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Safe Travels

Evaluating Transportation Demand Management Traffic Safety Impacts

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Abstract

This report investigates the relationships between mobility (the amount people travel) and crash risk, and the safety impacts of *Transportation Demand Management (TDM)* strategies that change how and how much people travel. This research indicates that per capita traffic crash rates tend to increase with per capita vehicle travel, and TDM strategies can provide significant safety benefits. Strategies that reduce per capita vehicle travel or shift travel from automobile to alternative modes tend to reduce overall crash risk. Smart Growth development policies, which create more compact development, tend to significantly reduce per capita crash casualty rates, but by increasing traffic density may increase minor crash rates per vehicle-mile. Strategies that reduce traffic speeds reduce crash frequency and severity. Conventional traffic risk analysis understates many of these impacts. This analysis indicates that TDM is a cost effective traffic safety strategy, and increased safety is one of its largest but often undervalued benefits.

Summarized in:
Todd Litman (2019), "Toward More Comprehensive Evaluation of Traffic Risks and Safety Strategies" *Research in Transportation Business & Management* (doi.org/10.1016/j.rtbm.2019.01.003).

Contents

Executive Summary

A *paradigm shift* is changing the way traffic risks are defined and potential solutions evaluated (Litman 2017; Welle, et al. 2018). The old paradigm assumes that motor vehicle travel is overall a safe activity, since most accidents are associated with special risks such young or old drivers, driver impairment or hazardous roadway conditions. From this perspective, it would be inefficient and unfair to reduce total driving for safety sake because that would punish all motorists for dangers created by a minority. As a result, the old paradigm emphasizes targeted safety programs designed to reduce high-risk driving activities. Such programs tend to reduce *distance-based* crash rates (such as per 100 million vehicle miles or billion vehicle-kilometers), but are less successful when measured *per capita* because their safety benefit are often offset by increased vehicle travel, resulting in high crash casualty rates in high annual mileage countries such as the United States.

A new safety paradigm recognizes that all vehicle travel incurs risks, and that high-risk and low-risk driving are complements: transport and land use policies that increase per capita vehicle travel inevitably increase high-risk driving. For example, in automobile-dependent communities people often drive to events where alcohol is consumed, most young males have drivers' licenses and cars, and seniors continue driving despite declining ability because mobility alternatives are unavailable and stigmatized. The new paradigm recognizes the safety benefits of both targeted programs and *Transportation Demand Management* (TDM, also called *mobility management*) strategies that reduce total vehicle travel.

Although not all experts understand or endorse the new safety paradigm it is gaining accepted. For example, the Federal Highway Administration 2010 *Transportation Planner's Safety Desk Reference* (FHWA 2012) recognizes that, "By providing mobility alternatives to the auto, transit reduces vehicle miles traveled (VMT), resulting in fewer traffic incidents, injuries, and fatalities. Transit ridership can be encouraged among the groups with the highest crash rates, such as young and older drivers, to reduce the potential for crashes." That is a major step toward recognizing mobility management as a traffic safety strategy. However, the *Safety Desk Reference* provides no guidance on how to calculate mobility management safety benefits or incorporate mobility management into traffic safety programs.

The new paradigm supports more integrated and beneficial planning. Most conventional safety strategies impose significant costs and provide few other benefits. For example, driver impairment reduction strategies require restrictive drinking policies and increased policing, improved vehicle crash protection adds equipment costs and vehicle weight, and reducing roadside hazards often involves more costly roadway engineering and loss of roadside trees. In contrast, most mobility management strategies provide significant co-benefits including congestion reduction, road and parking facility cost savings, consumer savings, energy conservation and emission reductions, and improved mobility for non-drivers, and improved public fitness and health, in addition to increased safety.

The table below summarizes these impacts. Most conventional transport safety and health strategies provide limited benefits. Most TDM strategies provide various safety, health and other benefits, and so are justified by more comprehensive analysis.

Table ES-1 **Transport Safety and Health Strategies Impact Summary**

Strategies	Safety	Pollution	Fitness	Basic Access	Other Impacts
Conventional Safety and Health Strategies					
Targeted safety programs	Large benefits	No benefit	No benefit	No benefit	More regulations and program costs
Crash protection	Large benefits	No benefit	No benefit	No benefit	Equipment costs and heavier vehicles
Road safety design	Moderate benefits	No benefit	No benefit	No benefit	Increased roadway costs, loss of trees
Efficient and alt. fuel vehicles	No benefit	Large benefits	No benefit	No benefit	Varies. Energy conservation
Exercise and sport promotion	No benefit	No benefit	Large benefits	No benefit	Increased user enjoyment
Mobility Management Strategies					
Traffic calming and speed control	Large benefits	Mixed. Can increase local emissions	Large benefit	Large benefit	Program costs. Lower travel speeds
Active transport improvements	Benefits if programs increase walking & cycling safety	Large benefits	Large benefits	Large benefits	Program costs. Reduced congestion. User enjoyment
Public transit improvements	Large benefits	Large benefits	Large benefits	Large benefits	Program costs. Reduced traffic and parking congestion.
Transport pricing reforms	Large benefits	Large benefits	Large benefits	Mixed. Can improve travel options.	Additional user costs. Revenues. Reduced traffic and parking congestion
Mobility management marketing	Moderate benefits	Moderate benefits	Moderate benefits	Small benefits	Program costs. Reduced traffic and parking congestion
Smart growth development policies	Large benefits	Mixed. Reduces emissions but may increase proximity	Large benefits	Large benefits	Various costs and benefits

This table summarizes the impacts of various traffic safety strategies, including mobility management.

The new paradigm tends to face two general types of criticism. First, that the relationship between mobility and crashes is uncertain. However, researchers have accumulated abundant evidence that crash rates increase with vehicle travel and can be reduced by various mobility management strategies, as described in this report. Second, that by reducing vehicle travel, mobility management is burdensome to individuals and harmful to the economy. However, there is evidence that many people would prefer to drive less and rely more on alternative modes, and that many mobility management strategies are justified on efficiency principles and help support economic development.

Introduction

Public policies affect people's travel patterns, which affects their exposure to traffic risk, and therefore per capita crash costs. Policies that reduce vehicle travel, reduce traffic speeds, and improve travel options, particularly for higher risk drivers (younger and older drivers, people out drinking alcohol), can improve traffic safety.

In total, residents of more accessible, multi-modal, *Smart Growth* communities have about a quarter the per capita traffic casualty rate in more automobile-dependent communities. Many families move to automobile-oriented communities because they want a safe and healthy to raise their children. They are mistaken. Overall, urban neighborhoods tend to be significantly safer than automobile-dependent locations, because any homicide risk increase (which are actually small or non-existent) is more than offset by higher traffic fatality risks in suburban and rural areas (Lucy 2003; Frumkin, Frank and Jackson 2004; Ewing and Dumbaugh 2009; Myers, et al. 2013).

Traffic crashes are a significant problem, causing tens of thousands of deaths, millions of injuries and hundreds of billions of dollars in economic costs annually (Miller 1991; Litman 2009). For people aged 1 to 33, traffic crashes are the single greatest cause of fatalities and disabilities, and therefore a major cause of potential years of productive life lost (CDC 2003; NHTSA 2005). Many consumers consider safety an important consideration when choosing vehicles and willingly pay a premium for optional safety features. Safety is also a paramount consideration in roadway design and operations. Yet, safety is not usually a consideration when evaluating policies that affect *how much* vehicle travel occurs or to justify traffic reduction programs. This may be an oversight. In fact, safety may be one of the greatest benefits of mobility management.

Transportation Demand Management (*TDM*, also called *mobility management*) includes various strategies that increase transportation system efficiency by changing travel frequency, destination, mode and timing. Table 1 lists various TDM strategies. These are an increasingly common response to urban traffic congestion and pollution problems. For example, the Congestion Management and Air Quality (CMAQ) program and many regional transport plans include mobility management components.

Table 1 **Transportation Demand Management Strategies** (VTPI 2004)

Improves Transport Options	Pricing Incentives	Land Use Management	Implementation Programs
Transit improvements Walking and cycling improvements Rideshare programs Flextime Telework Carsharing Guaranteed ride home	Congestion pricing Distance-based fees Parking cash out Parking pricing Pay-as-you-drive vehicle insurance and registration fees Fuel tax increases	Smart growth New urbanism Parking management Transit oriented development Complete streets Car-free planning Traffic calming	Commute trip reduction programs School and campus transport management Freight transport management Tourist transport management Marketing programs

This table lists various mobility management strategies.

This report explores the relationships between mobility (how much and how people travel) and crash risk, the potential traffic safety impacts of mobility management, and the degree these impacts are considered in conventional transport planning. It builds on an extensive body of research concerning these relationships (Ahangari, Atkinson-Palombo and Garrick 2017; Duduta, Adriazola-Steil and Hidalgo 2013; Vickrey 1968, Haight 1994; Edlin and Karaca-Mandic 2006).

Table 2 **Factors Affecting Traffic Casualty Rates**

User Behavior	Vehicles	Facilities	Mobility
Attitudes Impairment Seatbelt and helmet use	Road worthiness Occupant restraints Other safety devices Crash-protection design	Road design & maintenance Pedestrian and cycling facilities Traffic speeds Emergency response and medical care	Per capita vehicle travel (exposure) Mode share

Many factors affect per capita traffic casualty rates. Some affect crash frequency, others crash severity (the risk of injury or death when a crash occurs), or emergency response and medical care.

This issue is both simple and complex. It is simple because, all else being equal, per capita vehicle travel undoubtedly affects crash frequency, but is complex because many other factors also affect crash rates (Table 2), and mobility management strategies affect travel in many ways (Table 3) with various impacts on crash frequency and severity. Different mobility management programs affect different types of travelers and trips, such as commute trips or short-distance urban trips, which have different risk profiles. Some travel changes reduce risk for one group but increase it for others. It is therefore important to understand how individual mobility management strategies affect travel and how such changes affect crash risks.

Table 3 **Examples of TDM Travel Impacts**

TDM Strategies	Travel Changes
Commute trip reduction	Reduces automobile commute trips, shifts to alternative modes.
Flextime	Reduces peak-period vehicle travel on a particular roadway by shifting travel time.
Compressed workweek	Reduces commute trips.
Fuel tax increases	Reduces vehicle travel and traffic speeds
Congestion pricing	Reduces peak-period vehicle travel on a particular roadway by shifting travel route, time, destination and mode.
Efficient parking pricing	Reduces vehicle ownership (in residential buildings) and trips (in commercial)
Distance-based charges	Reduces overall vehicle travel.
Transit improvements	Shifts mode, increases transit use.
Rideshare promotion	Increases vehicle occupancy, reduces vehicle trips.
Walking and cycling improvements	Increases walking and cycling safety, reduces automobile travel.
Telework	Reduced vehicle travel.
Carsharing	Reduces vehicle ownership and trips.
Smart Growth, New Urbanism	Creates more accessible land use, reduces trip distances, shifts modes (to walking, cycling and public transit) and reduces travel speeds. Increases traffic density.
Traffic Calming	Reduces traffic speeds, improves pedestrian conditions.

Different types of TDM strategies cause different types of travel changes.

This issue is controversial. Some experts challenge the idea that mileage is a significant risk factor and that mobility management is an appropriate safety strategy. Some argue that "there are no accidents," claiming that every crash has a preventable cause, so safety interventions could provide virtually risk-free travel. Most experts devote their careers to reducing specific risk factors such as impaired driving and risky roadway conditions, and are proud of their efforts. Similarly, transport planners and engineers, who work to accommodate increased vehicle travel, also tend to resist the idea that their efforts may increase overall traffic risk. Individual motorists consider safe driving a point of pride – the majority of drivers consider their driving skills "above average" – and so find insulting the idea that their own driving is dangerous and reducing their driving would increase safety (Williams 2003).

As a result safety experts and individual drivers tend to prefer targeted campaigns that discourage specific risky behaviors or driving by particularly high-risk groups, such as alcohol drinkers and young males, rather than overall vehicle travel (Mathis 2014). From this perspective, efforts to increase safety by reducing total vehicle travel seem confusing because it contradicts their primary safety messages, and unfair because they "punishe" all drivers for risks imposed by a few.

Although these arguments are partially justified, they are overall wrong. It is true that specific risk factors such as alcohol impairment or drivers with poor driving records contribute to approximately half of all casualty crashes,[1] but that leaves about half of all crashes caused by sober, average-risk drivers making normal errors. Even drivers who never violate traffic rules face risks beyond their control – errors by another driver, an animal running into the roadway, catastrophic mechanical failure, a sudden medical problem – and most drivers take minor risks with small but real chances of contributing to a crash. If half of all casualty crashes are caused by average-risk driving, and half the victims of crashes causes by high risk driving are occupants of other vehicles, then three-quarter of all road casualties can be avoided by reducing average-risk vehicle travel.

This is not to suggest that targeted programs are misguided. However, to the degree that they are successful and reduce higher risk driving, the portion of crashes caused by lower-risk driver will increase, and so will the safety value of mobility management.

Mobility management is seldom implemented primarily for safety sake; its objectives are usually congestion reduction, road and parking cost savings, energy conservation and emission reductions, or improved mobility options for non-drivers. However, recognizing safety benefits can increase support for mobility management, and therefore significantly expand its implementation. Attitudes and institutions will need to changes for mobility management strategies to be implemented to the degree justified for their safety benefits as well as other planning objectives (May, Tranter and Warn 2011).

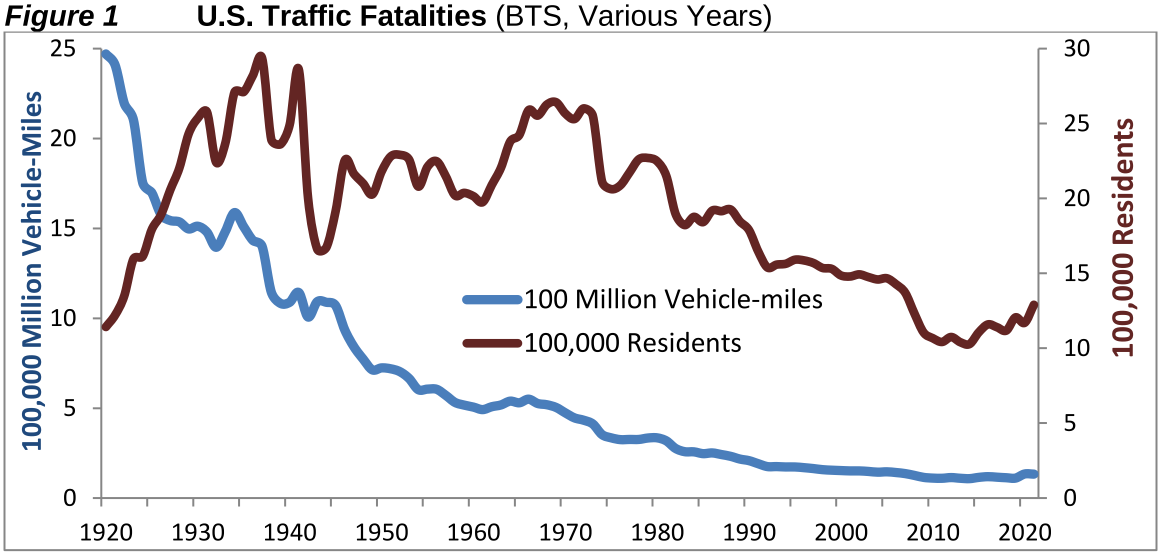
[1] According to National Highway Traffic Safety Administration's *Traffic Safety Facts 2006*, alcohol contributed to 42% of crashes and speeding to 31% (many crashes involved both).

Evaluating Risk

Traffic safety evaluation is affected by how risk is measured. Different types of data can result in very different conclusions about the nature of traffic risk and how safety can be improved. Traffic safety studies measure *crashes* (also called *incidents*, *accidents* or *collisions*), *injuries*, *fatalities* and *casualties* (human injuries and fatalities). Crash statistics definitions may vary between jurisdictions, such as which types of injuries and deaths are included. Traffic fatality data tends to be more available and reliable than for other crash types. For each motor vehicle crash death, typically eight people are hospitalized, and 100 are treated and released from a clinic or hospital emergency room (Bergen, et al. 2014). Crash statistics may reflect either *reported* crashes or estimated *total crashes* (reported crashes increased by some value to include estimated unreported crashes). Casualty statistics for a particular mode may include only users of that mode or they may include other road users. Casualty rates for some modes (such as automobile and rail) are affected by whether or not suicides are included (presumably, many of these would choose another way to die if that transport mode were unavailable).

The units used to measure risk can also affect analysis. For example, *crash* rates tend to increase with urban densities due to more frequent interactions between vehicles, but crash *severity* and therefore *casualty* (injury and death) rates tend to be higher in rural areas due to higher traffic speeds. Similarly, risk analysis is affected by the *reference units* used (Aurbach 2016). For example, Figure 1 illustrates traffic fatality rates using two different denominators. Measured using *distance-based units* (per 100 million vehicle-miles or billion vehicle-kilometers), fatality rates declined more than two thirds during the last half century. From this perspective, traffic safety programs were successful and should be continued to further reduce road risk.

Figure 1 **U.S. Traffic Fatalities** (BTS, Various Years)

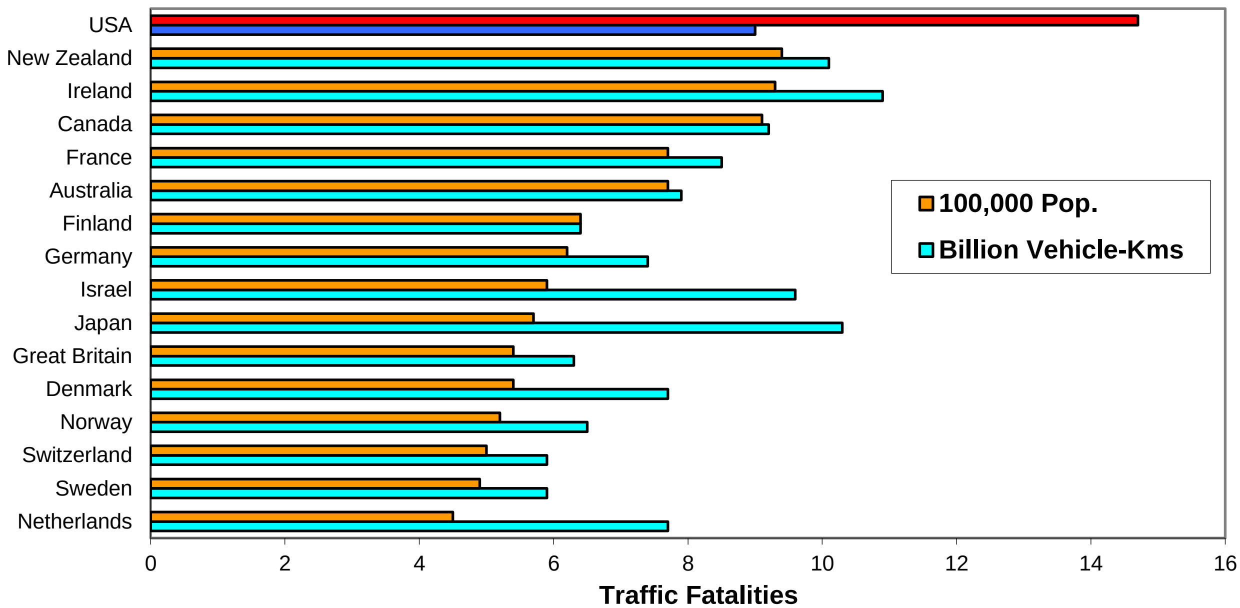


This figure illustrates traffic fatality trends between 1920 and 2020. Per mile crash rates declined substantially, but per capita crash rates declined little despite significant traffic safety efforts. Per capita crash rates increased after 2010.

Although crash rates per 100 million vehicle-miles declined significantly during this period, that was partly offset by large increases in per capita vehicle travel. When measured *per capita* (e.g., per 100,000 population), as with other health risks, there was little improvement during this period despite significant road and vehicle design improvements, increased use of safety devices, reduced drunk driving, and better emergency response and medical care. Taking these factors into account, much greater casualty reductions are expected. For example, seat belt use increased from nearly 0% in 1960 to 75% in 2002, which by itself should reduce per capita traffic fatalities by about 33% (wearing a seat belt typically reduces the chances of dying in a car crash about half), yet, per capita traffic deaths declined only about 25%. Recently, traffic crash rates have started to increase, indicating that the effectiveness of existing traffic safety strategies has peaked and new approaches are needed to achieve additional safety gains.

Traffic crashes continue to be one of the greatest single causes of deaths and disabilities for people aged 1-44 years (CDC 2003). Although the U.S. has one of the lowest traffic fatality rates *per vehicle-mile*, it has one of the highest traffic fatality rates *per capita* among peer countries (BITRE 2018), as illustrated in Figure 2. Traffic risk continues to be a major problem.

Figure 2 **International Traffic Fatality Rates** (based on WHO and OECD data)



The USA has the highest per capita traffic fatality rate among peer countries and one of the highest distance-based fatality rates.

The distinction between distance-based and per capita traffic risk analysis has particular important for evaluating TDM. Distance-based analysis treats mobility (the amount that people travel) as exogenous, outside the scope of policy interventions. When road risk is evaluated using distance-based units, increased vehicle mileage is not considered a risk factor, and mobility management is not considered a safety strategy. From this perspective, an increase in total crashes is not a safety problem provided that there is a comparable increase in vehicle travel; in fact, increased vehicle mileage under relatively safe conditions appears to increase safety because more low-risk miles reduce per-mile crash rates. For example, grade-separated highways have low per-mile crash rates and stimulate increased vehicle mileage. As a result, they tend to reduce per-mile crash rates but increase per capita crash rates (Noland 2003).

Comprehensive safety analysis should account for both *internal* risk (borne directly by the person imposing the risk) and *external* risk (borne by others in society). For example, increasing vehicle weight reduces occupants' risk but increases risk to other road users. Many safety strategies (seat belts and airbags) reduce a vehicle occupants' risk but not the risk to other road users. Strategies that reduced vehicle mileage or speed, or increase driver caution, reduce crash frequency and therefore both internal and external risks.

Traffic safety analysis is complicated by the tendency of risks to maintain equilibrium, that is, when risk is considered excessive, individuals and society respond until it is reduced to a more acceptable level, called *offsetting behavior* or *target risk* (Adams 2010). This can involve responses by individual travelers who become more cautious, and safety programs that target specific geographic areas, groups or modes considered high risk. Conversely, motorists tend to take small additional risks (they drive more *intensely*) when they feel relatively safe, such as driving faster, or talking on a telephone while driving, and deferring vehicle maintenance because they consider themselves more skilled than average and their driving conditions are considered normal risk. As a result, it can be difficult to ascertain the safety impacts of a particular strategy or program.

Sorensen and Mosslemi (2009) make a distinction between *objective* (actual) and *subjective* (perceived) risks. Of 125 traffic safety strategies they evaluated, 78 were found to have positive effects on both subjective and objective safety, 25 have conflicting effects (improves objective but reduces perceived safety), and 20 have uncertain effects.

In addition to crashes, transport policies affect other major health risks: exposure to pollution emissions, and physical fitness (Frumkin, Frank and Jackson 2004; Litman 2003; DHHS 2008). Reductions in per capita vehicle travel tend to reduce total pollution emissions, although more compact development patterns may increase emission density (the amount of pollution emitted per acre), and therefore increase exposure to certain harmful emissions, such as carbon monoxide. Improved walking and cycling conditions, more mixed land use (so destinations such as shops and schools are within walking distance of homes and worksites), and increased public transit use (since most transit trips involve walking or cycling links) tend to increase per capita walking and cycling activity, leading to improved physical fitness and health. However, these relationships are complex: increases in active transport (walking and cycling) and associated reductions in obesity rates do not necessarily lead to increased longevity, indicating that other factors, such as diet and stress may be more important (Grammenos 2011).

Sustainable traffic safety planning favors crash reduction strategies that are durable and cost effective, and integrated with other sustainable planning efforts (Litman 2023). It applies seven basic principles: evaluate all traffic risks, both borne and imposed; measure risk per capita rather than using distance-based units; account for offsetting behavior that reduces long-term effectiveness; account for induced vehicle travel impacts that increase risk and resource consumption; consider TDM strategies; consider other sustainability goals; and consider safety in all planning. Most current traffic safety and emission reduction plans fail to reflect these principles, which often results in traffic safety strategies that increase emissions and emission reduction strategies that increase traffic risk. Sustainability principles identify win-win solutions: safety strategies that help achieve other planning goals. Applying these principles can significantly reduce both crashes and emissions.

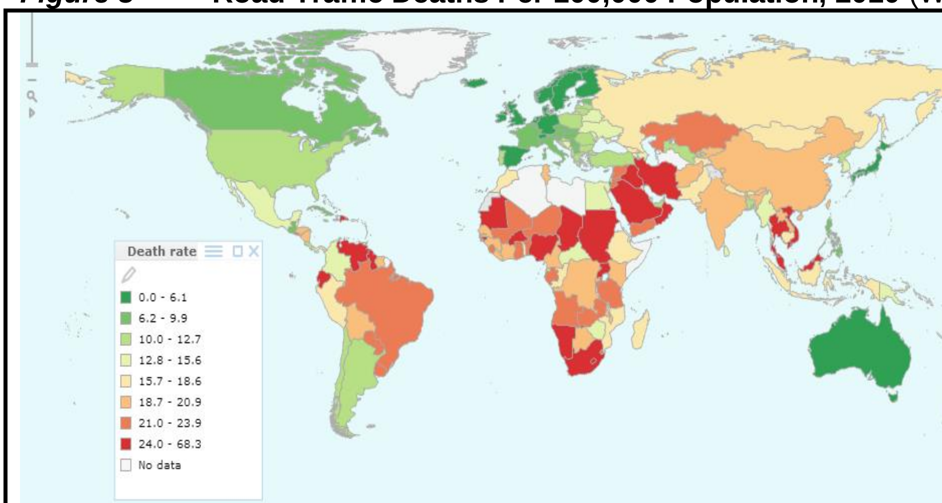
Relationships Between Mobility and Crash Risk

To evaluate mobility management safety impacts it is important to understand the relationships between mobility (amount and mode of travel) and crash risk. Per capita crash risk can be considered the product of two factors: crash rates per kilometer or mile times annual mileage. Changing either factor affects total crashes. Although many factors affect distance-based crash rates, these generally change little when individual motorists reduce their annual vehicle travel. A high-risk driver may average one crash every 50,000 kilometers, while a lower-risk driver may average one crash every 500,000 kilometers, but in either case reducing annual vehicle travel reduces their risk. Even drivers who never violate traffic rules contribute to crashes by being a target of other motorists' errors and risks beyond their control, such as animals in the roadway or mechanical failures.

Crash casualty rates vary significantly due to demographic, geographic and transport policy factors. Per capita traffic fatality rates typically range from about 2 to 30 annual deaths per 100,000 residents, a 0.15% to 1.5% lifetime risk for an average person. Each fatality is estimated to represent 15 severe injuries requiring hospital treatment, 70 minor injuries, and about 150 property damage only (PDO) traffic crashes, so typical lifetime crash injury rates range from 2% to 22% (WHO 2004).

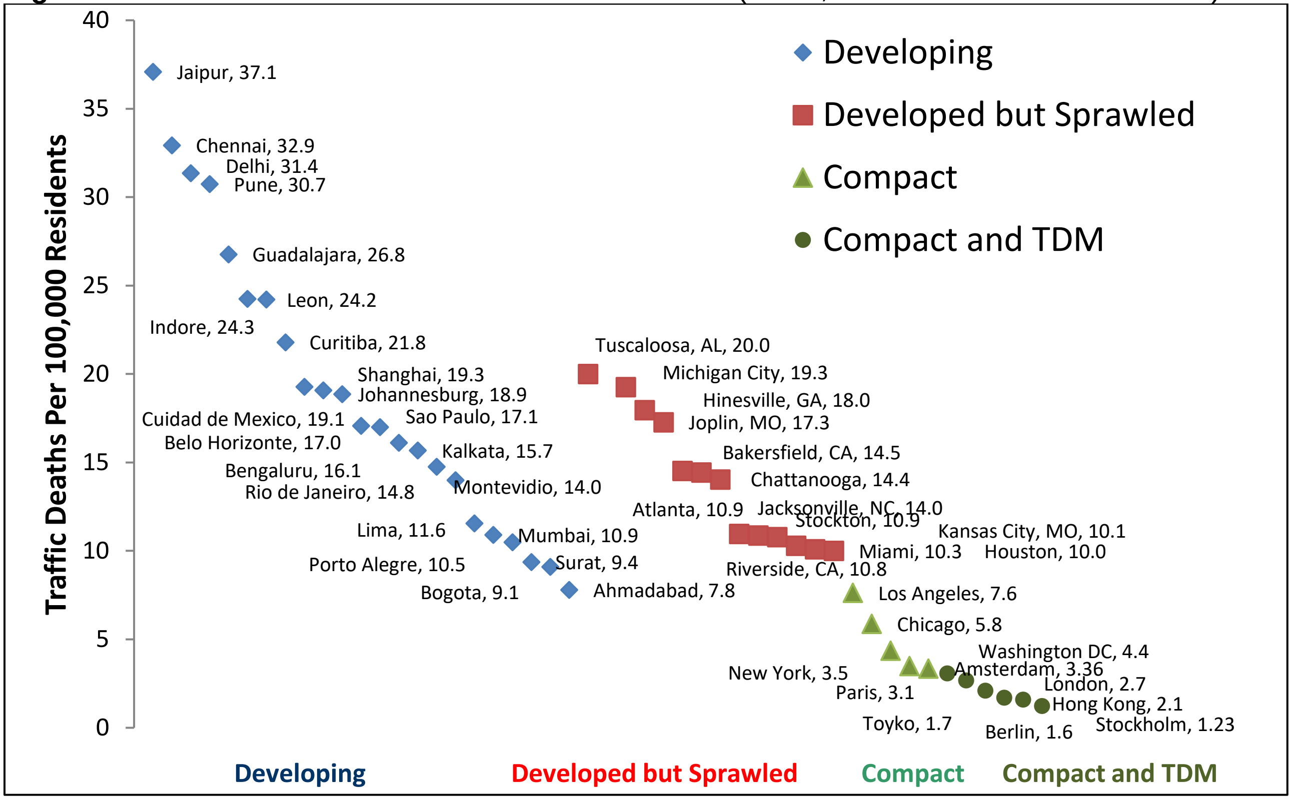
Less developed countries tend to have high per capita traffic fatality rates, despite low levels of motorization, and these crash rates generally decline with economic development, as illustrated in figures 3 and 4. This suggests that increased per capita vehicle travel actually reduces crash risk. However, these trends reflect other factors associated with wealth: better driver training, vehicles, roadway facilities, law enforcement, emergency response and medical care.

Figure 3 **Road Traffic Deaths Per 100,000 Population, 2010** (WHO 2012)



Per capita traffic fatality rates tend to be highest in low-income countries and decline with development.

Figure 4 Traffic Death Rates for Selected Cities (Welle, et al. 2015 and USDOT Data)



Traffic death rates tend to be high in developing country urban regions and decline as they develop. How much they decline depends on transport and land use policies. Developed but sprawled regions tend to have higher fatality rates than compact regions, and the lowest rates occur in compact cities with TDM strategies.

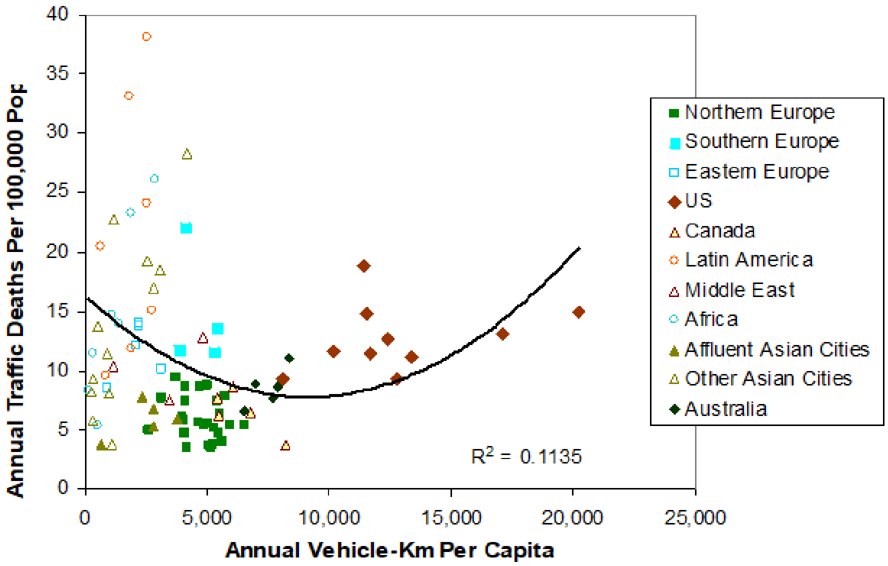
Within a group or area with similar risk profiles there is a positive relationship between per capita vehicle mileage and crash rates (Clark and Cushing 2004; Edlin and Karaca-Mandic 2002 and 2006; Frumkin, Frank and Jackson 2004; Ilyushchenko 2010; Roberts and Crombie 1995; Vickrey 1968). For example, Segui-Gomez, et al. (2011) found a strong positive relationship between self-reported annual vehicle travel and crash injuries in a panel study of Spanish university graduates. Even small reductions in annual vehicle travel can significantly reduce motor vehicle crashes and casualties.

Ahangari, Atkinson-Palombo and Garrick (2017) used U.S. traffic casualty data from 1997 to 2013 to analyze how travel activity and behavior, socioeconomics, macroeconomics, safety policies, and health care quality affect traffic casualty rates. Using sophisticated statistical analysis they found that the most important factors were Vehicle Miles Traveled and Vehicles per Capita, closely followed by Infant Mortality Rates which they consider a proxy for health care quality. They found that state-level traffic fatality rates decline with urban density and walking. They found that conventional traffic safety strategies, such as Graduated Driver's Licenses have limited safety benefits.

Blower, et al. (2020) used sophisticated statistical analysis to evaluate factors that contributed to the substantial decline in traffic fatalities during the 2008 to 2011 economic recession. The analysis indicates that safety gains resulted from reductions in total vehicle travel, traffic speeds and rural driving, particularly by younger and lower-income drivers. They found that roadway improvements and traffic safety policies and programs had little safety impact.

Figure 5 shows the relationship between per capita vehicle travel and traffic fatalities in various cities. It is U-shaped: crash rates decline up to about 10,000 annual kilometers after which they begin to increase. The lowest fatality rates occur in higher income, lower-annual-kilometer cities in Northern Europe and Asia.

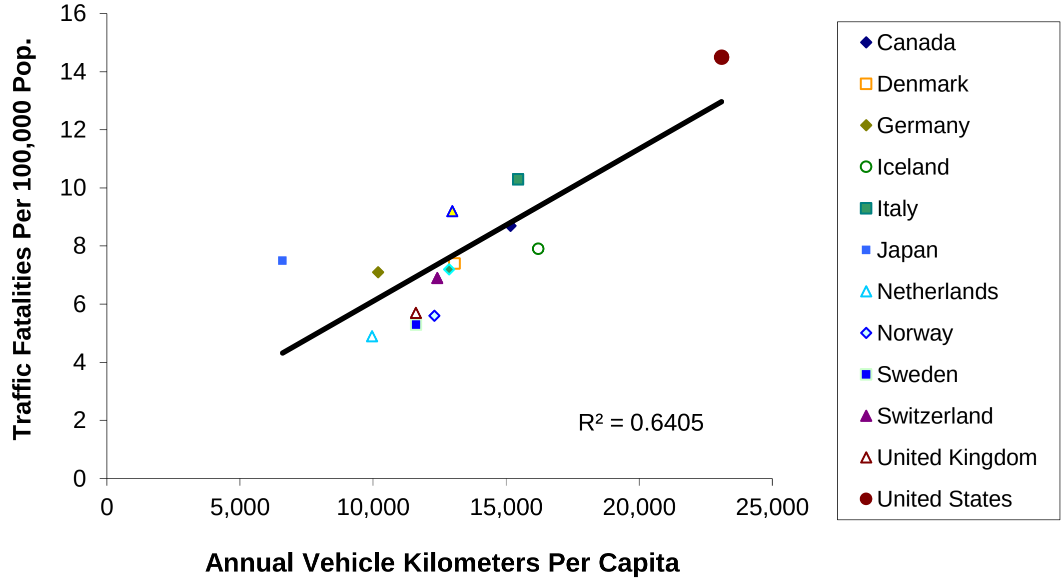
Figure 5 **Per Capita Vehicle Travel and Fatalities In Various Cities** (UITP 2000)



Overall, per capita traffic fatality rates have a U-shaped relationship to per capita vehicle mileage, declining until about 10,000 annual kilometers after which they tend to increase.

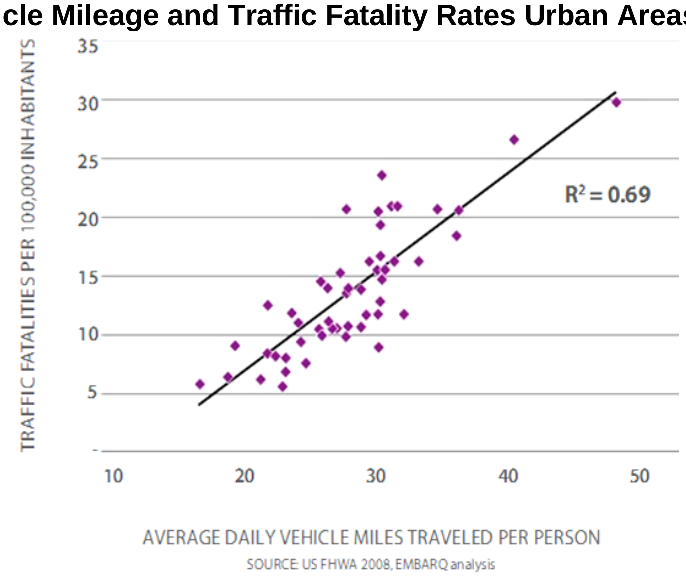
Figure 6 illustrates a strong positive relationship between per capita annual vehicle travel and crashes among OECD (Organization for Economic Cooperation and Development) countries. Figure 7 illustrates a similar positive relationship among various cities. This indicates that, among economically similar countries and cities, increased vehicle travel tends to increase traffic fatalities.

Figure 6 **Vehicle Mileage and Traffic Fatality Rates In OECD Countries** (OECD Data)



Among economically developed countries there is a strong positive relationship between per capita vehicle travel and traffic deaths.

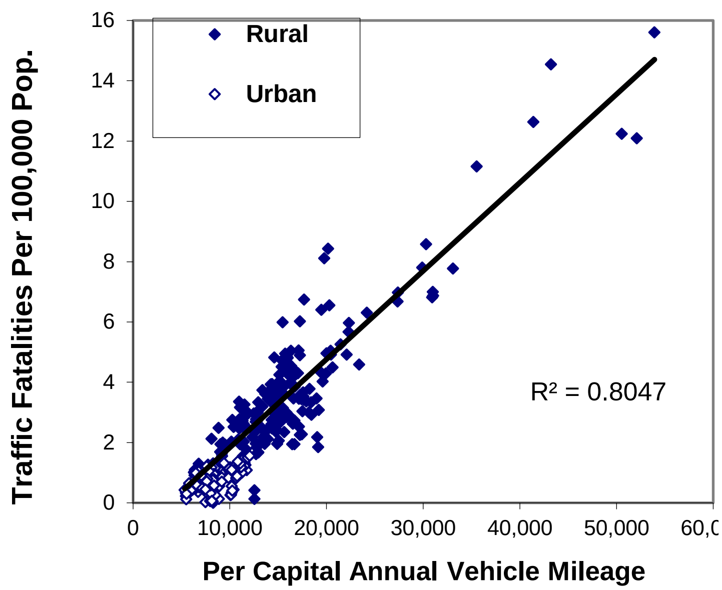
Figure 7 **Vehicle Mileage and Traffic Fatality Rates Urban Areas** (EMBARQ 2012)



There is a strong relationship between per capita vehicle mileage and traffic fatalities among cities.

Figures 8 through 11 show the relationship between per capita mileage and traffic fatality rates for the urban and rural areas of each U.S. state over a seven year period using FHWA data, which are considered relatively reliable and consistent. Figure 6 shows urban and rural areas together. A linear model applied to this data has an R-Squared value of 0.862, indicating a strong relationship between variables. Per capita traffic fatality rates tend to decline with urbanization (Ilyushchenko 2010; Myers, et al. 2013).

Figure 8 **U.S. Traffic Fatality and Mileage Rates** (FHWA 1993-2002 data)



This graph indicates a strong positive relationship between per capita annual vehicle mileage and traffic fatalities in U.S. states, particularly in rural areas.

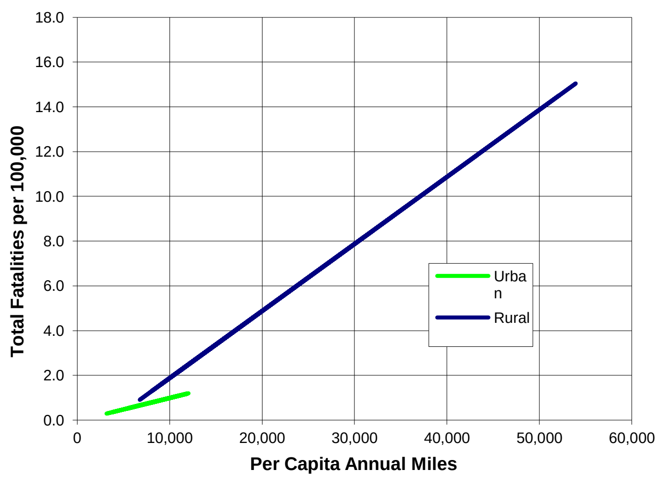
Urban and rural relationships can be calculated separately using the following equations.

Rural Traffic Fatalities = -1.123 + 0.0002998 * Rural Vehicle Mileage (2)

Urban Traffic Fatalities = -0.03465 + 0.0001022 * Urban Vehicle Mileage (3)

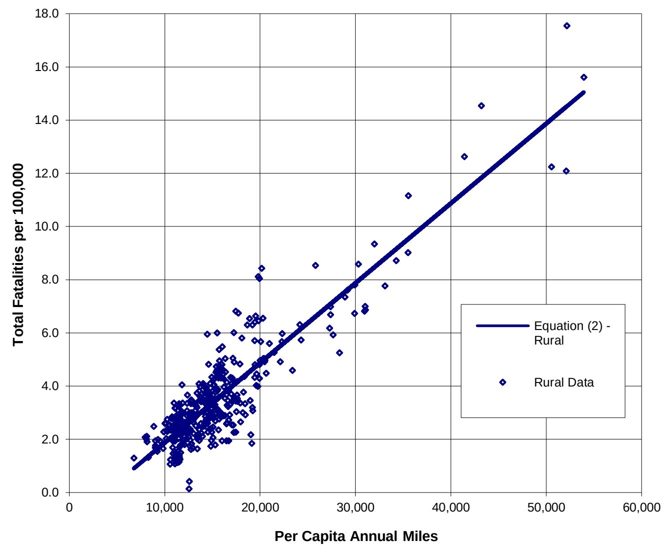
Figure 9 illustrates these equations. The rural area slope is about three times steeper than for urban areas, indicating that mileage has a stronger effect on fatalities in rural conditions, probably due to factors such as increased traffic speeds and emergency response time, less seatbelt and helmet use, and more higher-risk driving (such as young and elderly drivers) due to fewer transport alternatives (Rakauskas and Ward 2007).

Figure 9 **Rural and Urban Traffic Fatality and Mileage Rates** (FHWA 1995-2002 data)



This graph shows the regression lines for urban and rural areas calculated separately.

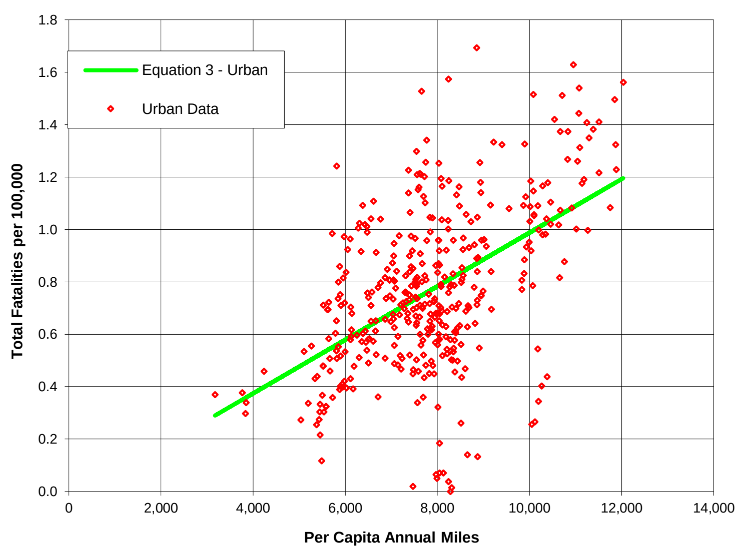
Figure 10 **Rural Traffic Fatality and Mileage Rates** (FHWA 1995-2002 data)



This graph shows a strong relationship between annual mileage and crash rates in rural areas (R^2=0.80).

Figure 10 shows the equation associating rural fatalities and mileage. Although most rural areas average less than 25,000 annual miles per capita, the few with very high annual mileage also have very high fatality rates. Figure 11 shows data for the urban portion of each state. The equation's shallow slope likely reflects the tendency of urbanization to increase traffic congestion, which increases collision frequency but reduces severity and therefore fatalities (Marchesini and Weijermars 2010; Shefer and Rietvald 1997; Zhou and Sisiopiku 1997).

Figure 11 **Urban Traffic Fatality and Mileage Rates** (FHWA 1995-2002 data)



This graph shows a weaker relationship between annual mileage and crash rates in urban areas.

There are other indications of a positive relationship between mileage and crash rates. Garceau, et al. (2013) found higher traffic fatality rates in U.S. states with higher per capita vehicle travel:

states with three times the per capita VMT had five times the traffic fatality rates. Sivak (2008 and 2009) found that a 2.7% decline in U.S. vehicle travel caused by fuel price increases and a weak economy during 2007-08 resulted in a much larger 17.9% to 22.1% month-to-month declines in traffic fatalities. These results can be explained by the disproportionate reductions in vehicle travel by lower income drivers (who tend to be young and old, and therefore higher than average risk), proportionately large reductions in rural and leisure travel (which tend to have higher fatality rates than urban and commute vehicle travel), and speed reductions to save fuel.

Grabowski and Morrisey (2004 and 2006) estimate that each 10% fuel price increase reduces total automobile deaths by 2.3%, with about twice as large an impact on younger drivers who tend to be particularly price sensitive. At the neighborhood level, Lovegrove and Sayed (2006) found a positive relationship between total vehicle traffic and crashes.

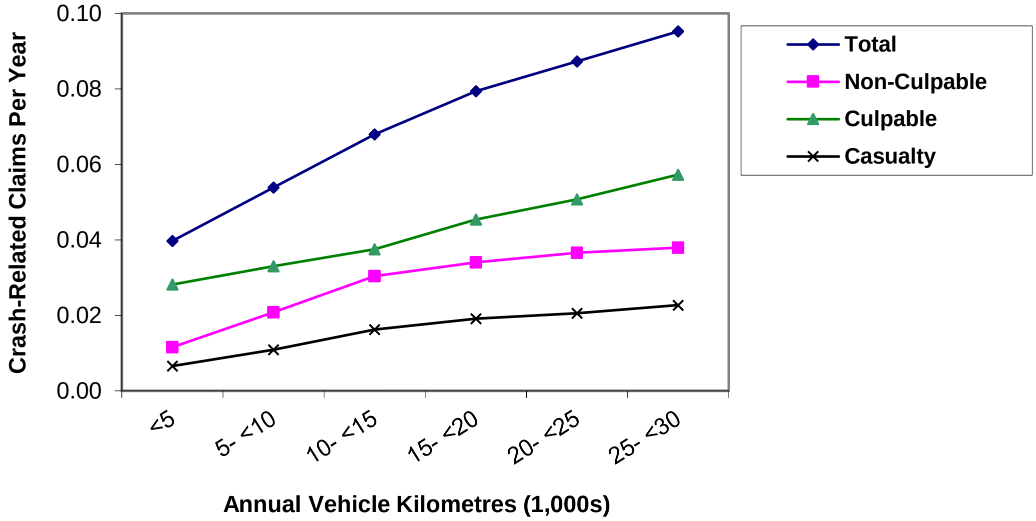
Balkin and Ord (2001) found seasonal highway fatality cycles, with annual peaks during holiday seasons when VMT increases. Reductions in annual mileage during economic recessions due to reduced employment and incomes often reduce per capita crash rates. For example, a recession in 1981-82 caused a 10% reduction in vehicle travel and a 12% reduction in insurance claims in British Columbia (ICBC data). Another study found traffic casualty rates tend to decline with unemployment, apparently because it reduces annual vehicle use (Mercer 1987). As Figure 11 indicates, when U.S. annual mileage increased relative to the long-term trend, crashes also tend to increase, and periods with reduced mileage tend to have reduced crashes.

Sivak and Schoettle (2010) compared U.S. traffic crash data for 2005 (when the U.S. had 43,510 traffic fatalities) and 2008 (when the U.S. had 37,261 traffic fatalities). The results identify various factors that contributed to this decline, many of which involved vehicle travel reductions (including reductions in commuting, long-distance leisure driving, freight truck transport, and driving by younger drivers), and others that involved reductions in per-mile risk (such as reduced traffic speeds, more airbags and reductions in drunk driving). Luoma and Sivak (2012) found that the significantly lower traffic fatality rates in Northern European countries compared with the U.S. are explained by lower per capita vehicle travel.

Elderly drivers tend to have high per-mile crash rates but low vehicle-year crash rates due to low annual mileage. Jun, Ogle and Guensler (2012) found that during a six-month period, elderly drivers involved in crashes averaged 38% more mileage (6,992 compared with 4,359 vehicle-miles) than non-crash-involved drivers. Female drivers' lower crash rates are approximately equal to their lower average mileage (Butler 1996).

The analysis described so far indicates the relationships between mileage and crash rates for a large number of vehicles in aggregate. Other types of analysis investigate the relationships between mileage and crash risk for individual drivers or vehicles. Insurance actuaries have long recognized that annual vehicle mileage is a significant factor in annual crash and claim rates (CAS 1996, p. 35, 242 and 250; Butler 1996). Insurance industry representatives sometimes argue that mileage is a relatively minor risk factor (Cardoso and Woll 1993), but until recently the industry lacked reliable vehicle travel data (their analysis was based on motorists' self-reported predictions of their future mileage which are extremely unreliable). More recent research based on more reliable vehicle-travel data shows a strong positive relationship between annual mileage and annual crash risk for a particular driver or vehicle (that is, holding constant other risk factors such as driver history, vehicle type and location).

Figure 12 **Crash Rates by Annual Vehicle Mileage** (Litman 1997)



Claims per vehicle tend to increase with annual mileage. ("Culpable" means a driver was considered responsible for causing the crash. "Casualty" means a person was killed or injured.)

Figure 12 illustrates the relationship between annual mileage and crash rates, based on mileage readings collected during annual emission inspections matched with individual vehicles' insurance claims for more than 700,000 vehicle-years (Litman 1997). The data show that annual claims increase with increased annual mileage. Similar relationships were found when these data were disaggregated by factors such as driver history, type of vehicle use and territory. The results indicate that, all else being equal, annual crash and insurance claims increase with annual mileage.

Ferreira and Minike (2010) matched annual vehicle-mileage data from odometer readings collected during mandatory safety checks with insurance claim costs for 2.87 million vehicle exposure-years and 34 billion miles of travel in Massachusetts during 2006. The results indicate a strong relationship between miles driven and auto accident claims frequency and loss costs. This relationship between risk and mileage is less than linear when all vehicles are considered together, but it becomes considerably more linear when class and territory are differentiated, that is, for otherwise similar vehicles.

Several factors partly offset this positive relationship between mileage and crashes (Janke 1991; Maycock and Lockwood 1993):

- Higher-risk-per-vehicle-mile motorists, due to inexperience or disability, tend to drive fewer annual miles, while high-annual-mileage motorists tend to be relatively capable drivers.
- Newer, mechanically safer vehicles tend to be driven more each year than older vehicles.
- Urban drivers tend to have higher crash rates due to increased traffic density, and drive fewer annual miles than rural drivers.
- High mileage motorists tend to do a greater share of driving on grade-separated highways that have relatively low per-mile crash and fatality rates.

- There may be other types of offsetting behaviors by which higher-mileage drivers take more precautions to limit their risk, such as purchasing safer vehicles.

These factors can explain why per-mile crash rates decline at high annual mileages, as indicated in Figure 12. These data indicate differences *between different motorists*, few of these factors apply when an *individual driver* marginally reduces annual mileage, so the relationship between mileage and crashes for individual drivers is probably more linear. For example, a motorist whose annual mileage declines from 12,500 to 11,500 miles in response to improved travel options or pricing incentives is unlikely to become less skilled or more risky, so the mileage reduction should cause an approximately proportional reduction in their crash rate. Put differently, there is no reason to believe that miles driven at the beginning of the year are more dangerous than miles driven at the end of the year, although this is what is implied by a declining mileage-crash curve.

Reductions in total vehicle travel can cause proportionally larger reductions in *total* crash damages, since about 70% of crashes involve multiple vehicles. Each vehicle removed from traffic reduces both its chances of causing a crash *and* of being the target of crashes caused by another vehicle, and reducing multi-vehicle crash reduces multiple claims (Vickrey 1968; Edlin and Karaca-Mandic 2006). Even a perfect driver who never violates traffic rules increases safety by driving less, because this reduces their chance of being a target of another road user's mistake.

To illustrate this concept, divide the crashes you could experience into four categories labeled A-D, depending on whether or not you are culpable and whether the crash involves single- or multiple-vehicles. We assume you are an "average" driver, so you or mechanical problems with your vehicle, cause about half the crashes you are involved in.

Table 4 **Crash Categories**

Your Fault (50%)		Others' Fault (50%)	
Single-Vehicle (30%)	**Multi-Vehicle (70%)**	**Multi-Vehicle (70%)**	Single-Vehicle (30%)
A	**B**	**C**	D

Changes in vehicle travel affect different categories of crashes in different ways. Multi-vehicle crashes are affected by both your behavior and the behavior of other motorists. Bold categories (B & C) involve multiple vehicles and so cause greater costs per crash.

If you reduce your chances of *causing* a crash by 10% (perhaps by driving more cautiously or using a vehicle with better crash prevention features), you reduce crash categories A and B, and your total crash risk declines by 7%, since 30% of crashes you are involved in are caused by other motorists' mistakes, and those are not reduced. If your annual mileage declines by 10%, your chance of causing a crash declines by 10% (crash categories A and B), and your risk of being in a collision caused by other drivers' errors (crash category C) also declines 30%. If all other motorists reduce their mileage by 10%, but you do not, you can expect a 7% reduction in crash risk, since 70% of your crashes involve another vehicle (you are less exposed to their mistakes and they are less exposed to your mistakes), resulting from reduction in crash category C. If all motorists reduce their per-mile risk or their total mileage by 10% and other factors are held constant, total crashes should decline about 17% (10% + 7%), resulting from reductions in all crash categories, A through D. Table 5 summarizes these impacts.

Table 5 **Summary of Risk Impacts**

Type of Change	Crash Reduction Categories	Your Risk Reduction	Others' Risk Reduction
You reduce your per-mile risk 10%	A & B	7%	3.5%
You reduce your mileage 10%	A, B & C	10%	7%
Others reduce their per-mile risk 10%	C & D	3%	10%
Others reduce their mileage 10%	A, B & C	7%	10%
Everybody reduces per-mile risk 10%	A, B, C & D	17%	17%
Everybody reduces mileage 10%	A, B, C & D	17%	17%

This table summarizes the categories of crashes reduced by various types of safety actions. Bold categories indicate crashes involving multiple vehicles.

Reductions in crash categories B and C provide greater total safety benefits than reductions in crash categories A and D, because they involve multiple vehicles and so cause greater physical damage and injury per crash. Thus, an action that reduces multi-vehicle crash by 10% reduces total crash costs by about 20%, because each crash causes about twice the damage as a single-vehicle crash. Put differently, reduced vehicle mileage in an area tends to reduce crashes by reducing *traffic density* (VMT per lane-mile). Multi-vehicle crash rates tend to increase with traffic density, which is why crash rates and insurance costs tend to be higher in urban areas (Dougher and Hogarty 1994; Clark and Cushing 2004; Ong 2004). Maze, *et al* (2005) found that rural highway crash rates per million vehicle miles increase with roadway traffic volumes, particularly at intersections.

Various factors may partly offset this additional risk from increased traffic density. Denser areas tend to have lower traffic speeds and therefore lower crash severity, and drivers may be more cautious in denser traffic (Marshall and Garrick 2011; Shefer and Rietvald 1997; Marchesini and Weijermars 2010; Zhou and Sisiopiku 1997). Increased mileage may justify roadway improvements, such as grade separation, which reduce per mile crash rates. However, most empirical evidence indicates that an increase in vehicle mileage causes a proportionately greater increase in crashes and crash costs, all else being equal, which suggests that a mobility management strategy that reduces overall mileage in an area can provide relatively large safety benefits.

Some studies have calculated the ratio between aggregate mileage and crash rates, fatality rates and insurance claim costs in a particular geographic area. Using data from the London region, Dickerson, Peirson and Vickerman (1998) found a near proportional relationship between traffic volumes and crash rates on roads with low to moderate traffic flows, but marginal crash rates rise substantially with high traffic flows.

Analyzing U.S. state-level traffic density and insurance claim costs, Edlin (1998) calculated marginal crash costs per additional vehicle-mile driven. He found the elasticity of claim costs with respect to mileage is between 1.42 and 1.85, meaning a 10% reduction in vehicle mileage reduces total crash costs 14% to 18%. Similarly, Edlin and Karaca-Mandic (2006) found that in high traffic density states, an increase in density dramatically increases claim costs, although this does not occur in low-density states. For example, they estimate that each average-risk motorist added to the California traffic flow increases total insurance costs by $1,271-2,432. Their model indicates that U.S. national accident externalities (the incremental risk caused by each additional vehicle mileage) total $140 billion annually, averaging about 5¢ per vehicle mile.

This suggests that the elasticity of crashes to vehicle mileage is about 1.5 in urban areas and declines to about 1.0 in rural areas, all else being equal. Of course, these impacts are affected by the type of mileage reduced. A strategy that reduces average risk miles by 10% should reduce total crash costs about 17% (a 10% risk reduction to motorists who reduce mileage plus a 7% risk reduction to other road users). A strategy that reduces low-risk miles will cause a smaller reduction in total crash costs, while a strategy that reduces higher risk miles will cause a larger reduction. It is wrong to assume that safety benefits only result from reductions in relatively high-risk driving. Motorists considered low risk (i.e., they quality for "safe driver" insurance discounts) are involved in about half of all casualty crashes, and even faultless drivers reduce crash risk when they reduce mileage by reducing their exposure to crashes caused by other road users' errors.

Certain risk factors deserve special consideration when evaluating mobility management safety impacts:

- Many mobility management strategies target urban commuting, which tends to have high crash but low fatality rates due to high traffic densities. For example, a transit use incentive program is likely to reduce crashes and insurance claims proportionately more than fatalities.
- Some mobility management strategies affect vehicle travel by higher-risk drivers. For example, a transport management program that improves travel options for high school students or seniors may reduce mileage by higher-risk drivers.
- Improved travel options may shift public attitudes, making it easier for courts to revoke driving privileges of higher-risk drivers.
- Traffic management strategies, such as traffic calming and new urbanist roadway design, reduce traffic speeds and therefore crash frequency and severity.
- Smart growth land use strategies increase land use density, which tends to increase crash frequency but reduces crash severity.

Crime Risks

People sometimes fear that shifting from driving to alternative modes imposes other risks, such as risk of criminal assault when walking, cycling or riding public transit. However, much of this fear may be perception rather than true risk (Litman 2005). There is little evidence that these risks are greater than risks facing motorists such as road rage, vehicle theft and vandalism.

For example, in 2001 (the most recent available data) there were a total of 12 murders, 4,599 assaults and 12,302 property crimes committed against public transit patrons (APTA 2003). In comparison, during that year a total of 1,439,480 violent crimes were reported in the U.S. including 16,037 murders, approximately 40,000 carjackings (most involving a gun and about 15% resulting in injuries to victims), approximately 909,023 aggravated assaults and 423,557 robberies, plus approximately 40,000 traffic deaths and 1,500 people seriously injured or killed in "roadrage" incidents (Klus 1999; AAA 1995). Although some terrorism attacks have targeted public transport vehicles and stations, this risk is overall relatively small (Litman 2005), and can be reduced with good planning (Brozen 2023).

Several studies show that, all else being equal, crime rates decline in more compact, mixed, walkable neighborhoods, apparently due to more passive surveillance (also called *eyes on the street*) by non-criminal bypassers.

For example, after adjusting for socioeconomic factors such as age, employment status and income, Browning, et al. (2010) found that in Columbus, Ohio, per capita violent crime rates increased with population and commercial density up to approximately the city's median density, but above that level crime rates decline significantly with increased density, with particularly large declines in the most economically disadvantaged neighborhoods. After adjusting for socioeconomic factors, Christens and Speer (2005) found a significant negative relationship between census block population density and per capita violent crime rates in Nashville, Tennessee and nearby suburban communities. Similarly, Gilderbloom, Riggs and Meares (2015) found that, normalizing for other factors, higher WalkScore ratings are associated with lower crime rates in Louisville, Kentucky neighborhoods.

Hillier and Sahbaz (2006) analyzed residential burglary and robbery rates in an economically and socially diverse London neighborhood. They found that, all else being equal, these crime rates were inversely related to the number and density of dwellings on a street, on both through streets and cul-de-sacs. For example, the mean cul-de-sacs burglary rate is 0.105, but those with fewer than 11 dwellings have a higher 0.209 rate. Similarly, grid street segments with more than 50 dwellings have a burglary rate of 0.142, but those with 100 dwellings have a much lower rate of 0.086. The researchers conclude that crime risk tends to decline on streets that have more through traffic, and crime are lower if commercial and residential buildings are located close together.

Li and Rainwater (2000) analyzed crime patterns in Irving, Texas. They found that crime rates are primarily explained by socioeconomic factors such as income, and land use factors that affect crime opportunity. For example, burglary, rape, assault and robbery rates are higher in areas with more concentrated poverty, residential burglary rates are higher in wealthier neighborhoods, and automobile thefts are highest in major commercial centers where large malls and shops are concentrated where high concentrations of vehicles and crowds provided auto theft opportunities.

These studies indicate that, all else being equal, crime rates are negatively associated with development density and mix, and increased pedestrian activity. They support Jane Jacob's hypothesis that more walkable and mixed development neighborhoods tend to increase public safety by providing more "eyes on the street" and daily interactions among neighbors. Although some of these effects may result from crimes shifted from one location to another, the results suggest that in many situations, more surveillance and neighborhood interactions may reduce total regional crime rates.

According to research sponsored by the AAA Foundation for Traffic Safety, between January 1990 to September 1996 there were at least 10,037 reported incidents of criminal aggressive driving that resulted in at least 218 murders and at least 12,610 injuries, including scores of cases in which people suffered paralysis, brain damage, amputation, and other seriously disabling injuries (Mizell 1995). The number of reported aggressive driving cases increased every year between 1990 and 1995, when the study was completed.

Safety Impacts of Specific Mobility Management Strategies

This section describes the traffic safety impacts of various mobility management strategies. There is limited research on many of these factors, and these impacts can vary depending on particular circumstances, so these findings are tentative and general, and may not apply in a particular situation. More research is needed to better determine the safety impacts of specific mobility management policies and programs.

Multimodal Planning

Automobile-oriented planning increases automobile travel and crash rates by increasing total vehicle travel and traffic speeds (Zipper 2021). Nehiba and Tyndall (2023) found that proximity to Interstate Highways increases pedestrian traffic deaths; they found that census tracts bisected by Interstates have significantly higher pedestrian death rates, including deaths on the Interstate and on access roads that tend to have high traffic volumes and speeds.

Vehicle Ownership Reductions

Some mobility management strategies reduce vehicle ownership by improving alternatives or changing the cost structure. These include carsharing, transit improvements and transit-oriented development, unbundled residential parking (parking is rented separately from building space), location-efficient mortgages (which improves mortgage options for home buyers who choose a less automobile-oriented location). For example, unbundling residential parking typically reduces automobile ownership by 8-15% ("Parking Management," VTPI 2004) and residents of transit-oriented developments tend to own about 30% fewer cars than otherwise comparable household in automobile-dependent neighborhoods ("Transit Oriented Development," VTPI 2004).

Vehicle ownership reductions tend to reduce total vehicle mileage, although the vehicles given up tend have relatively low annual mileage, and some mileage may be shifted to other vehicles. In a typical case, a 2-driver household eliminates a second car that was driven 6,000 annual miles, and adds 1,000 annual miles to their primary vehicle, to rental vehicles, or to vehicle travel by friends who make additional chauffeur trips, resulting in a net reduction of 5,000 vehicle-miles for the household.

Pricing Reforms

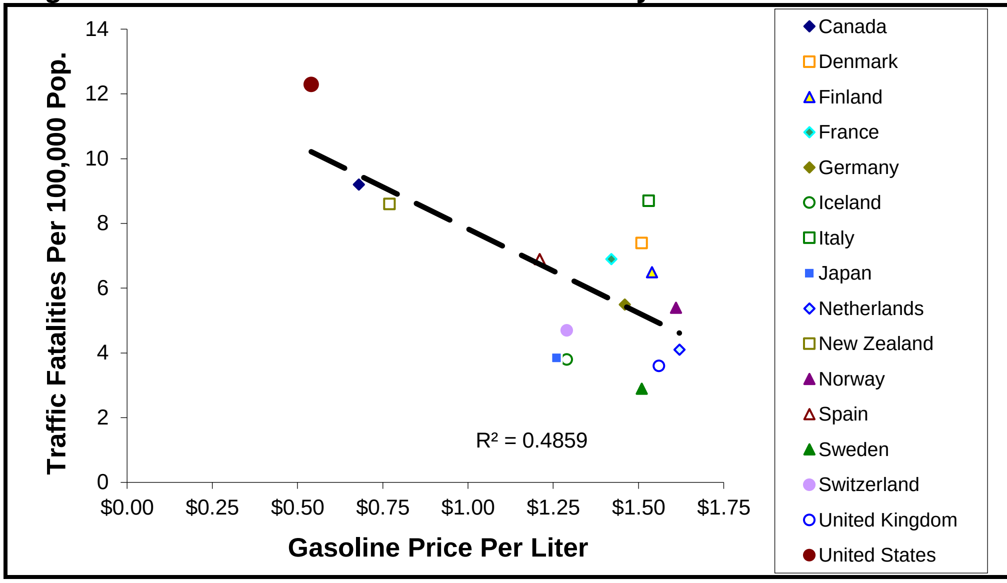
Various transportation price reforms are advocated to achieve various objectives, including road and parking congestion reduction, emission reductions, and increased fairness (Litman 2011). These reforms can cause various travel changes, including shifts in route, travel time, mode, destination and trip frequency, which have a variety of safety impacts. Individual pricing reforms are discussed below.

Fuel Price Increases (www.vtpi.org/tdm/tdm17.htm)

Fuel price increases can be justified as a way to finance transportation programs and as an energy conservation strategy ("Fuel Price Increases," VTPI 2004). The long-term elasticity of fuel consumption with respect to price is about –0.7, so a 10% price increase causes a 7% reduction in fuel use, but about two thirds of this result from consumers purchasing more fuel efficient vehicles, and only about one third from vehicle mileage reductions. This means that a 10% increase in fuel price reduces mileage 2-3%.

Various studies indicate that, all else being equal, higher fuel prices tend to reduce per capita traffic fatality rates. Figure 13 indicates that among OECD countries, per capita traffic fatality rates decline with higher fuel prices.

Figure 13 **Vehicle Fuel and Traffic Fatality Rates In OECD Countries**[2]



Among economically developed countries, per capita traffic fatalities decline with higher fuel prices.

Sivak (2008) found that a 2.7% decline in vehicle travel caused by fuel price increases and a weak economy during 2007-08 resulted in much larger 17.9% to 22.1% month-to-month traffic fatality reductions, probably due to disproportionate reductions in vehicle travel by lower income drivers (who tend to be young and old, and therefore higher than average risk) and speed reductions to save fuel.

Grabowski and Morrisey (2004) estimate that each 10% fuel price increase reduces total traffic deaths 2.3%, with a 6% decline for drivers aged 15 to 17 and a 3.2% decline for ages 18 to 21 according to analysis. In follow-up research, Grabowski and Morrisey (2006) estimate that a one-cent increase in state gasoline taxes will yield a 0.25% decrease in per capita traffic fatalities and a 0.26% decrease in fatalities per VMT.

Zhu, et al. (2016) modeled the effects of fuel price changes on motorcycle and nonmotorcycle crash injury rates. They estimate that a $1.00 per gallon fuel price increase would reduce 8,348 annual nonmotorcycle hospitalizations, saving $143 million in medical costs, but would increase 3,574 motorcycle injury hospitalizations adding $73 million in medial costs. They therefore recommend that fuel price increases be implemented with motorcycle safety strategies to increase net safety benefis.

Studies by Chi, et al. (2010a, 2010b, 2011 and 2013) evaluate fuel price impacts on traffic safety. They find that fuel price increases reduce traffic crashes, with impacts that increase over time and vary by geographic and demographic factors. For example, they find that fuel price

[2] Gerhard Metschies (2005), *International Fuel Prices 2005*, International Fuel Prices at www.international-fuel-prices.com/downloads/FuelPrices2005.pdf. *List of Countries by Traffic Fatality Death Rate*, Wikipedia http://en.wikipedia.org/wiki/List_of_countries_by_traffic-related_death_rate (9 February 2011).

increases cause larger short-term crash reductions by younger drivers, and larger intermediate-term reductions by older drivers and male drivers (2010a; 2011), and tend to have particularly large effects on drunk driving crash (2010b).

Ahangari, et al. (2014) employed a panel data model of 14 industrialized countries between 1990 and 2000 using gas prices, unemployment, health index, vehicle ownership and vehicle travel as independent variables and per capita traffic deaths as a dependent variable. The results revealed a significant inverse relationship between gas prices and the road fatality rates. The elasticity analysis indicates that a 10% decrease in gasoline prices resulted in a 2.19% increase in road fatalities. Likewise, a 10% decrease in unemployment rate resulted in a 0.65% increase in road fatalities. The analysis also implied that the health index has the highest impact on road fatality rates.

Using data for 144 countries from 1991-2010, Burke and Nishitateno (2014), found that the average reduction in road fatalities resulting from a 10% increase in the gasoline pump price is in the order of 3-6%, and estimate that approximately 35,000 deaths per year could be avoided by the removal of global fuel subsidies.

Leigh and Geraghty (2008) estimate that a sustained 20% gasoline price increase would reduce approximately 2,000 traffic crash deaths (about 5% of the total), plus about 600 air pollution deaths. Using a Crash Prediction Model (CPM) based on fatal and injury crashes observed between 2004 and 2007 in Flanders, Belgium, Pirdavani, et al. (2013) find that a 20% fuel price increase would reduce the annual vehicle travel by 11.6% which would reduce total injury crashes by 2.8%.

There is debate concerning the safety impacts of more fuel efficient vehicles. Occupants of lighter vehicles face greater risk in crashes with heavier vehicles or stationary objects, but this seems to be offset by their lower crash frequency, reduced risk to others, and improved safety designs (CBO 2003). To the degree that higher fuel prices reduce mileage they probably provide net safety benefits, while regulatory requirements to increase fleet vehicle efficiency reduce the per-mile cost of driving, which tends to increase per capita annual mileage and therefore total crashes (Litman, 2005b).

Courtemanche (2008) found that gasoline prices are positively associated with walking activity, and negatively associated with body weight and the frequency of eating at restaurants. The analysis implies that 8% of the rise in obesity between 1979 and 2004 can be attributed to a decline in real fuel prices, and that a permanent $1 increase in gasoline prices would reduce U.S. overweight and obesity rates by 7% to 10%.

Road and Parking Pricing (www.vtpi.org/tdm/tdm35.htm)

Road pricing means that motorists pay tolls for driving on specific roads. *Parking pricing* means that motorists pay directly for using a parking space. Charging users direct for roadway costs typically reduces affected vehicle travel 10-30% compared with untolled roads, and charging motorists directly for parking costs, or offering a *Cash Out* option (travelers can choose cash rather than a parking subsidy) typically reduces affected vehicle travel 10-30% (CARB 2014; Wardman 2022).

A systematic literature review of congestion pricing impacts on safety found that, while some studies found short-term increases in bicyclists and motorcyclists injuries, virtually all studies found overall reductions in crashes and injuries over the long run (Singichetti, et al 2022). The city of London's congestion fee reduced city center vehicle trips by 20%, and crashes in that area declined about 25% (Ding, et al. 2021; TfL 2004), and Milan, Italy's city center road pricing reduced vehicle travel 28% and injury crashes 26% (ITF 2014). Analyzing crash rates at a fine geographic scale, Lovegrove and Litman (2008) concluded that a typical congestion pricing program that encourages sifts to alternative modes is likely to reduce neighbourhood collision frequency by approximately 19% (total) and 21% (severe).

Distance-Based Pricing (www.vtpi.org/tdm/tdm10.htm)

Distance-based (also called *Pay-As-You-Drive* or *Per-mile*) *p*ricing converts vehicle insurance premiums and registration fees from fixed into variable costs by prorating existing fees by average annual mileage (Litman 1997; Edlin 1998). This price structure gives motorists a new financial incentive to reduce their annual mileage, with incentives that increase with risk ratings. For example, a low-risk motorist who currently pays $300 annual premiums would pay about 2.5¢ per mile, and so is predicted to reduce their mileage about 5%, while a higher-risk motorist who currently pays $1,800 would pay 15¢ per mile, and so should reduce their annual mileage by 20%, since they receive greater savings with each mile reduced. This should provide relatively large safety benefits. The average per-mile premium would be about 5¢ per mile, which is predicted to reduce average annual mileage of affected vehicles by 10-12%, while higher risk motorists would pay significantly more and so are expected to reduce their mileage more than average. If fully implemented in an area, this should reduce traffic crashes by 12-15%.

There is some debate over the relative importance of mileage as a risk factor. Some experts argue that annual vehicle mileage is less important than other factors such as driver age, vehicle type and location (Cardoso and Woll 1993), but when other factors are held constant (that is, for a particular motorist), annual mileage appears to have a major effect on annual crash rates, and mileage reductions can be expected to reduce per capita crashes (Ferreira and Minike 2010).

Vickrey (1968) argues that marginal pricing of vehicle crash risks requires fees that reflect the incremental risk vehicles impose on other traffic and for currently uncompensated crash costs (Litman 2007). This should further reduce crashes.

Pricing Impact Summary

Table 6 summarizes pricing reforms and their impacts. Total safety impacts depend on the amount and type of travel reduced. These reforms tend to be most effective and acceptable if implemented as an integrated program that includes improvements to alternative modes, encouragement programs, and smart growth land use policies. In addition to their direct impacts, pricing reforms help create political and social support for more multi-modal transport planning. Comparisons between otherwise similar geographic areas indicate that those with more efficient transport pricing have significantly less per capita vehicle travel and traffic casualties (typically 40-60% lower) than those where fuel, road and parking prices are lower.

Table 6 **Transport Pricing Reform Impacts**

Pricing Type	Description	Travel Impacts	Traffic Safety Impacts
Higher fuel prices	Increase fuel prices to finance roads and traffic services, and to internalize fuel economic and environmental costs.	European-level fuel prices reduce per-capita vehicle travel 30-50% compared with North America. Affects most vehicle travel.	Vehicle travel reductions provide proportionate or greater reductions in crashes (i.e., a 30% mileage reduction provides about 30%+ fatality reduction).
Road pricing	Tolls to reduce congestion and generate revenue.	Typically reduces affected vehicle travel 10-30%. Usually applies to a small portion of total travel.	Can have significant safety benefits where applied, but total impacts are generally small.
Parking pricing	User fees to finance parking facilities. Can also include parking cash out and unbundling.	Typically reduces affected vehicle trips 10-30%. Most common in city centers, campuses and hospitals.	Can have significant safety benefits where applied, but total impacts are usually moderate due to limited application.
Distance-based pricing	Prorates vehicle insurance premiums and registration fees	Fully-prorated pricing typically reduces affected vehicle travel 8-12%, although most current examples have smaller price and travel impacts.	Potentially large safety benefits to affected vehicles. If widely applied can provide large total safety benefits.

This table summarizes major pricing reform categories and their travel and safety impacts.

Advocates usually focus on individual reforms intended to provide specific benefits while safety benefits are often overlooked or undervalued. For example, road toll advocates generally focus on congestion reductions and increased revenues, safety benefits are not usually mentioned. Similarly, safety benefits are seldom mentioned by advocates of efficient parking pricing, fuel tax increases or public transit fare reductions. However, virtually all of these pricing reforms provide safety benefits, and if implemented to the degree justified on economic principles, the impacts could be significant, reducing vehicle travel and crashes by 30-60% (Litman 2007).

Mode Shifting

Many mobility management strategies cause shifts from automobile to alternative modes, by making alternative modes more attractive or by increasing the cost of automobile use. The safety impacts of such shifts are discussed below.

Table 7 **Passenger Fatalities per Billion Passenger-Miles** (Savage 2013)

Travel Mode	Deaths Per Billion Passenger-Miles
Riding a motorcycle	212.57
Car or light truck driver or passenger	7.28
Passenger on a local ferry boat	3.17
Commuter rail and Amtrak	0.43
Urban mass transit rail (subway or light rail)	0.24
Bus (transit, intercity, school, charter)	0.11
Commercial aviation	0.07

Traffic casualty rates vary significantly between modes.

Traffic risk varies by mode and how risk is measured (Savage 2013), as indicated in tables 7 and 8. For example, compared with driving, the fatality rate of walking is about ten times higher *per mile*, but only about a 40% higher rate *per hour* of travel, and about equal *per trip*. If the choice is between driving or walking to a particular destination, driving is generally safer, but if the choice is between driving fifteen minutes to a shopping center or walking to a local store, the user risks are similar.

Table 8 **U.S. Transportation Fatalities, 2001**[3]

	Fatalities			Veh. Travel	Occupancy	Pass. Travel	Fatality Rate	
	User	Others	Totals	Billion Miles		Billion Miles	User	Others
Passenger Car	20,320	3,279	23,599	1,628	1.59	2,589	7.9	1.3
Motorcycle	3,197	19	3,216	9.6	1.1	10.6	303	1.8
Trucks – Light	11,723	3,368	15,091	943	1.52	1,433	8.2	2.3
Trucks – Heavy	708	4,189	4,897	209	1.2	251	2.8	16.7
Intercity Bus	45		45	7.1	20	142	0.3	-
Commercial Air						-	0.3	
Transit Bus	11	85	96	1.8	10.8	19	0.6	4.4
Heavy Rail	25	6	31	0.591	24	14	1.8	0.4
Commuter Rail	1	77	78	0.253	37.7	9.5	0.1	8.1
Light Rail	1	21	22	0.053	26.8	1.4	0.7	14.8
Pedestrians	4,901	0	4,901	24.7	1	25	198	-
Cyclists	732	0	732	8.9	1	8.9	82.2	-

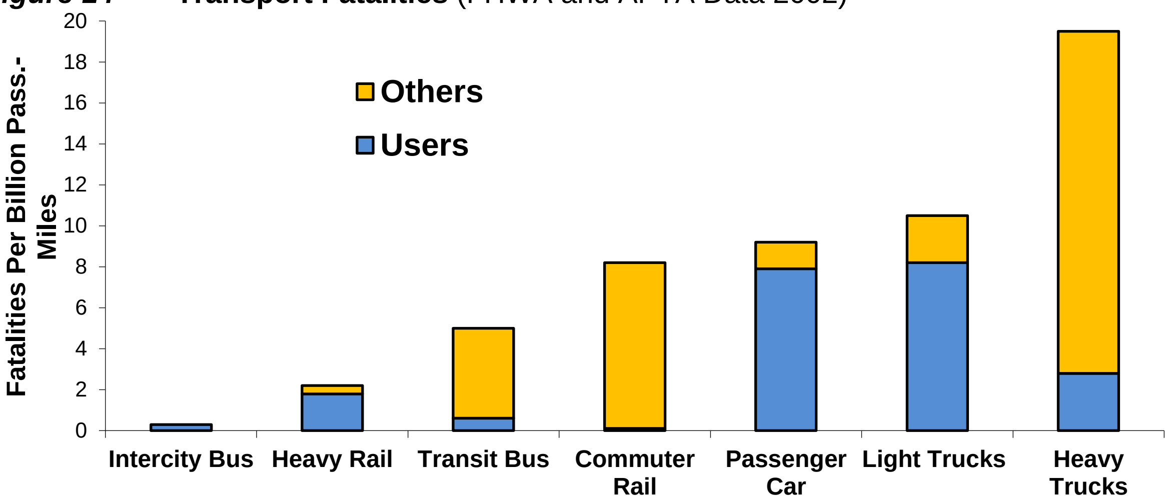
This table indicates traffic fatality rates per billion miles of travel for various modes.

[3] Based on BTS, *National Transportation Statistics* (www.bts.dot.gov), 2003, Tables 1-32, 2-1 and 2-4; APTA, *Safety Summary By Mode* (www.apta.com), 2003. Pedestrian and cycling mileage is based on FHWA, *National Bicycling and Walking Study Ten Year Status Report*, (www.fhwa.dot.gov), 2004, assuming 0.7 mile average walking trip and 2.3 mile average cycling trip length. Light truck "Others" deaths are calculated based on a portion of pedestrian deaths, plus 1,282 additional automobile passenger deaths over what would occur if car/truck collisions had the same car occupant fatality rate as car/car collisions, based on analysis by Gayer, 2001. This is conservative because it does not account for the higher per mile collision involvement rates of light trucks compared with passenger cars.

Table 7 only reflects deaths to the mode user. Comprehensive safety analysis must also consider external risks imposed on other travellers. Table 8 indicates *user* and other (external). For this type of analysis, injuries that result from crashes between heavy and light vehicles (including motorcycles, bicycles and pedestrians), are generally assigned to the heavy vehicle on the assumption that the small vehicle would be less damaged had they crashed with a similar weight vehicle, since it is concerned with physical impacts, not the legal responsibility for the crash.

Figure 14 shows "User" and "Other" fatality rates per billion miles of travel for various modes. This represents a lower-bound estimate of "other" fatalities for passenger cars because it ignores the contribution a vehicle may make to deaths in similar or larger size vehicles, including crashes caused when a larger vehicle take evasive action to avoid crashing into a smaller vehicle. Parry (2004) develops a detailed analysis of the external crash costs of various vehicle types. His model assumes that the average portion of external crash costs each motorist imposes on others in multi-car accidents ranges from 0% up to 1/(*n*-1) of the injuries, where *n* is the number of vehicles in the crash (for example, a vehicle can be considered responsible for up to 100% of the crash costs in a two-vehicle crash, and up to 50% in a three vehicle crash). Applying this approach would significantly increase the allocation crash fatalities to passenger cars.

Figure 14 **Transport Fatalities** (FHWA and APTA Data 2002)



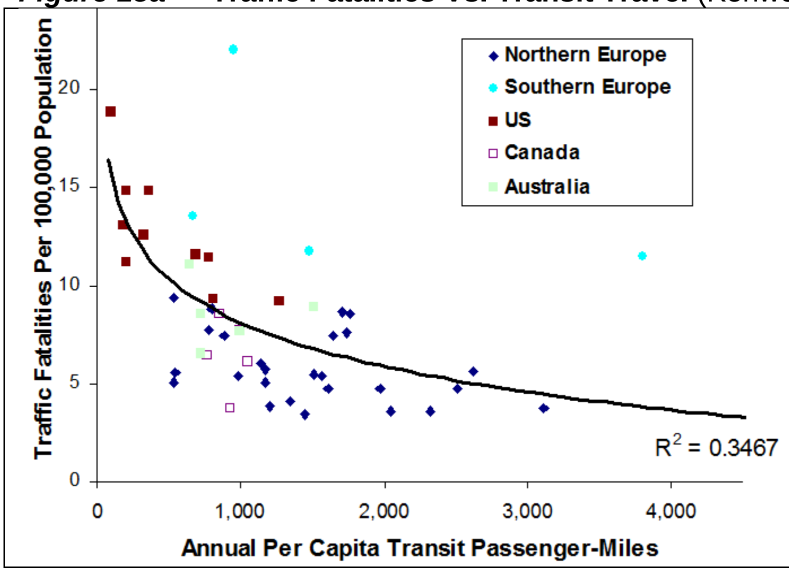
Motor vehicle travel imposes risks on both occupants and other road users. As vehicle weight increases their internal risk tends to decline and their external risk tends to increase.

Lovegrove and Litman (2008) and Lovegrove, Lim and Sayed (2010), using community-based, macro-level collision prediction models suggests that improving transportation options (better walking and cycling conditions, and improved ridesharing and public transit services) could reduce collision frequency by 14% (total) and 15% (severe). Although mode shifting can crash risk, most motorists rate themselves as safe drivers, making mode shift an infrequent way for individuals to reduce traffic risk (Ibrahim, et al. 2023).

Transit

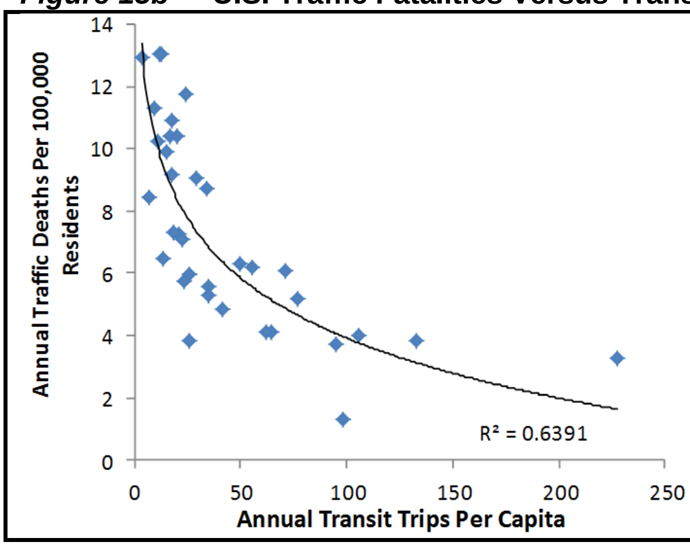
Public transportation is a very safe travel mode overall. Transit travel has about a tenth the traffic casualty (death or injury) rate as automobile travel, and residents of transit-oriented communities have about a fifth the per capita crash casualty rate as in automobile-oriented communities (Litman 2014 and 2016; Scheiner and Holz-Rau 2011). Relatively small transit ridership gains are associated with proportionately larger reductions in per capita crash rates (Duduta, et al. 2012 and 2013). For example, analyzing 29 years of traffic data for 100 U.S. cities, Stimpson, et al. (2014) found that a 10% increase in transit mode share is associated with 1.5% reduction in total traffic deaths. Since only about 2% of total person-miles are currently by transit, this means that a 1% increase in transit mode share is associated with a 2.75% decrease in fatalities per 100,000 residents, which translates into a 5% decrease in total traffic fatalities. The figures below illustrate this relationship in U.S. and international cities.

Figure 15a **Traffic Fatalities Vs. Transit Travel** (Kenworthy and Laube 2000)



International data indicate that urban region per capita crash rates decline with increased transit ridership.

Figure 15b **U.S. Traffic Fatalities Versus Transit Trips** (FTA 2012; NHTSA 2012)

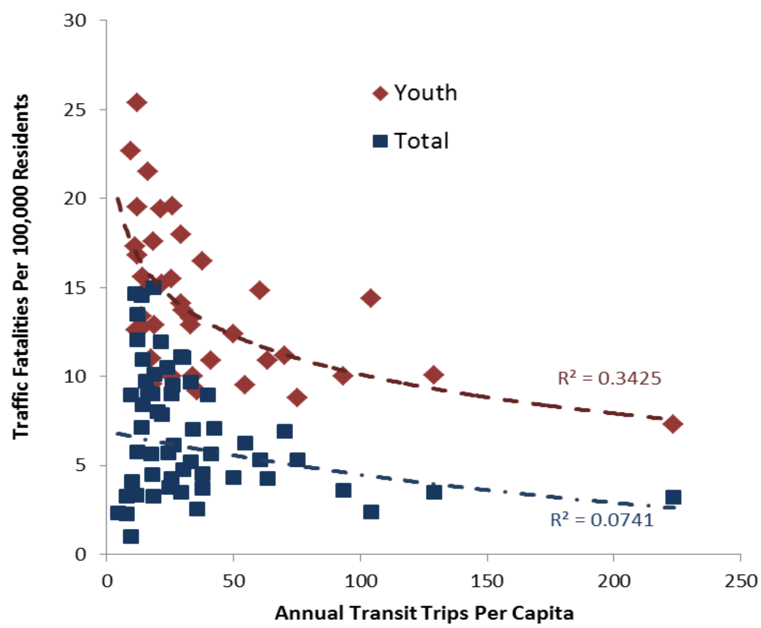


This graph illustrates the relationship between per capita transit ridership and total (including pedestrian, cyclist, automobile occupant and transit passenger) traffic fatalities for 35 large North American cities.

As transit travel increases, traffic fatalities tend to decline significantly. Cities with more than 50 annual transit trips per capita have about half the average traffic fatality rate as regions with less than 20 annual trips per capita, indicating that relatively modest increases in transit travel are associated with large traffic safety gains.

Public transport traffic safety benefits are particularly large for youths. On average, urban teens take five times as many transit trips and drive half as much and have about half the per capita traffic fatality rate as rural teens (NHTSA 2009). Nationwide, youths aged 15-25 average 17.3 traffic fatalities per 100,000 population, 56% higher than 11.1 overall rate, and urban youths had 10.9 deaths per 100,000, 38% higher than the 7.9 overall urban rates. Both youth and overall traffic fatality rates tend to decline as public transportation travel increased in their community, they are about half as high in urban regions where residents take more than 50 annual transit trips compared with those that do not, as illustrated in Figure 16.

Figure 16 **Youth and Total Traffic Fatality Rates** (CDC 2012)



Youths (15-25 years old) have about twice the average traffic fatality rates as the overall population. Both youth and total traffic fatality rates decline significantly with increased transit travel: cities where residents take more than 50 transit trips have about half the average traffic fatality rate as cities where residents average fewer than 20 annual transit trips. The statistical relationship between transit ridership and traffic safety is particularly strong for youths (R^2 = 0.3425), suggesting that many young people are willing to reduce their higher-risk driving if given suitable alternatives.

Truong and Currie's (2019) study of Melbourne, Australia crash rates found that shifts from private vehicle to public transport (i.e. train, tram, and bus) commuting tend to reduce both total crashes and severe injury crashes. They estimate that, holding all other variables (including proportions of commuting by tram, bus, walking, cycling, and motorbike) constant each percentage point increase in the proportion of commuting from a zone by train reduce 2.2 total crashes and 0.86 severe crashes, and a percentage point increase in bus mode share reduces an even larger 5.7 total crashes and 1.8 severe crashes. Increases in walking, bicycle and motorcycle mode shares, higher speed roads and industrial areas all tend to increase crashes in a zone.

Morency, et al. (2017) used 2001-2010 travel and accident data to compare injury rates for car and city bus occupants, and pedestrian and cyclist injuries associated with car and bus travel on ten urban arterial roads in Montreal, Canada. For all routes studied the injury and fatality rate ratios where more than three times greater for car occupants than for bus occupants, and rates of pedestrian and cyclist injuries per hundred million passenger-kilometres travelled was significantly greater for car travel than for bus travel. These results indicate that bus travel is safer than car travel on arterial roadways, so modal shifts from car to public transit can significantly improve road safety for all mode users.

Services that target higher risk groups can provide particularly large safety gains. For example, Jackson and Owens (2010) found that extending night transit service reduced drunk driving and accidents: they found that for each additional service hour DUI *arrests* declined 15.6%, and *fatal accidents* involving intoxicated drivers declined 70% near Metro stations. Broyles (2014) found that Phoenix, Arizona university students are significantly less likely to drink and drive if they live close to the city's light rail transit system which connects student housing with commercial and entertainment districts. Similarly, Lichtman-Sadot (2019) found that young driver traffic crash rates declined an average of 37%, and their crash injuries decrease 24%, after late-night buses began operating in Israeli cities in 2007.

In addition to previously-mentioned factors that discourage youth driving, many in this age group attend colleges and universities with campus transportation management programs which often include walking and cycling improvements, transit service improvements, U-Passes (students ride transit fare-free, so a student-body card becomes a transit pass), special night transport services, and efficient parking fees (Van Heeke, Sullivan and Baxandall 2014). Such policies tend to reduce the portion of students who bring motor vehicles to campus, and make it convenient and socially acceptable to use public transportation when traveling to events that involve alcohol or drug consumption, which reduces high-risk driving.

Even campuses in relatively automobile-dependent communities are implementing public transportation improvements and transportation management programs that reduce risky driving. For example, twenty bus routes serve the University of West Virginia, including one to downtown Morgantown which operates until midnight. This service is free to university and local high school students. The University of Arkansas has ten bus routes that are free for students, plus a *Safe Ride* program that provide students who feel threatened or too impaired to drive a free ride home from any location within the Fayetteville city limits. The Illinois State University has two local bus routes, plus *Nite Ride* and *Late Night Ride* bus service between campus and downtown Bloomington which operates as late as 2:25 a.m. on weekends. Late-night transit services can help reduce impaired driving, and associated crash risks.

Other studies find similar results. Using sophisticated statistical analysis, Hamidi, et al. (2015) found that more compact communities have significantly higher transit ridership, slightly higher *total* crash rates, but much lower *fatal* crash rates than sprawled communities: each 10% increase in their compact community index is associated with an 11.5% increase in transit commute mode share, a 0.4% increase in total crashes, and a 13.8% reduction in traffic fatalities. Lim, et al (2006) and Allen (2013) describes how Bus Rapid Transit improvements in Seoul, South Korea increased transit ridership more than 20% but reduced bus casualties 11% and total traffic crashes by 26%.

Karim, Wahba and Sayed (2012) found that Vancouver region crash rates decline significantly with bus stop density, transit travel relative to auto travel, and walking, biking, and transit commute mode share. Their modeling indicates that a strategic transport plan that encourages use of alternative modes tends to reduce total, severe, and property damage only collisions. Analyzing 29 years of traffic data for 100 U.S. cities, and accounting for various other demographic and geographic factors, Stimpson, et al. (2014) found that a 10% increase in the portion of passenger-miles made by transit is associated with 1.5% reduction in total traffic deaths. Since only about 2% of total person-miles are currently by transit, this means that a 1%

increase in transit mode share is associated with a 2.75% decrease in fatalities per 100,000 residents, which translates into a 5% decrease in total traffic fatalities in the 100 cities included in their study.

More convenient taxi and ridesharing services may provide similar safety benefits. According to a study by Uber and Mothers Against Drunk Driving, Uber travel demand tends to peak during bar closing times, and impaired driving arrests and crashes tend to declined significantly after Uber services became available in a city (Greenwood and Wattal 2015; Uber and MADD 2015). Taxis and ridesharing services do not eliminate the value of public transit in reducing drunk driving, they work together to reduce the need to own and drive private cars, for example, when people take transit to a restaurant or bar, and taxis and rideshare services home.

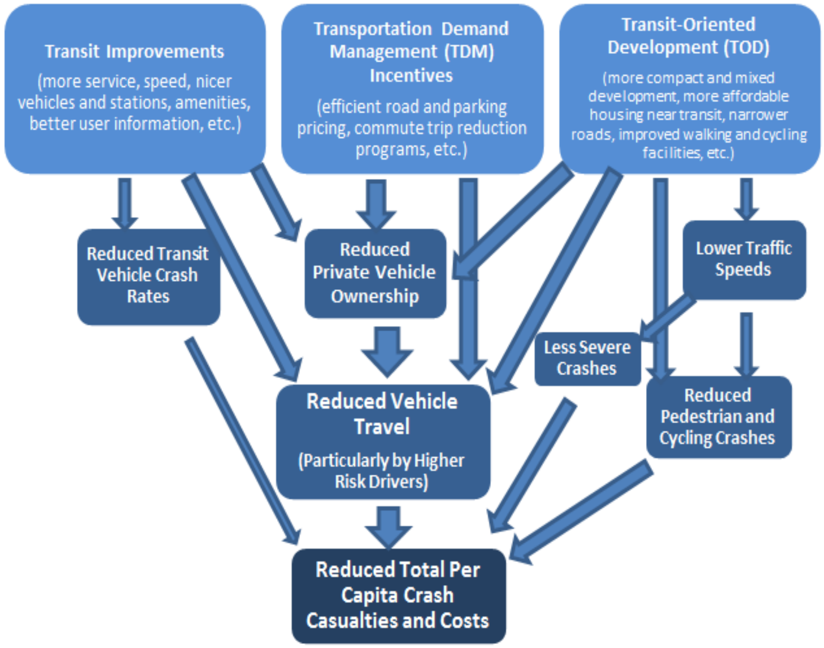
Several factors help explain the large crash reductions associated with modest transit ridership increases. Residents of cities with high quality transit tend to own fewer vehicle, drive less (due to more compact and mixed land use patterns), have lower traffic speeds (due to more compact urban development), and have less high-risk (youth, senior, impaired and distracted) driving. For example, teenagers and elderly people are less likely to have a drivers license and own a vehicle in communities with better travel alternatives, and in transit-oriented communities, residents are more likely to walk, take transit or taxis rather than drive to restaurants and bars. The traffic safety impacts of more accessible land use patterns are discussed in more detail later.

As a result, traffic safety policies and programs intended to reduce higher-risk driving, such as graduated licenses, senior driver testing, and drunk- or distracted-driving discouragement campaigns, are more effective if implemented with appropriate transit improvements. Since most casualty crashes involve multiple vehicles, even responsible drivers who always observe traffic laws and never use transit can benefit from transit improvements that reduce total vehicle traffic and higher-risk driving, and therefore their risk of being the victim of another drivers' error.

Duduta, et al. (2014) show that high quality public transport systems that incorporate high quality infrastructure and safety features can provide significant safety benefits on the streets where they are implemented, reducing injuries and fatalities as much as 50%. Their report provides detailed recommendations for incorporating safety into the design, planning, and operation of different types of bus systems.

Figure 17 illustrates various ways that pro-transit strategies help increase traffic safety. A particular policy or planning decision may have multiple impacts. For example, a commuter-oriented transit improvement will directly reduce risk to the travelers who shift mode, and reduce risk indirectly if some households to reduce their vehicle ownership which reduces their non-commuter vehicle travel. As a result, pro-transit policies, such as service improvements, TDM incentives, and transit-oriented development tend to have cumulative and synergistic effects: implemented together their impacts are greater than if implemented separately.

Figure 17 **Transit Improvements, Incentives and TOD Safety Impacts** (Litman 2014)



Public transit service improvements, transportation demand management (TDM) incentives, and transit-oriented development tend to increase safety in several ways. They reduce traffic speeds, reduce per capita vehicle travel, and are often particularly effective at reducing higher risk (youth, senior and impaired) driving.

Ridesharing

Ridesharing refers to carpooling and vanpooling. Ridesharing reduces total vehicle mileage which should reduce total vehicle crashes, but this will be partly offset by increased injuries per crash. People who rideshare rather than drive alone bear about the same level of internal risk but reduce risk to others by reducing traffic volumes. For example, if increased ridesharing caused average vehicle occupancy to increase 10% and mileage to declined 10%, and the elasticity of crashes to mileage is 1.5 as suggested earlier, total crashes should decline 15%, but the casualty rate per crash should increase by 10%, so total casualties would only decline about 5%. Ridesharing may increase safety if drivers are more cautious when they have passengers, or if they rely on the most skilled driver or safest vehicle in the group. However, some HOV lanes have relatively high crash rates (Cothron, et al, 2005), and loaded vans may have a relatively high rollover rate which may increase risk under some conditions (NHTSA, 2001).

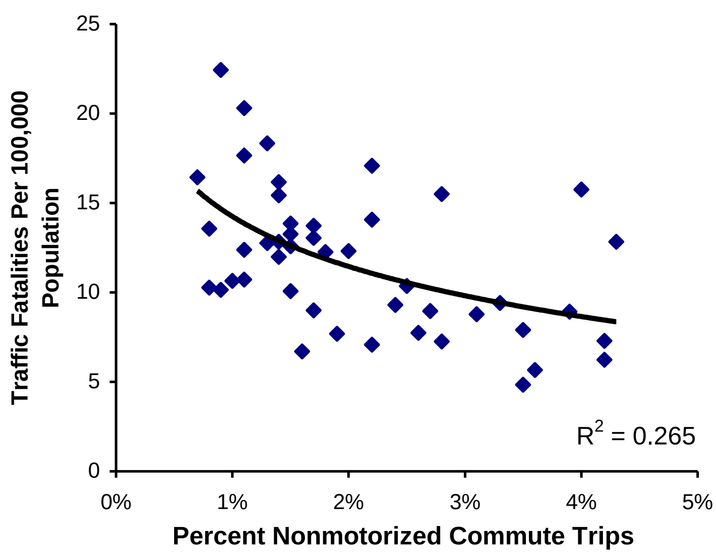
Active Transport

Walking and cycling tend to have higher crash rates per travel-mile than motorized modes, but as active travel increases in an area, both distance-based and total per capita casualty rates tend to decline (Lian, et al. 2022; Murphy, Levinson and Owen 2017). This effect is called *safety in numbers* (Jacobsen 2003).

Jacobsen (2003) calculated that collisions motorists and nonmotorists increase at roughly the 0.4 power of the amount of walking and cycling in a community (e.g., doubling active travel increases pedestrian/cycling injuries by 32%), and the probability that a motorist will strike an active traveler declines with the roughly -0.6 power of the amount of active travel (e.g., risk of a pedestrian being hit by a motorists declines 34% if walking and cycling double in a community). Wardlaw (2001) found that in various geographic conditions, doubling cycling mileage only increases cycling deaths by 25%. Robinson (2005) found similar results using Australian data: doubling bicycle travel reduces cyclist risk per kilometer by about 34%; and conversely, halving bicycle travel increases risk per kilometer about 52%.

The following two figures illustrate this relationship.

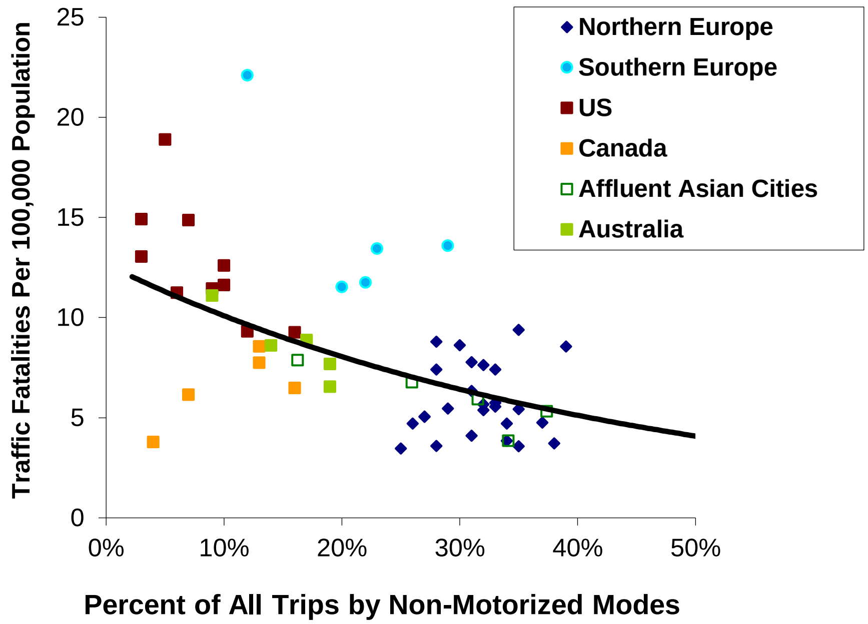
Figure 18 **Traffic Fatalities Vs. Non-Motorized Transport** (US Census 2000)



As active travel increases in U.S. urban regions total (all mode) per capita traffic fatality rates tend to decline.

This equation has a low R-square (0.265), but the estimate coefficients are significant.

Figure 19 **Traffic Fatalities Vs. Non-Motorized Transport** (Kenworthy and Laube 2000)



International data indicate that per capita traffic fatality rates tend to decline in a city as the portion of active travel increases.

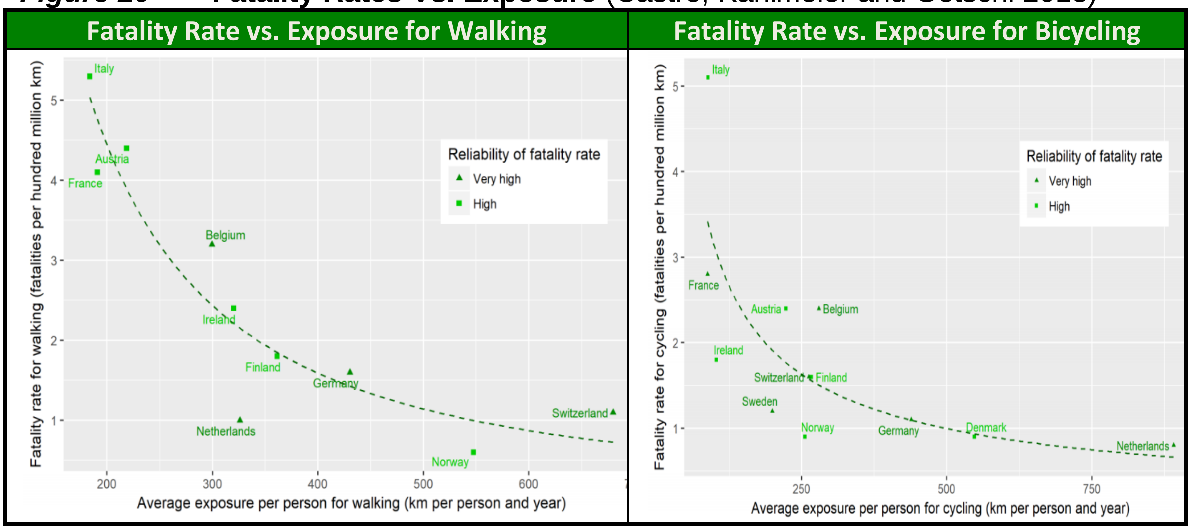
Comprehensive analysis by Marshall and Ferenchak (2024) found that total traffic fatality rates in U.S. cities decline significantly with increased bicycle mode shares. They note that the relationship between levels of bicycling and overall safety outcomes may be bi-directional: safer roads result in higher bicycle use, and higher bicycle use may result in safer roads. Murphy, Levinson and Owen (2017) found that in 448 Minneapolis city intersections, pedestrians had a lower risk of being hit by a car at intersections with higher pedestrian traffic, and motorists had lower risk of hitting pedestrians at intersections with more car traffic, demonstrating safety in numbers effects.

Buehler and Pucher (2021) found that pedestrian fatality rates per were 5–10 times higher, and bicyclist fatality rates 4-7 times higher, in the US than in Denmark, Germany, The Netherlands, and the U.K. This probably reflects a combination of better walking and bicycling infrastructure; lower urban speed limits; fewer vehicle km travelled; smaller and less powerful personal motor vehicles; and better traffic training, testing, and enforcement of traffic regulations.

Chu (2003 and 2006) concludes that walking has 1.7 times the fatality rate per minute of travel than motor vehicle travel, with significant variation by time of day, age of walker and how risk is measured. Death rates range from 1 pedestrian fatality per 10 million walking hours during early afternoon up to 400 deaths per 10 million hours late at night, and are particularly high for older pedestrians. Walking and driving fatality rates per minute are both higher in the U.S. than in European Union countries (Pucher and Dijkstra 2000). The incremental risk for responsible pedestrian or cyclist who observes traffic rules and takes precautions such as using a light at night and a helmet (for cyclists) is likely to be much lower than indicated by average per-mile fatality rates, and offset by reductions in risk to other road users and other health benefits.

Marshall and Garrick (2011) found that U.S. cities with higher per capita bicycling rates tend to have much lower traffic fatality rates for all road users than other cities. They conclude that this results, in part, because increased street network density both supports bicycling and reduces traffic speeds and therefore risk. Robinson (2005), Geyer, Raford and Ragland (2006), and Turner, Roozenburg and Francis (2006) also find that total per capita collisions between motorists, pedestrians and bicyclists decline as active transport activity increases. Castro, Kahlmeier and Gotschi (2018) estimated annual kilometers walked and bicycled for various countries and compared that information with pedestrian and bicycle traffic death rates. The results, illustrated in Figure 20, support the safety in numbers hypothesis.

Figure 20 **Fatality Rates Vs. Exposure** (Castro, Kahlmeier and Gotschi 2018)



Various factors help explain the negative relationship between active travel and crashes (Marshall and Ferenchak 2019):

- *Reduced external risk.* Pedestrians and bicyclists impose less risk on other road users.
- *Reduced total travel.* Shorter active trips often substitute for a longer automobile trip, for example, walking or biking to local shops rather than driving to regional shopping centers. Improving walking and cycling conditions reduces chauffeuring trips, which often require empty backhauls so active trips generate half as much mileage as the chauffeured trips they replace. Since most public transit trips involve walking and bicycling links, improving their conditions can increase transit travel.
- *Complementary factors.* Many factors and roadway design features that encourage walking and bicycling – such as connected streets, streetscaping, traffic calming and speed management – tend to increase safety for all road users.
- *Increased driver caution.* As walking and bicycling increases in an area, drivers are likely to become more aware and cautious.
- *Less high-risk driving.* Improving non-auto modes allows young, old, impaired and distracted travellers to reduce driving, increasing the effectiveness of safety programs such as graduated licenses, senior driver testing and anti-impaired and distracted driving campaigns.
- *Stronger traffic enforcement*. In automobile dependent communities, courts are less likely to restrict licensure and confiscate vehicles of high-risk drivers.

The World Health Organization' *Health Economic Assessment Tool for Cycling* (HEAT for Cycling) computer program estimates the monetized value of bicycling health benefits. Lindsay, Woodward and Macmillan (2008) used this model to estimate the effects on air pollution and health of replacing light vehicles with bicycles for varying proportions of short trips (≤7 km) by New Zealand urban adults. They conclude that total health benefits significantly outweigh incremental road crash costs. Due to *safety in numbers* effects, the benefit/cost ratio increases as bicycle mode share increases (the ratio is 3:1 for 1% substitution and over 30:1 for 20% substitution). Shifting 5% of vehicle km to cycling would be consistent with the New Zealand Transport Strategy goals of 30% of urban trips by active modes by 2040, which returns cycling to 1980 levels. This would save about 22 million litres of fuel annually and reduce about 0.35% of transport-related greenhouse emissions. The health effects would include 116 deaths avoided annually as a result of increased physical activity, 5.6 fewer deaths due to local air pollution from vehicle emissions, and an additional 5 cyclist fatalities from road crashes. In economic terms, the health effects would amount to net savings of approximately $193 million per year.

The San Francisco Department of Public Health developed an Vehicle-Pedestrian Injury Collision Model which predicts how demographic, geographic and land use planning factors affect the number of collisions resulting in pedestrian injury or death in an area (SFDPH 2008). The model indicates that pedestrian injuries and deaths increase with motor vehicle traffic volume, vehicle traffic speeds, pedestrian volume, and various intersection and street design factors.

Active travel provides physical exercise which can have substantial health benefits. Inadequate physical exercise and excessive body weight are increasing problems that results in a variety of medical problems, including cardiovascular diseases, bone and joint injuries, and diabetes. About ten times as many people die from these illnesses than traffic accidents. Although there are many ways to be physically active, increased walking and cycling are among the most practical and effective, particularly for inactive and overweight people. Residents of more walkable communities exercise more and are less likely to be overweight than residents of automobile-oriented communities (Ewing, Schieber and Zegeer 2003; Frank 2004).

Some studies quantify the overall health impacts that result if driving shifts to cycling, including increases in accident risk, air pollution exposure and improved public fitness (Litman 2009). Rojas-Rueda, et al. (2011) estimate that Barcelona residents that use the Bicing public bike rental system experience 0.03 additional annual traffic accident deaths, 0.13 additional air pollution deaths, and 12.46 fewer deaths from improved fitness, resulting in 12.28 fewer deaths and a 77 benefit:risk ratio. Similarly, Rabl and de Nazelle (2012) estimate that a typical commuter who shifts from driving to bicycling has physical activity health benefits worth about 1,300 € annually, and about 20 €/yr additional air pollution exposure costs, although other residents benefit from reduced pollution. The analysis implies that any additional accident costs are at least an order of magnitude smaller than physical activity health benefits.

In summary, although active travel is more hazardous to users per mile of travel, for various reasons increased walking and cycling tends to reduce total traffic risk in a community. There is no evidence that shifting travel from driving to active modes increases total public health risks, especially if traffic safety education and facility improvements are provided. Any increase in risk that does occur is probably more than offset by physical fitness benefits.

Mobility Substitutes

Mobility substitutes include telework and delivery services. These can reduce vehicle travel and therefore traffic accidents, although there may be rebound effects that offset a portion of mileage reductions and associated safety benefits (O'Brien and Aliabadi 2020). Telecommuters often make additional trips for errands that they would otherwise perform while commuting. Some employees choose more distant worksites or more isolated home locations if they are allowed to telecommute. For example, if allowed to telecommute three days a week an employee might move from an urban home with a 50 mile commute to a rural home with a 100 mile commute. Their 60% reduction in commute trips is offset by a 100% increase in commute distance, resulting in just a 20% net reduction in total commute mileage, and this may be offset further if the employee makes additional errand trips during commuting days or chooses a more automobile-dependent home location. Modeling by Pirdavani, et al. (2013) predicts that if 5% of current commuters shifted to teleworking in Flanders, Belgium, total vehicle crashes would decline approximately 2.5%.

Travel Time and Route Shifts

Strategies that shift vehicle travel from peak to off-peak periods, or from congested to less congested routes, have mixed safety impacts. Crash rates per mile are lowest on moderately congested roads, and increase at lower and higher congestion levels, but fatalities decline at high levels of congestion, indicating a trade-off between congestion reduction benefits and crash fatalities (Zhou and Sisiopiku 1997; Marchesini and Weijermars 2010; Shefer and Rietvald 1997). Shifting vehicle trips to less congested roadway conditions can reduce crashes, but the crashes that occur tend to be more severe due to higher travel speeds. As a result, the safety impacts of mobility management strategies that shift travel times and routes can vary, depending on specific circumstances, and are difficult to predict.

Traffic Speed Reductions

Traffic speed is a major crash risk factor, particularly for pedestrians and bicyclists (Brenneis 2021). Extensive research indicates that crash frequency and severity increase exponentially with traffic speeds: each 1% increase in average traffic speed increases injury crash frequency about 2%, severe crash frequency about 3%, and fatal crash frequency about 4% (Elvik 2009; ITF 2018). Reducing average traffic speeds by just 5% can reduce fatalities by approximately 20% (OECD/ECMT 2006). Even modest speed reductions can prevent many collisions and reduce the severity of damages and injuries that result when crashes occur, particularly on urban roads where there are many intersections, diverse traffic and many walkers and bicyclists (Martin 2019; Racioppi, et al. 2004). About 5% of pedestrians die when struck by a vehicle traveling 20 mph, 40% for vehicles traveling 30 mph, 80% for vehicles traveling 40 mph, and nearly 100% for speeds over 50 mph (McMillan and Cooper 2019).

One major study published in the *Lance Medical Journal* concluded that speed management has the greatest potential for reducing casualties of all major traffic safety interventions; they estimate that optimal speeds could save about 347,258 lives globally each year, nearly three times the 121,083 lives that could be saved by seatbelt interventions, seven times the 51,698 lives that could be saved by helmets, and about twenty times the 16,304 lives that could be saved through drink driving interventions (Vecino-Ortiz, et al. 2022).

Analysis by Redelmeier and Bayoumi (2010) estimate each hour spent driving is associated with approximately 20 minutes reduction in life expectancy due to crash risk. For the average driver, each one kilometer per hour (0.6-mph) increase in driving speed yielded a 26-second increase in total expected lost time because travel time savings were more than offset by increased crash delay. A 3 kilometer-per-hour (1.8-mph) decrease in average driving speed yielded the least amount of total time lost. This analysis indicates that U.S. drivers travel slightly too fast and could improve overall life expectancy with small reductions in average traffic speeds. Taylor, et al (2000) estimate that each 1 mph reduction in average traffic provides the following reductions in vehicle accidents:

- 6% for urban main roads and residential roads with low average speeds.
- 4% for medium speed urban roads and lower speed rural main roads.
- 3% for the higher speed urban roads and rural single carriageway main roads.

Reports such as the *Development of a Posted Speed Limit Setting Procedure and Tool* (TRB 2021), *Road Safety in Cities: Street Design and Traffic Management* (ITF 2022), and *City Limits: Setting Safe Speed Limits on Urban Streets* (NACTO 2020) provide guidance for optimizing traffic speeds.

Streetscaping, Traffic Calming and Road Diets

Streetscaping and traffic calming include various roadway design features that improve roadway aesthetics, accommodate diverse modes (sidewalks, bike lanes, high-occupant vehicle lanes, etc.), and reduce traffic speeds and volumes (VTPI 2004). These strategies tend to increase traffic safety (Ernst and Shoup 2009). Meta-analysis by Elvik (2001a) concluded that area-wide traffic calming can reduce injury accidents about 15%, with larger reduction on residential streets (25%) than on main roads (10%). Tasic and Porter (2018) find that, all else being equal, expanding sidewalks in an area tends to reduce non-motorized crash rates.

Marshall and Garrick (2011) conclude that more connected, multi-modal street design can significantly reduce traffic injury and fatality rates in U.S. cities. Wei and Lovegrove (2010) evaluated the road safety of five neighbourhood patterns – grid, culs-de-sac, and Dutch Sustainable Road Safety (SRS, or limited access), 3-way offset, and fused grid networks. Analysis using standard transportation planning methodology revealed that all can maintain similar levels of mobility and accessibility, but the 3-way offset, and fused grid patterns significantly improve road safety, by as much as 60% compared to prevalent patterns (i.e. grid and culs-de-sac). These results do not account for the additional safety benefits that result from roadway designs that, by improving non-motorized travel conditions tend to shift travel from auto to non-auto modes. As a result, these can be considered lower-bound estimates of safety benefits.

A *road diet* involves narrowing or eliminating travel lanes on an arterial roadway, often by creating center left turn lanes, which tends to reduce traffic speeds, improve pedestrian and cycling facilities, and reduce conflicts by left-turning vehicles. A major U.S. study (HSIS 2010) concludes that road diets typically reduce crash rates 47% on major highways through small urban areas, 19% on larger city suburban corridors, and 29% overall. Vollpracht (2010) describes accident and pollution exposure risks that often develop in lower-income countries as informal commercial and residential districts develop along highways. He recommends a combination traffic speed control, access management and better land use planning to reduce these risks.

A comprehensive study by Karim (2015) found that collision rates and severity tend to increase as lane widths exceed about 10.5 feet or are narrower than about 10 feet. He concluded that optimal urban street lane widths are between 10 and 10.5 feet. Analysis by Dumbaugh (2005) and a detailed review by MacDonald, Sanders and Supawanich (2008) concluded that roadside landscaping generally improves highway safety, although there is some uncertainty concerning roadside trees safety impacts. Analyzing road networks and traffic crash data in 16 randomly selected U.S. cities Mohan, Bangdiwala and Villaveces (2017) found that, more junctions per road length is significantly associated with a lower motor-vehicle crash and pedestrian mortality rates, and increased road kilometers of any kind is associated with higher fatality rates, with particularly large increases associated with more arterial highway and arterial road kilometers.

Vehicle Use Restrictions

Some communities restrict vehicle use, such as *No-Drive Days* which prohibit some vehicles from operating at certain times, and prohibitions on driving in certain areas. However, these may shift vehicle travel to other times and locations, rather than reducing total vehicle mileage. For example, motorists may simply defer automobile errand trips from prohibited to other days, and detour around car-free districts, resulting in no reduction in mileage or crash risk. Only if such restrictions are part of an overall program to improve travel options and create more accessible land use patterns are they likely to reduce total traffic risk.

Travel Management Programs

Travel management programs include commute trip reduction (CTR) and school transport management programs designed to reduce peak-period automobile commuting, and mobility management marketing programs designed to encourage community residents to try and use alternative travel options. Although primarily intended to reduce vehicle traffic congestion and pollution emissions, they may also reduce traffic accidents.

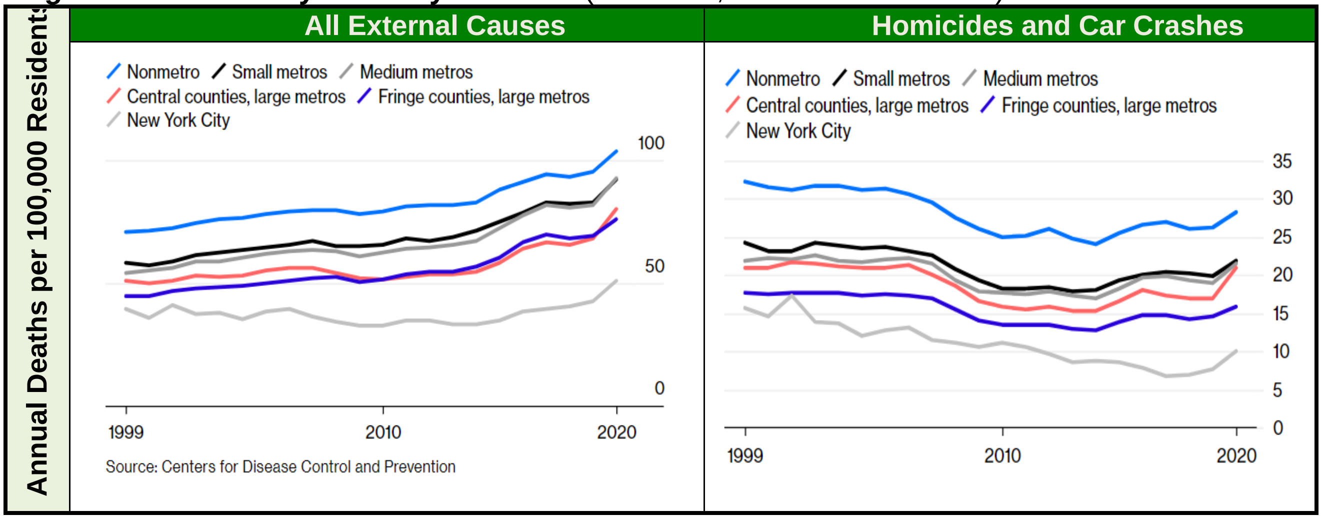
Wallington, et al. (2014) implemented a program to reduce traffic crashes by approximately 95,000 British Telecommunications employees. The project applied occupational health and safety principles to assess crash risks. This is justified because approximately 40% of worker fatalities involve vehicles and 50% of road deaths are work-related. The program included a combination of trip reduction and driver safety training; the results halved the company’s collision rate and costs, from about 60 monthly insurance claims per 1,000 vehicles in 2002 to less than 30 in 2012.

Geographic and Land Use Development Factors

Geographic and land use development factors can significantly affect safety and health risks, including homicides and traffic crash rates. Using sophisticated statistical analysis, Ewing, Hamidi and Grace (2015) and Yeo, Park and Jang (2014) found that more compact communities had significantly higher transit ridership, slightly higher *total* crash rates, but much lower *fatal* crash rates than sprawled communities: each 10% increase in their compact community index is associated with an 11.5% increase in transit commute mode share, a 0.4% increase in total crashes and a 13.8% reduction in traffic fatalities (Ewing and Hamidi 2014).

Fox (2022) and Myers, et al. (2013) analyzed how death rate from external risks, such as homicides and traffic crashes, vary by geographic location in the U.S. Their analysis indicates that most of these risks decrease with density. Residents of large metro regions tend to be safer than in small and medium metros, which tend to be safer than non-metro (rural) areas. Large metro fringe counties are often safer than central counties, probably due to lower poverty rates, but New York City is by far the safest jurisdiction overall, as illustrated below.

Figure 21 **Fatality Rates by Location** (Fox 2022, based on CDC Data)



Fatality rates tend to decline with density and city size, and are particularly low in large cities such as New York due in part to their low traffic death rates.

Many factors help explain these large variations. Using detailed data from 100 U.S. urban regions in 2010, Najaf, et al. (2018) find that per capita traffic deaths decline with increased population density and mix (job-housing balance), more transportation network connectivity, more public transit facilities, and fewer freeway- and arterial-miles. They estimate that, all else being equal, a 10% increase in urban density or jobs/housing balance reduces crash death 15%, a 10% increase in network connectivity reduces deaths 4.1% and a 10% increase in public transit supply reduces fatalities 8.3%. Similarly, using data from San Antonio, Texas neighborhoods and accounting for other demographic and economic factors Dumbaugh and Rae (2009) found that:

- Increased vehicle travel tends to increase crash rates, with approximately 0.75% more crashes for every additional million miles of vehicle travel in a neighborhood.
- Population density is significantly associated with fewer crashes, with each additional person per net residential acre decreasing crash incidence 0.05%.
- Each additional arterial-oriented commercial parcel increases crashes 1.3% and each big box store increases crashes 6.6%, while pedestrian-scaled commercial areas reduced crashes 2.2%.
- Each additional freeway-mile is associated with a 5% increase in traffic deaths, and an additional arterial-mile is associated with 15% more total crashes and 20% more traffic deaths.
- Three- and four-leg intersections were associated with significantly reduced fatal crash rates.
- The numbers of both young and older drivers were associated with increased total crashes.

The authors conclude that many urban planning and roadway planning practices previously recommended to increase traffic safety, such as residential and commercial separation, and hierarchal road systems with wider arterials and dead-end residential streets, actually increase total crash and fatality rates by increasing total vehicle travel and traffic speeds. Their analysis indicates that Smart Growth policies tend to increase traffic safety.

Scheiner and Holz-Rau (2011) find considerably lower per capita crash injury rates and costs in German cities than suburbs and rural areas. Garrick and Marshall (2011) analyzed how land use factors and roadway design affected mode choice and crash rates in twenty-four California cities; half were classified as "safe cites" (crash casualty rates one-third the state average), and half as "less safe cities" (crash casualty rates close to the state average). The safer cities were mainly established prior to 1950, while less safe cities tend to be newer and more sprawled. Even within cities there are large differences in safety related to street network design. For example, the pre-1940s sections of Davis, CA, (211 intersections/sq mi) had a fatal/severe crash rate half the post-1970 sections of town (111-132 intersections/sq mi). The walking-biking-transit mode share was 59% in the pre-1940 areas compared with 14% in the post-1980 areas.

Safer Cities

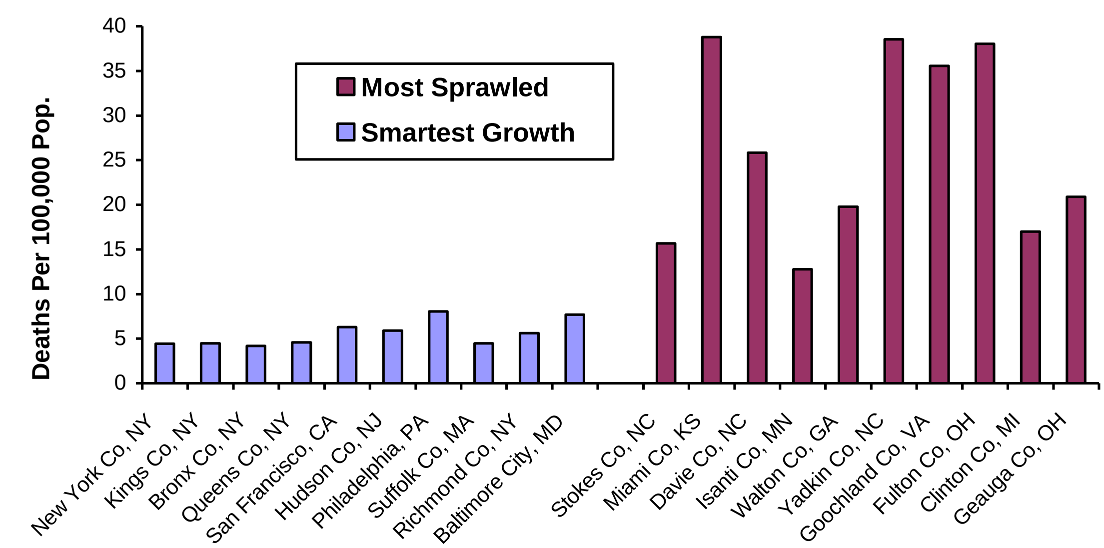
- 106/sq mile average intersection density.
- 16% walking/biking/transit mode share.
- 3.2 average annual traffic deaths per 100,000 population.

Less Safe Cities

- 63/sq mile average intersection density.
- 4% walking/biking/transit mode share.
- 10.5 average annual traffic deaths per 100,000 population.

S*mart growth* (also called *new urbanism* and *transit oriented development*) consists of land use development policies that more compact, mixed use, multi-modal communities. This is an alternative to dispersed, automobile-dependent, urban fringe development, commonly called *sprawl*. Ewing, Schieber and Zegeer (2003) find that per capita traffic fatality rates increase with the degree of sprawl in a community, as indicated in Figure 22. They found that each one percent increase in their index toward smart growth reduces the area's traffic fatality rate 1.5%.

Figure 22 **Annual Traffic Death Rate** (Ewing, Schieber and Zegeer 2003)



The ten counties with the lowest sprawl rating have about a quarter of the per capita annual traffic fatality rates of the most sprawled counties.

Several factors may contribute to these safety impacts. Smart growth reduces per capita vehicle mileage, but typically only by 10-20%, which does not fully explain these safety benefits. Other factors probably include lower traffic speeds due to lower roadway design speeds and increased congestion, more caution by drivers as traffic density increases, and less driving by higher-risk drivers (young males, people with disabilities, or a history of traffic violations and crashes), due to better mobility options. For example, Scheiner and Holz-Rau (2011) found that in German cities, only 23% of 18–19 year olds and 33% of 20-21 year olds had access to a car, compared with 42% and 57% in suburban fringe areas. Overall, city residents are safer, taking into account risks that increase with urban living, such as pedestrian fatalities and homicides (Lucy 2002 and 2003).

The comprehensive report, *Cities Safer By Design* (Welle, et al. 2015), describes how to Smart Growth development patterns and multi-modal roadway design can significantly reduce urban traffic risks. It describes 34 different design elements that can help reduce traffic risks and provide other livability benefits.

Safety Impacts Summary

Table 10 summarizes the travel, safety and health impacts (pollution exposure and physical fitness) of various mobility management strategies.

Table 10 **Mobility Management Safety and Health Impact Summary**

Category	Travel Changes	Safety Impacts	Health Impacts
Active mode (walking and bicycling) improvements	Shifts motorized travel to active modes	Can increase per-mile risks to users but by reducing external risks and total vehicle travel increases safety overall, called *safety in numbers*.	Provide significant health benefits. Reduces pollution emissions.
Transit improvements, HOV priority, park & ride	Shifts automobile travel to transit. Also increases active travel.	Moderate to large safety benefits. Shifts from automobile to transit reduce per-mile crash rates and total vehicle travel.	Reduces pollution emissions, and increases active travel which increases physical fitness.
Ridesharing, HOV priority	Shifts single occupant travel to ridesharing	Moderate safety benefits. Reduces total vehicle traffic, but crashes that occur may involve more victims.	Reduces total emissions and may increase active travel and therefore physical fitness.
Pricing reforms (road and parking pricing, increased fuel taxes, etc.).	Reduces vehicle mileage.	Moderate to large safety benefits. Vehicle mileage reductions generally cause proportional or greater reductions in total crash damages.	Some shifts to alternative modes which reduces total pollution emissions and increases physical fitness.
Distance-based (PAYD) insurance.	Reduces mileage in proportion to risk class.	Large potential safety benefits. Reduces total traffic and gives high-risk motorists an extra incentive to reduce mileage.	Some shifts to non-auto modes which reduces emissions and increases physical fitness.
Telework, delivery services	Reduces total vehicle travel.	Modest benefits. Reduced vehicle travel reduces crashes, but benefits may be offset by rebound effects.	Generally positive. Reduces total pollution emissions.
Flextime	Shifts travel from peak to off-peak	Mixed. Reducing congestion tends to reduce crash frequency, but higher speeds increase severity.	Uncertain. May reduce per-mile emissions.
Streetscaping, traffic calming and speed enforcement	Reduces traffic speeds.	Large safety benefits where applied. Reduces total vehicle travel, crash frequency and severity..	Tends to improve walking and bicycling conditions, providing health benefits.
Time and location driving restrictions.	Reduces vehicle travel and increases active in those areas.	Increases safety where vehicle travel is reduced, but may increase risks elsewhere if traffic is diverted.	Reduces pollution and increases fitness if total vehicle travel declines and use of non-motorized travel increases.
Smart Growth (more compact, mixed, multimodal development).	Reduces vehicle travel and traffic speeds, increases non-auto travel.	Large safety benefits. Reduces per capita vehicle travel.	Reduces total emissions but increased density can increase exposure to local pollutants. Tends to increase active travel and therefore fitness.

This table summarizes the safety and health impacts of various mobility management strategies.

Types of Driving

Mobility management traffic safety impacts are affected by the type of travel changes that occur, particularly the relative risk of vehicle miles reduced.

- If motorists primarily reduce lower-risk vehicle travel (for example, sober, daytime, grade-separated driving) then mileage reductions may provide proportionately smaller reductions in crashes. For example, a 10% reduction in miles may provide only a 5% reduction in crashes and fatalities.
- If motorists reduce overall average risk vehicle travel (an average mix of all types of driving) a reduction in mileage should provide a proportionate reduction in crash risk to the vehicles that reduce miles, plus a reduction in risk to other road users, resulting in a proportionately larger reduction in crashes than mileage. For example, a 10% reduction in miles should provide a 10% reduction in crashes and fatalities to the motorists who reduce their mileage, plus a small reduction ion mileage to other road users.
- If motorists primarily reduce higher-risk vehicle travel (drunk, weekend-nights, surface streets) mileage reductions should provide proportionately larger crash and fatality reductions.

Traffic safety experts often assume that mobility management strategies mainly reduce lower-risk vehicle travel, such as commuting, and so are inefficient at increasing traffic safety. They point to evidence that a large portion of crashes (about half) result from specific high-risk behaviors (drivers impaired by alcohol or drugs, distracted by mobile phones, etc.), or higher risk (young men or very old) drivers. This perspective argues that automobile travel is not inherently dangerous and need not be discouraged; safety programs should target specific risks and groups.

But the research described in this report indicates that mobility management strategies that reduce overall vehicle travel, which primarily consists of lower-risk driving, do significantly reduce overall per capita crash rates. There are several explanations for this.

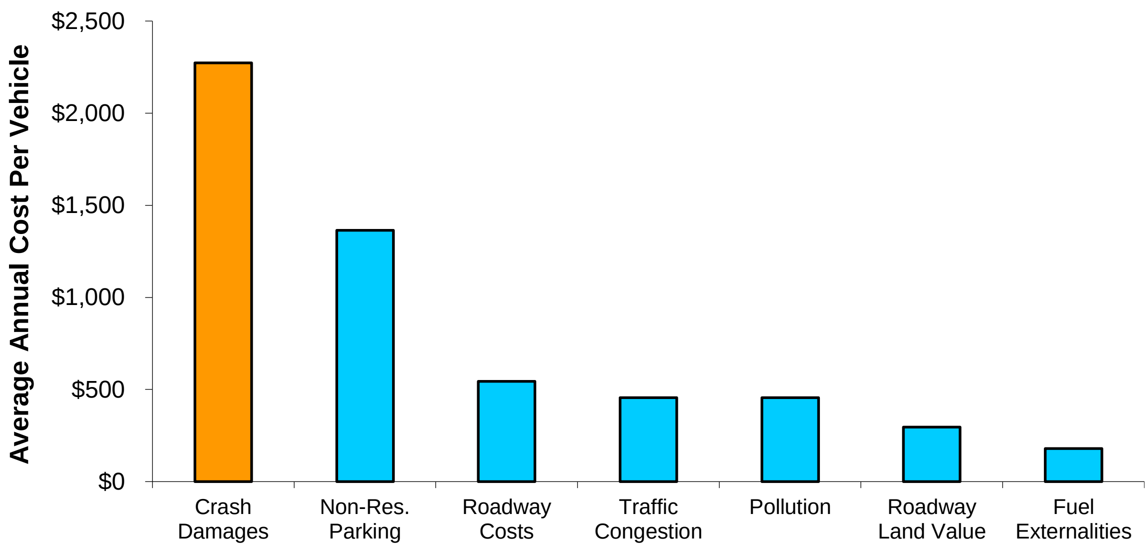
First, a significant portion of crashes (about half) involve normal drivers under normal driving conditions, without any specific risky behaviors. Second, reductions in error-free driving reduce crashes because those vehicles are no longer targets when other motorists make a mistake. Third, safe driving probably stimulates risky driving. For example, a commuter who drives to work in the morning is more likely to drive to a bar for a drink that evening than if they had commuted by an alternative mode, so a commute trip reduction program can leverage reductions in drunk driving. Similarly, smart growth land use policies, which create more compact, multi-modal communities, reduce all sorts of driving, including high risk driving, by reducing the need for teenagers to obtain a drivers license, providing convenient alternatives (walking, taxis and public transit) for drinkers to return home from a bar, and reduces traffic speeds and therefore crash severity.

Mobility Management Benefit Evaluation

Mobility management programs are currently evaluated primarily on their cost effectiveness for achieving one or two specific objectives. For example, transportation agencies generally evaluate mobility management based on its ability to reduce road congestion, and environmental agency generally evaluate it based on its ability to reduce pollution emissions. Other impacts are often overlooked. Traffic safety impacts are generally given little consideration in mobility management evaluation.

Various studies have *monetized* (measure in monetary value) transportation costs, including crash costs (Miller 1991; Litman 2009). Crash costs are one of the largest categories of societal costs associated with motor vehicle use. Total annual U.S. motor vehicle crash costs are estimated to exceed $500 billion, about five times greater than traffic congestion or vehicle air pollution costs, as illustrated in Figure 23.[4]

Figure 23 **Costs of Motor Vehicle Use in the U.S.** (Litman 2009)



This figure illustrates the estimated magnitude of various transportation costs. Crash costs (including market and non-market, internal and external costs) are the largest category, far greater than congestion or pollution costs.

The relative magnitude of these costs has important implications for transportation planning. It suggests that a congestion or emission reduction strategy may not be worthwhile overall if it causes even a modest increase in crash costs. For example, if roadway capacity expansion reduces congestion costs by 10% but increases crash costs by 2% due to induced vehicle travel or higher traffic speeds, it is a poor investment. On the other hand, a congestion reduction strategy provides much greater total benefits if it causes even small reductions in crashes. A

[4] Some studies give lower total estimates of crash costs because they are based on a "human capital" methodology, which only considers people's economic productivity, rather than a comprehensive analysis based on willingness-to-pay to reduce risks, including non-market values. Most experts agree that willingness-to-pay is the appropriate methodology for valuing safety programs that avoid damages. A human capital methodology may be more appropriate for damage compensation.

mobility management strategy that reduces congestion costs by 5%, provides twice as much total benefit to society if it also reduces crash costs by 1%.

Current transport planning practices give little or no consideration to safety impacts of changes in vehicle mileage. This tends to overvalue roadway and vehicle improvements that increase vehicle mileage (such as highway capacity expansion which induce vehicle travel on a particular roadway, and vehicle fuel efficiency and safety improvements that increase per capita vehicle mileage), and undervalues mobility management programs that reduce vehicle mileage.

For example, in recent years there has been considerable debate concerning the effects that generated and induced mileage have on congestion reduction efforts and vehicle emissions, but this debate has given relatively little consideration to safety impacts. Elvik (2001b) points out that, although highway capacity expansion is often justified based on projected crash reductions, total road safety will only increase if the roadway improvement avoids increasing traffic volumes and speeds. Research by Noland (2003) suggests that highway improvements tend to increase crashes overall, apparently due to increased vehicle traffic mileage and speed.

Similarly, there has been considerable debate over the value of corporate fuel efficiency standards, which force vehicle manufactures to sell more fuel efficient vehicles. A key issue in this debate is the effect these standards have on traffic safety due to their impacts on vehicle size and crash protection (CBO 2003). However, there has been little debate over their traffic safety impacts due to increased mileage (increased fuel efficiency reduces per-mile vehicle operating costs, leading to increased average annual mileage), although this effect is probably larger (Litman 2007).

Mileage related safety impacts are also generally ignored in the evaluation of land use policies, such as optimal parking standards (higher standards encourage vehicle ownership and use, and create more dispersed, automobile-dependent land use patterns), the consolidation of public facilities such as schools and recreational centers (more centralized facilities require more driving, and encourage families to purchase vehicles for their teenage children), debates between smart growth and sprawl, and countless other public policy decisions that directly or indirectly affect the amount of vehicle travel that will occur in an area.

How Much Safety Can Mobility Management Provide?

It is interesting to speculate how much traffic safety mobility management can provide cost effectively, and how this compares with other safety strategies. Below are examples.

- Pay-As-You-Drive vehicle insurance and registration fees convert two major fixed costs into variable costs with respect to vehicle travel. Together they are predicted to reduce mileage by 10-12% and crashes by 12-15%.
- Parking Pricing and Parking Cash Out tend to reduce automobile trips by about 20% where applied. Assuming that these strategies could be applied to half of all parking activity, crashes would decline approximately 10%.
- Personalized marketing programs and targeted improvements in walking, cycling and transit service have successfully reduced local vehicle trips by 7-14%, suggesting that such programs could reduce crashes 5-10%.
- London's congestion pricing program reduced crashes within that charge area about 25%. Assuming that 20% of all vehicle trips face congestion, this implies that congestion pricing could reduce total crashes about 5%.
- Residents of smart growth communities tend to drive 15-25% fewer miles and have 20-40% fewer per capita crash fatalities than residents of conventional, automobile-oriented communities.

Care is needed when calculating the cumulative impacts of multiple strategies. Total impacts are multiplicative not additive, because each additional factor applies to a smaller base. For example, if one factor reduces travel by 20%, and a second factor reduces travel an additional 15%, their combined effect is calculated 80% x 85% = 68%, a 32-point reduction, rather than adding 20% + 15% = 35%. This occurs because the 15% reduction applies to a base that is already reduced 20%. On the other hand, many strategies have synergistic impacts (total impacts are greater than the sum of their individual impacts). A mobility management program that incorporates a variety of cost-effective strategies (e.g., road and parking pricing, improved travel options, and smart growth land use policies) can be expected to reduce per capita crashes 20-30% or more where applied.

Contrast these predicted safety gains with the crash reductions likely to be achieved by more well-known traffic safety strategies. For example, the National Highway Traffic Safety Administration estimates that each 1 percentage point increase in seatbelt use saves approximately 250 lives, so increasing seatbelt use from the current 75% to 90% would reduce crash fatalities by about 10% (NHTSA 2002). Airbags are estimated to reduce crash fatality risk by 7-10%, so doubling the portion of vehicles with airbags is likely to reduce fatalities by 3-5%.

This suggests that cost-effective mobility management programs can provide crash reductions comparable in magnitude to many well-known safety strategies, while also providing additional benefits from congestion reductions, road and parking facility cost savings, consumer benefits, environmental quality improvements, and exercise-related health benefits.

Are There Offsetting Factors?

Some people are skeptical of mobility management benefits. They concede that reducing vehicle travel can reduce problems such as accidents and traffic congestion, but believe that travel reductions are difficult to accomplish, or argue that the benefits are offset by reduced consumer welfare and economic productivity. After all, motorists must consider their incremental crash risk worth their incremental benefits, so policies to discourage driving must make them worse off overall. Similarly, automobile travel is associated with economic development, so reductions in vehicle ownership and use must be harmful to the economy. However, these arguments fail to consider several important issues.

First, there is evidence that at the margin (that is, compared with current travel patters), many motorists would prefer to drive somewhat less and rely more on travel alternatives, provided that they have suitable options and incentives ("TDM Marketing," VTPI 2004).

Second, many mobility management strategies reduce travel by giving consumers better options or positive incentives. For example, consumers who reduce their automobile travel in response to improved transit services or cycling conditions, or in response to a positive financial incentive such as Parking Cash Out, must be better off or they would not make the change. Even financial disincentives may have neutral consumer impacts overall if they reduce other consumer costs. For example, road and parking fees are simply an alternative way to finance roads and parking facilities, and so these fees are offset by reductions in taxes, rents or other funding sources.

Third, market distortions create a disconnect between the incentives that consumers face and what is socially optimal. Virtually all economists agree that automobile travel is underpriced to some degree, taking into account congestion externalities, underpricing of roadway and parking facility use, and uncompensated accident and environmental damages (Litman 2007). Until each of these costs is internalized, consumers will tend to drive more than is economically optimal, so disincentives to driving are justified on second best grounds (that is, to deal with a problem if optimal pricing is not possible).

If market incentives are correctly applied, travel reductions consist of lower-value trips that consumers are most willing to forego (Market Principles," VTPI 2004). If mobility management programs allow consumers to decide which automobile trips to take and which to forego, and include appropriate travel options such as transit improvements and rideshare services, net losses to consumers tend to be small.

Fourth, part of the reason that consumers drive is that alternative modes are stigmatized or considered unsafe. In many communities, walking, cycling and transit are uncommon activities that lack respect. To the degree that mobility management programs increase use of alternative modes by middle-class people, such programs make them safer and more socially acceptable, further increasing their use. This makes consumers better off overall.

Fifth, out of ignorance or psychological denial, most motorists understate their true crash risk. Vehicle travel is a common activity, and the risk of any particular trip or mile of travel seems miniscule. Most drivers consider their ability to be above average, and their crash risk below average. Many take pride in their driving ability, and so tend to be offended by suggestions that their driving is risky to themselves or others. It is therefore not surprising that through a combination of optimism, denial and externalization of costs, drivers are not usually influenced by the crash risks they impose on themselves and others, even if overall, it is one of the highest costs associated with motor vehicle travel.

Sixth, although increased vehicle ownership and travel are associated with increased wealth, there is little evidence that high levels of vehicle travel cause wealth or increase economic productivity. On the contrary, there is evidence that appropriate mobility management strategies (e.g., efficient pricing, improved travel options, more accessible land use patterns, etc.) improve economic efficiency and productivity ("TDM and Economic Development," VTPI 2004).

This is not to say that mobility management programs always make individual consumers better off. Some involve negative incentives that reduce the affordability or convenience of driving for a particular trip, although these are offset by increased convenience by other motorists and other modes, and revenues streams that can offset other consumer charges (for example, High Occupancy Vehicle priority strategies may increase automobile congestion delays but reduce delays to transit and rideshare occupants, and road and parking pricing simply substitutes for other taxes and fees used to fund these facilities). But it would be wrong to assume that consumers are necessarily worse off overall. Each program must be evaluated individually ("TDM Evaluation" VTPI, 2004). A well-designed mobility management programs based on market principles and sensitive to consumer needs can reduce a significant amount of driving while providing net benefits overall.

Conclusions

Past traffic safety programs have significantly reduced per-mile crash rates. This suggests that such programs are effective at improving safety and should be continued. However, increased vehicle mileage has offset much of these gains. Per capita crash risk has declined relatively little despite major improvements in roadway and vehicle designs, motorist behavior, emergency response and medical treatment. Traffic crashes continue to be a major health risk. When evaluated in this way, new approaches are justified to improve traffic safety.

Mobility management includes various strategies that change travel behavior to increase transportation system efficiency. It can provide a variety of benefits including traffic congestion reductions, road and parking facility cost savings, consumer cost savings, energy conservation, pollution reduction, and support for various land use and equity objectives. Mobility management also tends to increase traffic safety and public health.

Mobility management safety impacts are affected by the travel changes they cause. Although difficult to predict with precision, available information suggests the following effects:

1. Mobility management strategies that reduce overall vehicle travel probably provide proportional or greater reductions in crashes. Available evidence suggests that a 10% reduction in mileage in an area provides a 10-14% reduction in crashes, all else being equal.
2. Pay-As-You-Drive vehicle insurance reduces total vehicle mileage and gives higher-risk drivers an extra incentive to reduce their mileage, and so can be particularly effective at reducing road risk.
3. Strategies that shift travel from driving to transit or ridesharing tend to provide medium to large safety benefits, depending on specific conditions.
4. Strategies that shift automobile travel to active modes (walking and cycling) may increase per-mile risk for the people who change mode, but tend to reduce total crashes in an area due to reduced trip length and reduced risk to other road users. Active travel also provides health benefits that may more than offset any increased risk to users.
5. Strategies that reduce traffic congestion tend to reduce crash frequency but increase severity, because crashes occur at higher speeds. As a result, mobility management strategies that shift automobile travel time, route or destination but do not reduce total vehicle travel probably do little to increase road safety overall.
6. Strategies that reduce traffic speeds tend to reduce per-mile crash frequency and severity, particularly in congested urban areas with high pedestrian traffic.
7. Smart growth land use management strategies may increase crash rates per lane-mile (due to increased traffic density and congestion) but tend to reduce per capita casualties due to reduced vehicle travel, lower traffic speeds and more restrictions on higher-risk drivers.
8. Vehicle traffic restrictions may reduce crashes if they reduce total vehicle mileage, but may do little to improve safety overall if they simply shift vehicle travel to other times or routes.
9. Safety impacts are affected by specific demographic and geographic factors. For example, automobile to cycling mode shifts may reduce crashes by responsible adults in communities with good cycling conditions, but may increase crashes if those affected by less responsible or if cycling conditions are hazardous.

Crash damages are one of the largest categories of societal costs of motor vehicle use, much greater than congestion or pollution costs. This indicates that road safety impacts should be a priority when evaluating transport policies. A program that reduces traffic congestion or emissions by 10% but increases crash costs by 3% provides no overall benefit to society. On the other hand, a traffic congestion or pollution reduction strategy is far more valuable to society if it also reduces crash costs.

Most people realize that vehicle travel is risky (although surveys indicate that most drivers consider themselves "better than average," sometimes called the "Lake Woebegone Effect," apparently out of pride and possibly a form of psychological denial of the hazards they face and impose on others). Motor vehicle use therefore consists of travel in which user benefits exceed users' direct, perceived crash costs. Motorists would therefore not want to reduce their own vehicle mileage just for the sake of their own safety. However, reduced mileage reduces external crash costs, including uncompensated crash damages and risks imposed on other road users. These external benefits can therefore justify mobility management safety programs.

Traffic risk tends to maintain equilibrium, that is, when it is considered excessive individuals and communities take actions to reduce risks to a more acceptable level, for example, by driving more cautiously under dangerous conditions and implementing safety programs targeting higher-risk behaviors, conditions and groups (Adams 2010). This suggests that mobility management strategies can be relatively better than engineering strategies to reduce traffic risk, such as airbags and larger vehicles that give drivers the feeling of increased security and therefore tend to encourage riskier behavior. The effects of such offsetting factors should be taken into account when evaluating the safety impacts of any safety strategies, including mobility management.

Mobility management strategies can help achieve various planning objectives, including congestion reduction, road and parking facility cost savings, consumer cost savings, improved mobility options for non-drivers, support for strategic land use objectives (such as urban redevelopment and reduced sprawl), energy conservation and emission reductions, as well as reduced crash risks. More comprehensive analysis, which takes into account more of these impacts, tends to justify more emphasis on mobility management ("Comprehensive Transport Planning," VTPI 2004).

Transportation professionals generally focus primarily on congestion and vehicle emission impacts when evaluating decisions that affect total vehicle mileage. Safety impacts are often overlooked. As a result conventional planning tends to overlook the full costs of decisions that increase vehicle mileage (such as roadway capacity expansions and reduced vehicle user fees), and undervalues the full benefits of mobility management strategies that reduce mileage. Yet, increased safety appears to be one of the largest potential benefits of mobility management, and mobility management programs are likely to be among the most cost effective ways to improve traffic safety.

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