problems, highway expansions increase suburban development by 15-25%. These effects are likely to be much greater in large cities with significant congestion, where peak-period traffic congestion limits commute trip distances, and increased roadway capacity would significantly improve automobile access to urban fringe locations. This is particularly true if the alternative is to implement Smart Growth development policies and improved walking, cycling and transit transportation ("Smart Growth, VTPI 2006).

There has been considerable debate over the benefits and costs of sprawl and Smart Growth (Burchell, et al. 1998; Litman 2016). Table 2 summarizes some benefits that tend to result from reduced sprawl.

Table 2 **Smart Growth Benefits** ("Smart Growth, VTPI 2006)

Economic	Social	Environmental
Reduced development and public service costs. Consumer transportation cost savings. Economies of agglomeration. More efficient transportation.	Improved transportation choice, particularly for nondrivers. Improved housing choices. Community cohesion.	Greenspace and wildlife habitat preservation. Reduced air pollution. Reduce resource consumption. Reduced water pollution. Reduced "heat island" effect.

Costs of Induced Travel

Driving imposes a variety of costs, including many that are external, that is, not borne directly by users (Murphy and Delucchi 1998). Table 3 illustrates one estimate of the magnitude of these costs. Other studies show similar costs, with average values of 10-30¢ per vehicle-kilometer, and more under urban-peak conditions (Litman 2003).

Table 3 **Motor Vehicle Indirect and External Costs** (Delucchi 1996)

Cost Item	Examples	Vehicle-Year	Vehicle-Mile
Bundled private sector costs	Parking funded by businesses	$337-1,181	2.7-9.4 cents
Public infrastructure and services	Public roads, parking funded by local governments	$662-1,099	5.3-8.8 cents
Monetary externalities	External crash damages to vehicles, medical expenses, congestion.	$423-780	3.4-6.2 cents
Nonmonetary externalities	Environmental damages, crash pain.	$1,305-3,145	10.4-25.2 cents
Totals		*$2,727-6,205*	*22-50 cents*

This table summarizes an estimate of motor vehicle indirect and external costs. (US 1991 Dollars)

Any incremental external costs of generated traffic should be included in project evaluations, "incremental" meaning the difference between the external costs of the generated travel and the external costs of alternative activities. For diverted traffic this is the difference in external costs between the two trips. For induced travel this is the difference in external costs between the trip and any non-travel activity it replaces, which tends to be large since driving has greater external costs than most other common activities. Most generated traffic occurs under urban-peak travel conditions, when motor vehicle external costs are greatest, so incremental external costs tend to be high.

Incremental external costs depend on road system conditions and the type of generated traffic. Generated traffic often increases downstream congestion (for example, increasing capacity on a highway can add congestion on surface streets, particularly near on- and off-ramps). In some conditions adding capacity actually increases congestion by concentrating traffic on a few links in the network and by reducing travel alternatives, such as public transit (Arnott and Small 1994). Air emission and accident rates per vehicle-mile may decline if traffic flows more freely, but these benefits decline over time and are usually offset as generated traffic leads to renewed congestion and increased vehicle travel (TRB 1995; Shefer and Rietvald 1997; Cassady, Dutzik and Figdor 2004).

Table 4 compares how different types of generated traffic affect costs. All types reduce user travel time and vehicle costs. Diverted trips have minimal incremental costs. Longer trips have moderate incremental costs. Shifts from public transit to driving may also have moderate incremental costs, since transit service has significant externalities but also experiences economies of scale and positive land use impacts that are lost if demand declines ("Social Benefits of Public Transit," VTPI 2001). Induced trips have the largest incremental costs, since they increase virtually all external costs. Longer and induced vehicle trips can lead to more automobile dependent transportation and land use over the long term. These costs are difficult to quantify but are probably significant (Newman and Kenworthy 1998; Burchell, et al 1998).

Table 4 **Cost Impacts of Roadway Capacity Expansion**

Costs Reduced	Costs Increased		
	Diverted Trips	*Longer Trips*	*Induced Trips*
Travel Time Vehicle Operating Costs Per-mile crash rates (if implemented in conjunction with roadway design improvements, but these are often offset if traffic speeds increase). Per-mile pollution emissions (if congestion declines, but these may be offset if traffic speeds increase).	Downstream congestion	Downstream congestion Road facilities Traffic services Per-capita crash rates Pollution emissions Noise Resource externalities Land use impacts Barrier effect	Downstream congestion Road facilities Parking facilities Traffic services Per-capita crash rates Pollution emissions Noise Resource externalities Land use impacts Barrier effect Transit efficiency Equity Vehicle ownership costs

Increased roadway capacity tends to reduce two costs, but increases others.

The incremental external costs of road capacity expansion tend to increase over time as the total amount of generated traffic grows and an increasing portion consists of induced motor vehicle travel and trips.

Table 5 proposes default estimates of the incremental external costs of different types of generated traffic. These values can be adjusted to reflect specific conditions and analysis needs.

Table 5 **Estimated Incremental External Costs of Generated Traffic**

Type	Description	Cost Per Mile
Time and route shift	Trips shifted from off-peak to peak, or from another route.	5 cents
Transit-to-Auto mode shift, and longer trips	Trips shifted from transit to driving alone, and increased automobile trip lengths.	15 cents
Induced vehicle trip	Additional motor vehicle trip, including travel shifted from walking, cycling and ridesharing.	30 cents.

This table indicates the estimated incremental costs of different types of generated traffic.

There is considerable debate concerning the emission impacts of roadway expansion (TRB 1995). Although expanding highly congested roadways may reduce emission rates per vehicle-kilometer, expanding moderately congested roads may increase traffic speeds to levels (more than 80 kms/hr) that increase emission rates, and by inducing total vehicle travel tends to increase total emissions, particularly over the long run. According to a study by the Norwegian Centre for Transport Research (TØI 2009):

> “Road construction, largely speaking, increases greenhouse gas emissions, mainly because an improved quality of the road network will increase the speed level, not the least in the interval where the marginal effect of speed on emissions is large (above 80km/hr). Emissions also rise due to increased volumes of traffic (each person traveling further and more often) and because the modal split changes in favor of the private car, at the expense of public transport and bicycling.”

Table 6 summarizes roadway improvement emission impacts, including effects on emission rates per vehicle mile, increases in total vehicle mileage, and emissions from road construction and maintenance activities.

Table 6 **Roadway Expansion Greenhouse Gas Emission Impacts** (TØI 2009)

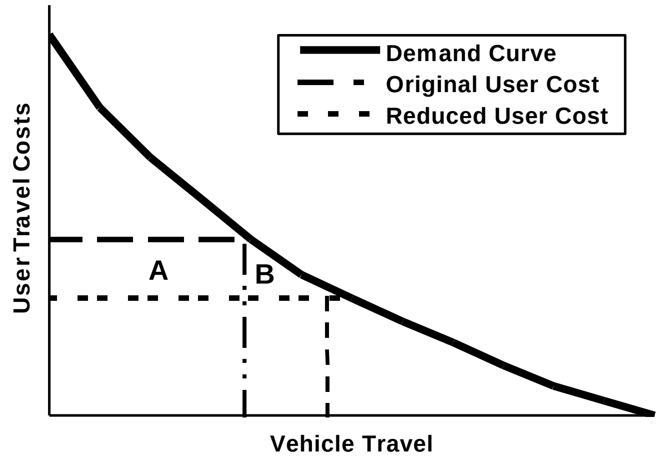
	General Estimates	Large Cities	Small Cities	Intercity Travel
Emission reductions per vehicle-kilometer due to improved and expanded roads.		Short term reductions. Stable or some increase over the long-term.	Depends on situation, ranging from no change to large increases.	Depends on situation. Emissions may decline or increase.
Increased vehicle mileage (induced vehicle travel), short term (under five years)	A 10% reduction in travel time increases traffic 3-5%	Significant emission growth	Moderate emission growth	Moderate emission growth
Increased vehicle mileage (induced travel), long term (more than five years)	A 10% reduction in travel time increases traffic 5-10%	Significant emission growth	Moderate emission growth	Moderate emission growth
Road construction and improvement activity	12 tonnes of CO_2 equivalent for 2-lane roads and 21 tonnes for 4-lane roads.	Road construction emissions are relatively modest compared with traffic emissions.		
Roadway operation and maintenance activity	33 tonnes of CO_2 equivalent for 2-lane roads and 52 tonnes for 4-lane roads.	Road operation and maintenance emissions are relatively modest compared with traffic emissions.		

This table summarizes roadway improvement emission impacts according to research by the Norwegian Centre for Transport Research.

Calculating Consumer Benefits

Generated traffic represents increased mobility, which provides consumer benefits. However, these benefits tend to be modest because generated traffic consists of marginal value trips, the trips that people are most willing to forego (Small 1998). To calculate these benefits economists use the *Rule of Half*, which states that the benefits of additional travel are worth half the per-trip saving to existing travelers, as illustrated in Figure 6 by the fact that B is a triangle rather than a rectangle (AASHTO 1977; Litman 2001a).

Figure 6 **Vehicle Travel Demand Curve Illustrating the Rule-of-Half**



Reduced user costs (downward shift on Y axis) increases vehicle travel (rightward shift on X axis). Rectangle A shows savings to existing trips. Triangle B shows generated travel benefits.

Explanation of the "Rule of Half"
When consumers change their travel in response to a financial incentive, the net consumer surplus averages half of their price change (called the "rule of half"). Let me illustrate.

Let's say that by purchasing a hybrid or electric car, your vehicle operating costs decline from 20₵ to 10₵ per mile, in response you increase 10,000 to 11,000 annual vehicle-miles. The added vehicle-miles have small incremental value to you, between 0¢ and 10¢. If you consider the additional mile worth less than 0¢ (i.e., it has no value), you would not take it. If you considered it worth more than 10¢ per mile, you would have driven that mile without the price reduction. Of the 1,000 miles added we can assume that the average net benefit to users (called the *consumer surplus*) is the mid-point of this range, that is, 5¢ per vehicle mile. Thus, we can calculate the value of the added miles as 5¢ times 1,000 added miles. Conversely, a 10₵ per mile price increase that reduces vehicle travel by 1,000 miles imposes a *net cost* to consumers of $50.

Some people complicate this analysis by trying to track individual changes in consumer travel time, convenience and vehicle operating costs, but that is unnecessary information. All we need to know to value the net consumer surplus is the perceived change in price, either positive or negative, and the resulting change in consumption. This incorporates all of the complex trade-offs that consumers make between money, time, convenience and the value off mobility.

Because induced travel provides relatively small user benefits, and imposes external costs such as downstream congestion, parking costs, accident risk imposed on other road users, pollution

emissions, sprawl and other environmental costs, the ratio of benefits to costs, and therefore total net benefits of travel, tend to decline as more travel is induced.

Failing to account for the full impacts of generated and induced travel tends to exaggerate the benefits of highway capacity expansion and undervalue alternatives such as transit improvements and pricing reforms (Romilly 2004). Some newer project evaluation models, such as the FHWA's SMITE and STEAM sketch plan programs, incorporate generated traffic effects including the Rule of Half and some externalities (FHWA 1997; FHWA 1998; DeCorla-Souza and Cohen 1998).

The benefits of increased mobility are often capitalized into land values. For example, a highway improvement can increase urban periphery real estate prices, or a highway offramp can increase nearby commercial land values (Moore and Thorsnes 1994). Because this increase in land values is an economic transfer (land sellers gain at the expense of land buyers), it is inappropriate to add increased real estate values and transport benefits, such as travel time savings (which represent true resource savings). This would double count benefits.

Emission Impacts

Highway expansion advocates sometimes claim that by reducing traffic congestion, such projects will reduce air pollution emissions, but research indicates that this is generally untrue (Noland and Quddus 2006). Per-mile emission rates are generally minimized at 20-50 miles per hour, as indicated in Figures 7 and 8. As a result, reducing extreme congestion (LOS E or F), so traffic speeds rise above 30 mph may reduce emission rates, but reducing mild congestion (LOS C or D), so traffic speeds increase above 50 mph are likely to increase emission rates, and if roadway expansions induce additional vehicle travel they are likely to increase total emissions.

Figure 6 **European Speed-Emission Curves** (Fontaras, et al. 2014)

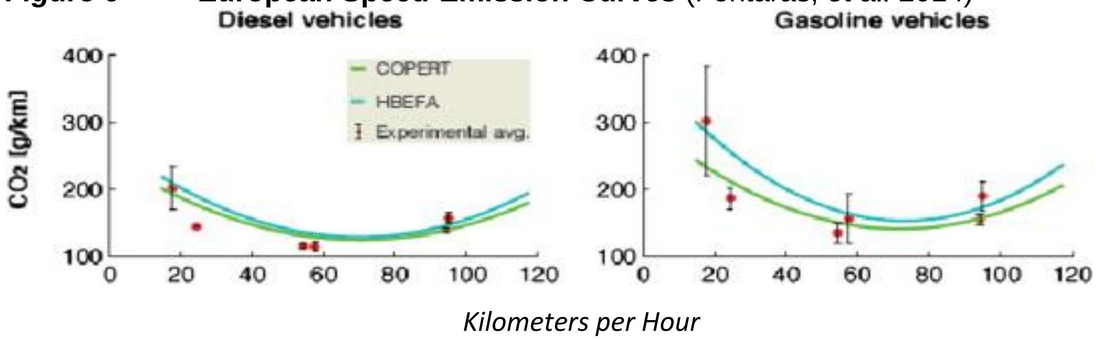
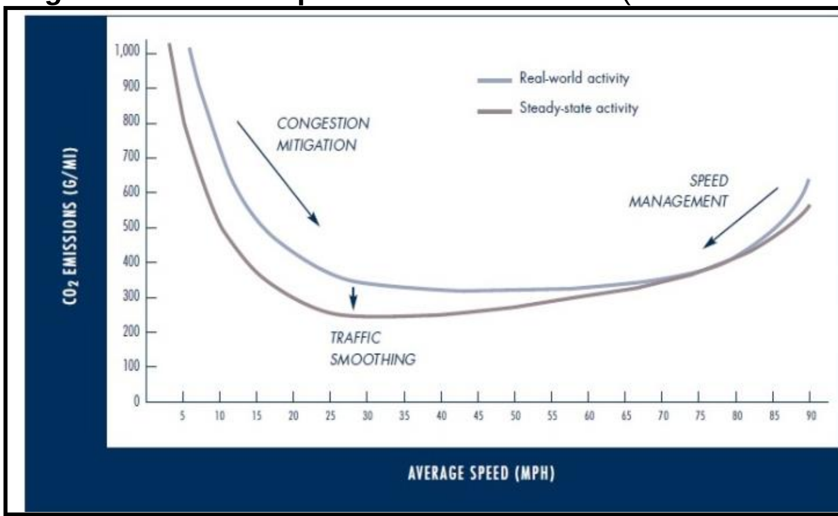


Figure 7 **U.S. Speed-Emission Curves** (Barth and Boriboonsomsin 2009)



Vehicle fuel consumption and emission rates are generally minimized at 20-50 miles per hour. As a result, reducing extreme congestion (LOS E or F), so traffic speeds rise above 30 mph may reduce emission rates, but reducing mild congestion (LOS C or D), so traffic speeds increase above 50 mph are likely to increase emission rates

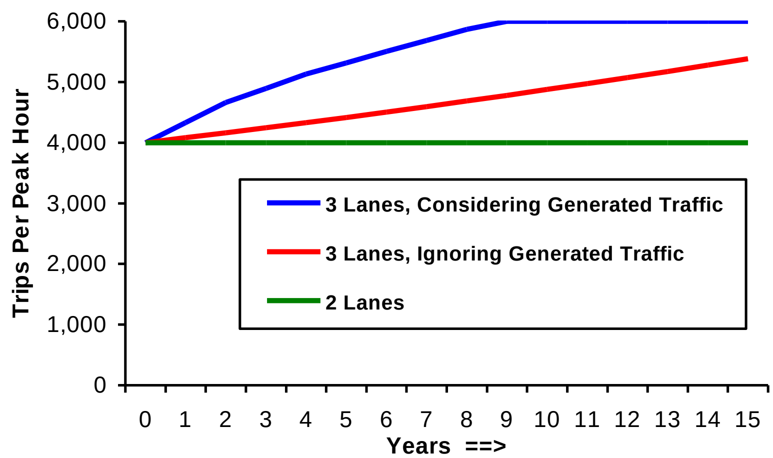
As a result, roadway expansions that reduce extreme congestion may reduce emission rates in the short run, but these impacts are generally small and more than offset over the long run by more high-speed driving and induced vehicle travel. In contrast, other congestion reduction strategies, such as high quality public transit, High Occupancy Vehicle (HOV) lanes, efficient road pricing, and commute trip reduction programs, provide much greater emission reductions (Litman 2019).

Example

A four-lane, 10-kilometer highway connects a city with nearby suburbs. The highway is congested 1,000 hours per year in each direction. Regional travel demand is predicated to grow at 2% per year. A proposal is made to expand the highway to six lanes, costing $25 million in capital expenses and adding $1 million in annual highway operating expenses.

Figure 9 illustrates predicted traffic volumes. Without the project peak-hour traffic is limited to 4,000 vehicles in each direction, the maximum capacity of the two-lane highway. If generated traffic is ignored the model predicts that traffic volumes will grow at a steady 2% per year if the project is implemented. If generated traffic is considered the model predicts faster growth, including the basic 2% growth plus additional growth due to generated traffic, until volumes levels off at 6,000 vehicles per hour, the maximum capacity of three lanes.

Figure 9 **Projected Traffic**

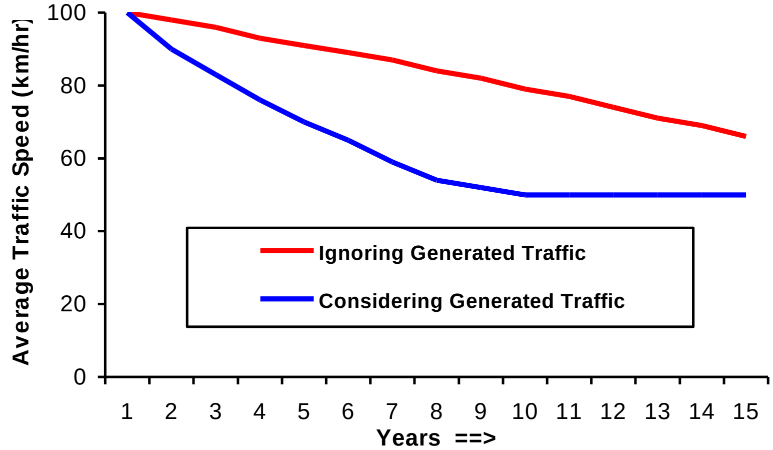


If generated traffic is ignored the model predicts that traffic volumes will grow at a steady 2% per year if the project is implemented. If generated traffic is considered the model predicts a higher initial growth rate, which eventually declines when the road once again reaches capacity and becomes congested. (Based on the "Moderate Latent Demand" curve from Figure 3)

The model divides generated traffic into diverted trips (changes in trip time, route and mode) and induced travel (increased trips and trip length), using the assumption that the first year's generated traffic represents diverted trips and later generated traffic represents induced travel. This simplification appears reasonable since diverted trips tend to occur in the short-term, while induced travel is associated with longer-term changes in consumer behavior and land use patterns.

Roadway volume to capacity ratios are used to calculate peak-period traffic speeds, which are then used to calculate travel time and vehicle operating cost savings. Congestion reduction benefits are predicted to be significantly greater if generated traffic is ignored, as illustrated in Figure 10.

Figure 10 **Projected Average Traffic Speeds**



Ignoring generated traffic exaggerates future traffic speeds and congestion reduction benefits.

Incremental external costs are assumed to average 10¢ per vehicle-km for diverted trips (shifts in time, route and mode) and 30¢ per vehicle-km for induced travel (longer and increased trips). User benefits of generated traffic are calculated using the Rule-of-Half.

Three cases where considered for sensitivity analysis. *Most Favorable* uses assumptions most favorable to the project, *Medium* uses values considered most likely, and *Least Favorable* uses values least favorable to the project. Table 7 summarizes the analysis.

Table 7 **Analysis of Three Cases**

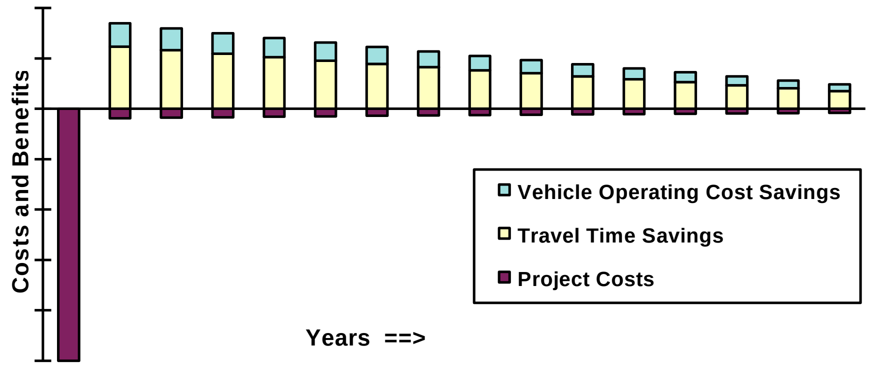
Data Input	Most Favorable	Medium	Least Favorable
Generated Traffic Growth Rate (from Figure 3)	L	M	H
Discount Rate	6%	6%	6%
Maximum Peak Vehicles Per Lane	2,200	2,000	1,800
Before Average Traffic Speed (km/hr)	40	50	60
After Average Traffic Speed (km/hr)	110	100	90
Value of Peak-Period Travel Time (per veh-hr)	$12.00	$8.00	$6.00
Vehicle Operating Costs (per km)	$0.15	$0.12	$0.10
Annual Lane Hours at Capacity Each Direction	1,200	1,000	800
Diverted Trip External Costs (per km)	$0.00	$0.10	$0.15
Induced Travel External Costs (per km)	$0.20	$0.30	$0.50
Net Present Value (millions)			
NPV Without Consideration of Generated Traffic	*$204.8*	*$45.2*	*-$9.8*
NPV With Consideration of Generated Traffic	*$124.5*	*-$32.1*	*-$95.7*
Difference	*-$80.3*	*-$77.3*	*-$85.8*
Benefit/Cost Ratio			
Without Generated Traffic	*6.90*	*2.30*	*0.72*
With Generated Traffic	*3.37*	*0.59*	*0.11*

This table summarizes the assumptions used in this analysis.

The most favorable assumptions result in a positive B/C even when generated traffic is considered. The medium assumptions result in a positive B/C if generated traffic is ignored but a negative NPV if generated traffic is considered. The least favorable assumptions result in a negative B/C even when generated traffic is ignored. In each case, considering generated traffic has significant impacts on the results.

Figure 11 illustrates project benefits and costs based on “Medium” assumptions, ignoring generated traffic. This results in a positive NPV of $45.2 million, implying that the project is economically worthwhile.

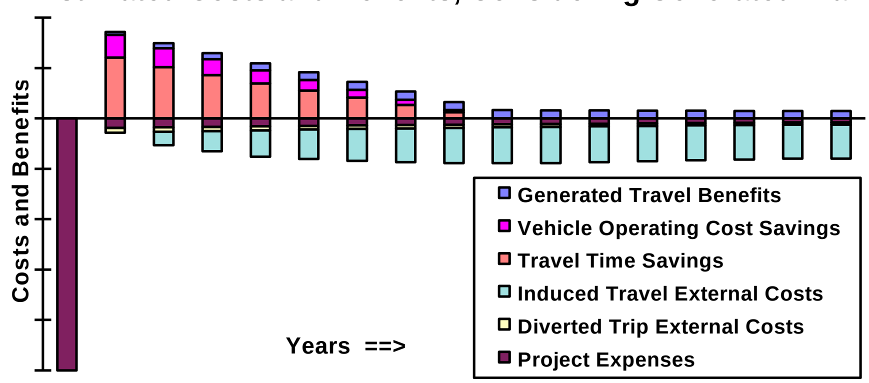
Figure 11 **Estimated Costs and Benefits, Ignoring Generated Traffic**



This figure illustrates annual benefits and costs when generated traffic is ignored, using “Medium” assumptions. Benefits are bars above the baseline, costs are bars below the baseline. Project expenses are the only cost category.

Figure 10 illustrates project evaluation when generated traffic is considered. Congestion reduction benefits decline, and additional external costs and consumer benefits are included. The NPV is –$32.1 million, indicating the project is not worthwhile.

Figure 10 **Estimated Costs and Benefits, Considering Generated Traffic**

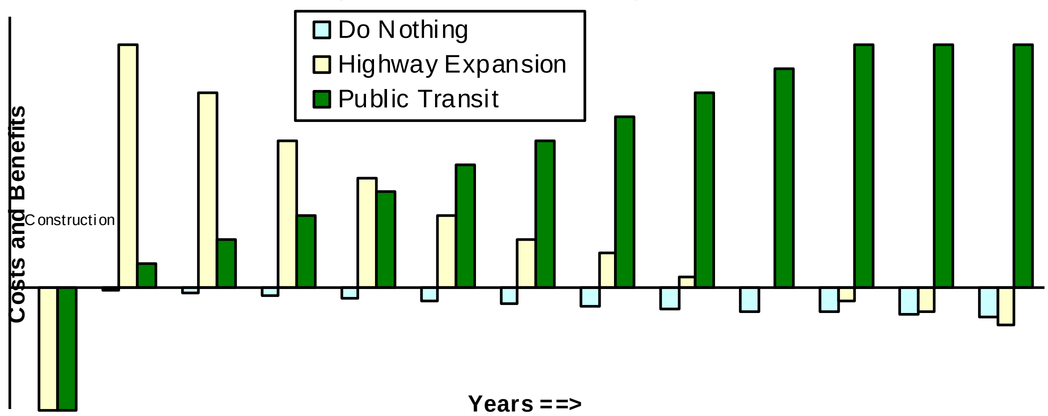


This figure illustrates benefits and costs when generated traffic is considered, using medium assumptions. Benefits are bars above the baseline, costs are bars below the baseline. It includes consumer benefits and external costs associated with generated traffic. Travel time and vehicle operating cost savings end after about 10 years, when traffic volumes per lane return to pre-project levels, resulting in no congestion reduction benefits after that time.

This analysis indicates how generated traffic can have significant impacts on project assessment. Ignoring generated traffic exaggerates the benefits of highway capacity expansion by overestimating congestion reduction benefits and ignoring incremental external costs from generated traffic. This tends to undervalue alternatives such as road pricing, TDM programs, other modes, and "do nothing" options.

For example, Figure 11 compares three possible responses to congestion on a corridor with increasing traffic demand. Do nothing causes traffic congestion costs to increase over time. Expanding general traffic lanes imposes large initial costs due to construction delays, but provides large short-term congestion reduction benefits. However, these decline over time, due to induced traffic, and the additional vehicle travel imposes additional external costs including downstream congestion, increased parking demand, accident risk and pollution emissions. Building grade-separated public transit (either a bus lane or rail line) also imposes short-run congestion delays, and the congestion reduction benefits are relatively small in the short term but increase over time as transit ridership grows, networks expand, and development becomes more transit-oriented.

Figure 11 **Road Widening Versus Transit Congestion Impacts**



A Do Nothing causes congestion costs to increase in the future. Highway expansion imposes short term construction delays, then large congestion reduction benefits, but these decline over time due to generated traffic. Grade-separated public transit provides smaller benefits in the short-term but these increase over time as public transit ridership grows.

Counter Arguments

"Widening roads to ease congestion is like trying to cure obesity by loosening your belt" Roy Kienitz, executive director of the Surface Transportation Policy Project

"Increasing highway capacity is equivalent to giving bigger shoes to growing children" Robert Dunphy of the Urban Land Institute

Some highway expansion advocates argue that generated traffic has minor implications for transport planning decisions. They argue that increased highway capacity contributes little to overall growth in vehicle travel compared with other factors such as increased population, employment and income (Heanue 1998; Sen 1998; Burt and Hoover 2006), that although new highways generate traffic, they still provide net economic benefits (ULI 1989), and that increasing roadway capacity does reduce congestion (TRIP 1999; Bayliss 2008).

These arguments ignore critical issues, and are often based on outdated data and inaccurate analysis. Overall travel trends indicate little about the cost effectiveness of particular policies and projects. For example, studies which indicate that, in the past, increased lane-miles caused minimal growth in vehicle travel (Burt and Hoover 2006), provide little guidance for future planning, since, in the past, much of the added highway lane-miles occurred on uncongested rural highways while most future highway expansion occurs on congested urban highways. Strategies that encourage more efficient use of existing capacity, such as commute trip reduction programs and road pricing, may provide greater social benefits, particularly considering all costs (Goodwin 1997).

Highway expansion advocates generally ignore or severely understate generated traffic and induced travel impacts. For example, Cox and Pisarski (2004) use a model that accounts for diverted traffic (trips shifted in time or route) but ignores shifts in mode, destination and trip frequency. Hartgen and Fields (2006) assume that generated traffic would fill just 15% of added roadway capacity, based on generated traffic rates during the 1960s and 1970s, which is unrealistically low when extremely congested roads are expanded. They ignore the incremental costs that result from induced vehicle travel, such as increased downstream traffic congestion, road and parking costs, accidents and pollution emissions. They claim that roadway capacity expansion reduces fuel consumption, pollution emissions and accidents, because they measure impacts per vehicle-mile and ignore increased vehicle miles. As a result they significantly exaggerate roadway expansion benefits and understate total costs.

Debates over generated traffic and its implications often reflect ideological perspectives concerning whether automobile travel (and therefore road capacity expansion) is "good" or "bad". To an economist, such arguments are silly. Some automobile travel provides large net benefits (high user value, poor alternatives, low external costs), and some provides negative net benefits (low user value, good alternatives, and large external costs). The efficient solution to congestion is to use pricing or other incentives to test consumers' willingness to pay for road space and capacity expansion.

If consumers only demand roadway improvements when they are shielded from the true costs, such projects are likely to be economically inefficient. Only if users are willing to pay the full incremental costs their vehicle use imposes can society be sure that increased road capacity and

the additional vehicle travel that results provides net benefits. Travel demand predictions based on underpriced roads overestimate the economically optimal level of roadway investments and capacity expansion. Increasing capacity in such cases is more equivalent to loosening a belt than giving a growing child larger shoes (see quotes above), since the additional vehicle travel is a luxury and economically inefficient.

Some highway advocates suggest there are equity reasons to subsidize roadway capacity expansion, to allow lower-income households access to more desirable locations, but most benefits from increased roadway capacity are captured by middle- and upper-income households (Deakin, et al. 1996). Improving travel choices for non-drivers tends to have greater equity benefits than subsidizing additional highway capacity since physically and economically disadvantaged people often rely on alternative modes.

Although highway projects are often justified for the sake of economic development, highway capacity expansion now provides little net economic benefit (Boarnet 1997). An expert review concluded, "The available evidence does not support arguments that new transport investment in general has a major impact on economic growth in a country with an already well-developed infrastructure" (SACTRA 1997). Melo, Graham and Canavan (2012) found a positive relationship between U.S. urban highway expansion and economic output between 1982 and 2009, but conclude that other types of transportation system improvements could provide greater net benefits.

Alternative Transport Improvement Strategies

Since roadway capacity expansion provides smaller net benefits than is often recognized, due to the effects of generated traffic, other solutions to transportation problems may provide relatively more benefits. A "No Build" option may become more attractive since peak-period traffic volumes will simply level off without additional capacity. This can explain, for example, why urban commute travel times are virtually unchanged despite increases in traffic congestion, and why urban regions that have made major investments in highway capacity expansion have not experienced significant reductions in traffic congestion (Gordon and Richardson 1994; STPP 1998).

Consideration of generated traffic gives more value to transportation systems management and transportation demand management strategies that result in more efficient use of existing roadway capacity. These strategies cannot individually solve all transportation problems, but a package of them can, often with less costs and greater overall benefit than highway capacity expansion. Below are examples (VTPI 2001):

- Congestion pricing can provide travelers with an incentive to reduce their peak period trips and use travel alternatives, such as ridesharing and non-motorized transport.

- Commute trip reduction programs can provide a framework for encouraging commuters to drive less and rely more on travel alternatives.

- Land use management can increase access by bringing closer common destinations.

- Pedestrian and cycle improvements can increase mobility and access, and support other modes such as public transit (since transit users also depend on walking and cycling).

- Public transit service that offers door-to-door travel times and user costs that are competitive with driving can attract travelers from a parallel highway, limiting the magnitude of traffic congestion on that corridor.

Legal Issues

Environmental groups successfully sued the Illinois transportation agencies for failing to consider land use impacts and generated traffic in the Environmental Impact Statement (EIS) for I-355, a proposed highway extension outside the city of Chicago (Sierra Club 1997). The federal court concluded that the EIS was based on the "implausible" assumption that population in the rural areas would grow by the same amount with and without the tollroad, even though project was promoted as a way to stimulate growth. The court concluded that this circular reasoning afflicted the document's core findings. The judge required the agencies to prepare studies identifying the amount of development the tollroad would cause, and compare this with alternatives. The Court's order states:

> Plaintiffs' argument is persuasive. Highways create demand for travel and expansion by their very existence…Environmental laws are not arbitrary hoops through which government agencies must jump. The environmental regulations at issue in this case are designed to ensure that the public and government agencies are well informed about the environmental consequences of proposed actions. The environmental impact statements in this case fail in several significant respects to serve this purpose. (ELCP)

In 2008 the California Attorney General recognized that regional transportation plans must consider induced travel impacts when evaluating the climate change impacts of individual projects to meet California Environmental Quality Act (CEQA) requirements (Brown 2008). CEQA requires that "[e]ach public agency shall mitigate or avoid the significant effects on the environment of projects that it carries out or approves whenever it is feasible to do so." The state Attorney General recognizes that transportation planning decisions, such as highway expansion projects, can have significant emission impacts due to induced vehicle travel.

Some new laws and regulations, such as California Senate Bill 743 (S.B. 743), prohibit the use of vehicle level of service (LOS) and similar measures as the sole basis for evaluating transportation improvement options; instead, policies and project are evaluated based on their ability to reduce vehicle miles traveled (VMT). This will require consideration of induced travel effects in analysis of roadway projects (Milam, et al. 2017).

In 2020, the California Department of Transportation established specific requirements for evaluating and mitigating the induced travel impacts of roadway expansion projects (Sundquist 2020). The analyses will be based on lane-miles-to-induced-VMT elasticities, as specified in the *Transportation Analysis Framework: Induced Travel Analysis* report (CALTRANS 2020), and estimated by the National Center for Sustainable Transportation's *Induced Travel Calculator* (NCST 2019).

Conclusions

Urban traffic congestion tends to maintain equilibrium. Congestion reaches a point at which it discourages additional peak-period trips. Increasing road capacity allows more vehicle travel to occur. In the short term this consists primarily of generated traffic: vehicle travel diverted from other times, modes, routes and destinations. Over the long run an increasing portion consists of induced vehicle travel, resulting in a total increase in regional VMT. This has several implications for transport planning:

- Ignoring generated traffic underestimates the magnitude of future traffic congestion problems, overestimates the congestion reduction benefits of increasing roadway capacity, and underestimates the benefits of alternative solutions to transportation problems.
- Induced travel increases many external costs. Over the long term it helps create more automobile dependent transportation systems and land use patterns.
- The mobility benefits of generated traffic are relatively small since they consist of marginal value trips. Much of the benefits are often capitalized into land values.

Ignoring generated traffic results in self-fulfilling *predict and provide* planning: Planners extrapolate traffic growth rates to predict that congestion will reach *gridlock* unless capacity expands. Adding capacity generates traffic, which leads to renewed congestion with higher traffic volumes, and more automobile oriented transport and land use patterns. This cycle continues until road capacity expansion costs become unacceptable.

The amount of traffic generated depends on specific conditions. Expanding highly congested roads with considerable latent demand tends to generate significant amounts of traffic, providing only temporary congestion reductions.

Generated traffic does not mean that roadway expansion provides no benefits and should never be implemented. However, ignoring generated traffic results in inaccurate forecasts of impacts and benefits. Road projects considered cost effective by conventional analysis may actually provide little long-term benefit to motorists and make society overall worse off due to induced travel external costs. Other strategies may be better overall. Another implication is that highway capacity expansion projects should incorporate strategies to avoid increasing external costs, such as more stringent vehicle emission regulations to avoid increasing pollution and land use regulations to limit sprawl.

Framing the Congestion Question
If you ask people, *“Do you think that traffic congestion is a serious problem?”* they frequently answer yes. If you ask, *“Would you rather solve congestion problems by improving roads or by using alternatives such as congestion tolls and other TDM strategies?”* a smaller majority would probably choose the road improvement option. This is how transport choices are generally framed.

But if you present the choices more realistically by asking, *“Would you rather spend a lot of money to increase road capacity to achieve moderate and temporary congestion reductions and bear higher future costs from increased motor vehicle traffic, or implement other types of transportation improvements?”* the preference for road building is likely to decline.

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