

## Safe Travels

### *Evaluating Mobility Management Traffic Safety Impacts*

22 February 2012

By Todd Litman  
*Victoria Transport Policy Institute*

and  
Steven Fitzroy  
*Fitzroy and Associates*



### **Abstract**

This report investigates the relationships between mobility (the amount people travel) and crash risk, and the safety impacts of *mobility management* strategies that change how and the amount people travel. Evidence summarized in this report indicates that per capita traffic crash rates tend to increase with per capita vehicle travel, and mobility management 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. Shifting vehicle travel to less-congested conditions tends to reduce crash frequency but may increase crash severity due to higher traffic speeds. Smart growth land use policies tend to reduce crash severity and fatality rates, although crash frequency may increase due to increased traffic density. Strategies that reduce traffic speeds reduce crash frequency and severity. Conventional traffic risk analysis understates many of these impacts. This analysis indicates that mobility management is a cost effective traffic safety strategy, and increased safety is one of the largest benefits of mobility management.

*Summaries of this research were presented at the 85<sup>th</sup> Transportation Research Board Annual Meeting (January 2006) and published in Injury Prevention, Vol. 15, Issue 6 (2009)*

Todd Litman & Steven Fitzroy © 2005-2011

You are welcome and encouraged to copy, distribute, share and excerpt this document and its ideas, provided the author is given attribution. Please send your corrections, comments and suggestions for improvement.

## Contents

Introduction .....	3
Evaluating Risk .....	6
Relationships Between Vehicle Mobility And Crash Risk.....	9
Safety Impacts of Specific Mobility Management Strategies.....	20
Vehicle Ownership Reductions .....	20
Pricing Reforms.....	20
Mode Shifting .....	25
Travel Time and Route Shifts.....	33
Traffic Speed Reductions .....	33
Streetscaping, Traffic Calming and Road Diets .....	34
Vehicle Use Restrictions .....	34
Smart Growth Land Use Policies .....	35
Safety Impacts Summary .....	38
Types of Driving .....	39
Mobility Management Benefit Evaluation.....	40
How Much Safety Can Mobility Management Provide? .....	42
Are There Offsetting Factors? .....	43
Conclusions .....	45
Acknowledgements .....	47
References.....	47

## 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 2002 and 2003; Frumkin, Frank and Jackson 2004; Ewing and Dumbaugh 2009; O’Malley Greenburg 2009).

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; WHO 2004). 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.

*Mobility management* (also called *transportation demand management* or *TDM*) includes various strategies that increase transportation system efficiency by changing travel frequency, destination, mode and timing. Table 1 lists various mobility management 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** Mobility Management Strategies (VTPI 2004)

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

*This table lists various mobility management strategies.*

This report explores the relationships between mobility (the amount 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 previous research concerning the relationships between vehicle travel and traffic risk (Vickrey 1968, Wilde 1984; Haight 1994; Dickerson, Peirson and Vickerman 1998; Andrey 2000; Edlin and Karaca-Mandic 2002 and 2006; LFC 2008).

**Table 2 Factors Affecting Traffic Casualty Rates**

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

*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. However, it is complex because many other factors also affect crash rates (Table 2), and mobility management strategies have various travel impacts (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.
Congestion pricing	Reduces peak-period vehicle travel on a particular roadway by shifting travel route, time, destination and mode.
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	Shifts mode, increases walking and cycling.
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. Many people challenge the idea that mileage is a significant risk factor and that mobility management is an appropriate safety strategy. Traffic safety experts often argue that “there are no accidents,” claiming that every crash has a preventable cause, allowing virtually risk-free travel. Most 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 and reduce crash risk, 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 many experts and individual drivers tend to prefer targeted campaigns that discourage specific risky behaviors or reduce driving by particularly high-risk groups, rather than vehicle travel in general or their own vehicle travel in particular. Efforts to reduce overall mileage for safety sake may strike them as surrender to failure and confusing because it contradicts their existing safety messages.

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,<sup>1</sup> 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 caused 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 change 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).

---

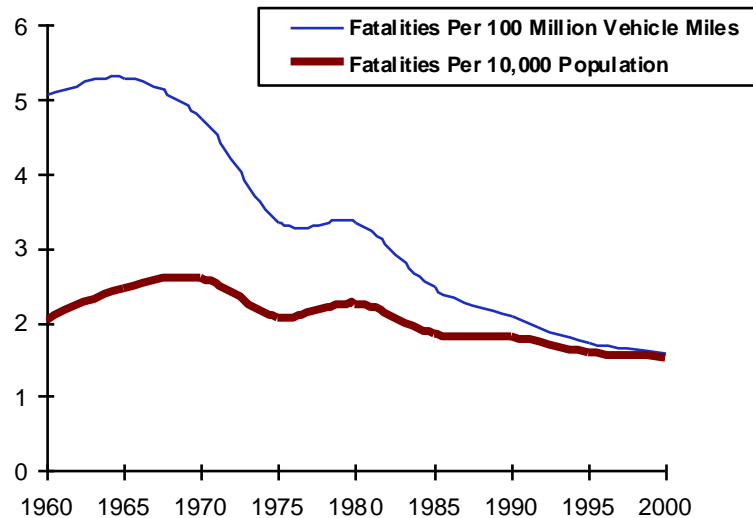
<sup>1</sup> According to National Highway Traffic Safety Administration’s *Traffic Safety Facts 2006*, alcohol contributed to 42% of crashes and speeding to 31% (many crashes involved both).

## 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. 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 because tend to occur at higher speeds. Similarly, risk analysis can be affected by the *reference units* (units used in the denominator) selected. For example, Figure 1 illustrates traffic fatality rates using two different denominators. When measured per unit of travel (per 100 million vehicle-miles or billion vehicle-kilometers), as traffic safety experts often do, fatality rates declined more than two thirds during the last four decades. From this perspective, traffic safety programs were successful and should be continued to further reduce road risk.

**Figure 1** U.S. Traffic Fatalities (BTS 2000)

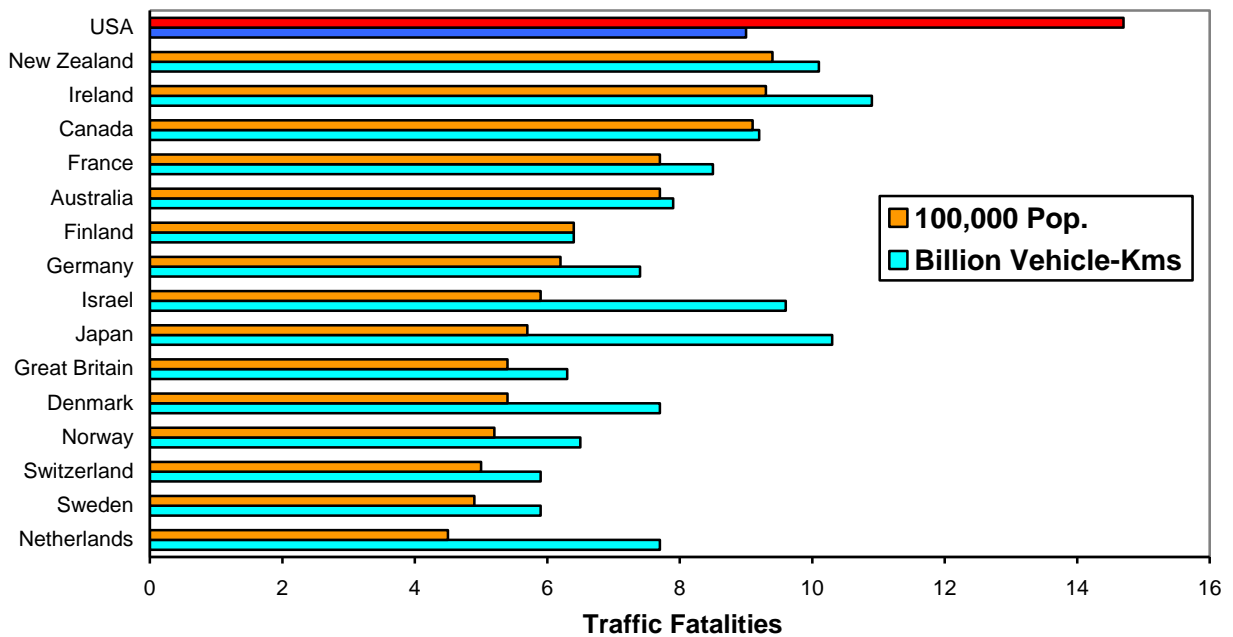


This figure illustrates traffic fatality trends over four decades. When measured per **vehicle-mile**, they declined significantly, but when measured **per capita** they show relatively little decline due to increased vehicle travel during this period.

But per capita vehicle mileage more than doubled in the U.S. over that time period, offsetting much of the decline in per-mile fatality rates. When measured *per capita* (e.g., per 10,000 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% (according to the National Highway Traffic Safety Administration, wearing a seat belt reduces the chances of dying in a car crash about 45%), yet, per capita traffic deaths declined only about 25%.

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*, as illustrated in Figure 2. From this perspective, traffic risk continues to be a major problem.

**Figure 2 International Traffic Fatality Rates** (Wikipedia 2009; 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 the issues analyzed in this report. 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* (Wilde 1994). 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 safety 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 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, as discussed by Grammenos (2011).

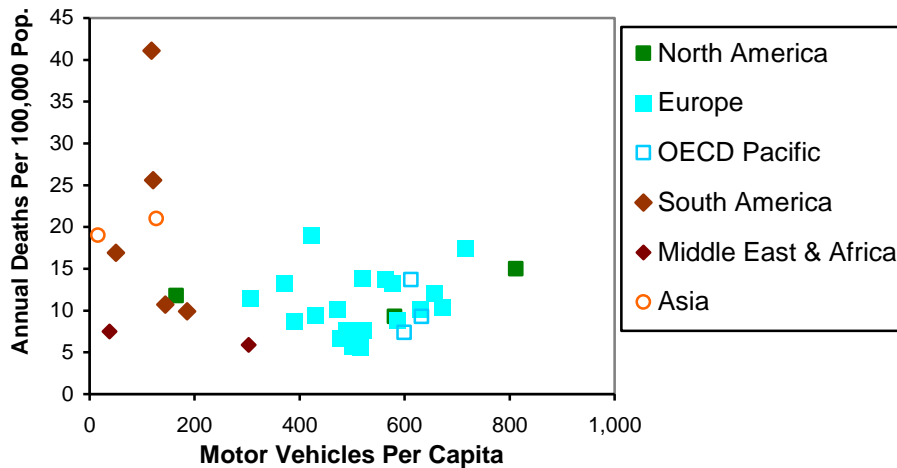
## Relationships Between Mobility And Crash Risk

To evaluate mobility management safety impacts it is important to understand the relationships between mobility (the amount and modes of travel) and crash risk. Per capita crash risk can be considered the product of two factors: per-mile crash rates times annual mileage. Changing either factor affects total crashes. Although many factors affect per-mile crash rates, these generally change little when individual motorists reduce their annual vehicle mileage. A high-risk driver may average one crash every 50,000 miles, while a lower-risk driver may average one crash every 500,000 miles, but in either case reducing annual mileage 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 20 annual deaths per 100,000 population, 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).

Because so many factors influence crash risk it can be difficult to isolate the effects of a particular factor. 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 (Kopits and Cropper 2003). Figure 3 shows the relationship between vehicle ownership and traffic fatality rates. This perspective suggests that increased per capita vehicle travel actually reduces crash risk. However, these trends probably reflect other factors associated with wealth: better driver training, vehicles, roadway facilities, law enforcement, emergency response and medical care.

**Figure 3** Per Capita Vehicle Ownership and Fatalities (WHO 2004)



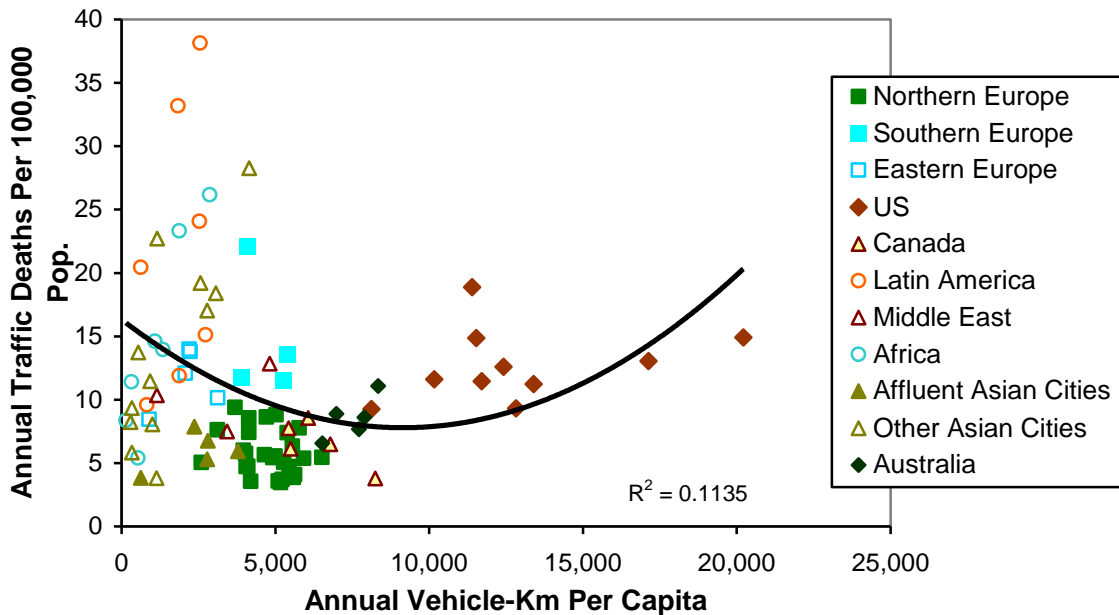
*Overall, crash rates tend to decline with increased vehicle ownership.*

There is considerable evidence indicates that for a particular area or group with similar risk profiles there is a positive relationship between per capita vehicle mileage and crash rates (Vickrey 1968; Roberts and Crombie 1995; Edlin 1998; Balkin and Ord 2001; Edlin and Karaca-Mandic 2002 and 2006; Clark and Cushing 2004; Frumkin, Frank and Jackson 2004; Ilyushchenko 2010).

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, which included 49,766 participant-years with an average yearly travel of 7,828 km per person-year. Even small reductions in annual vehicle travel has a statistically significant protective effect on the likelihood of sustaining hospitalization due to motor vehicle injury.

Figure 4 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.

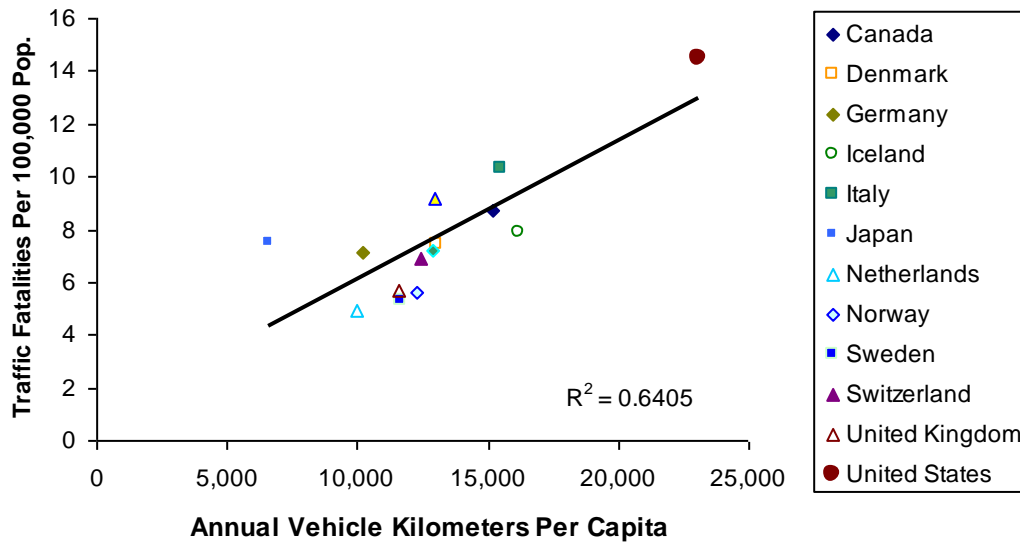
**Figure 4 Per Capita Vehicle Travel and Fatalities In Various Cities (UITP 2000)**



*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.*

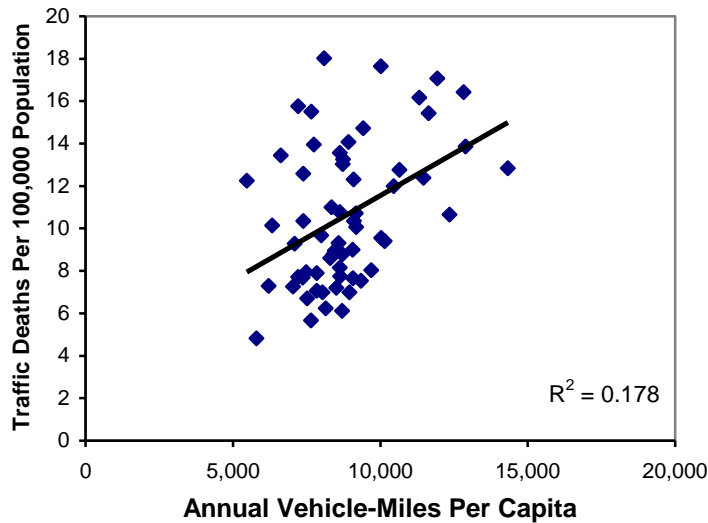
Figure 5 illustrates a strong positive relationship between per capita annual vehicle travel and crashes among OECD (Organization for Economic Cooperation and Development) countries. This indicates that, among economically developed countries, increased vehicle travel tends to increase traffic fatalities.

**Figure 5 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.*

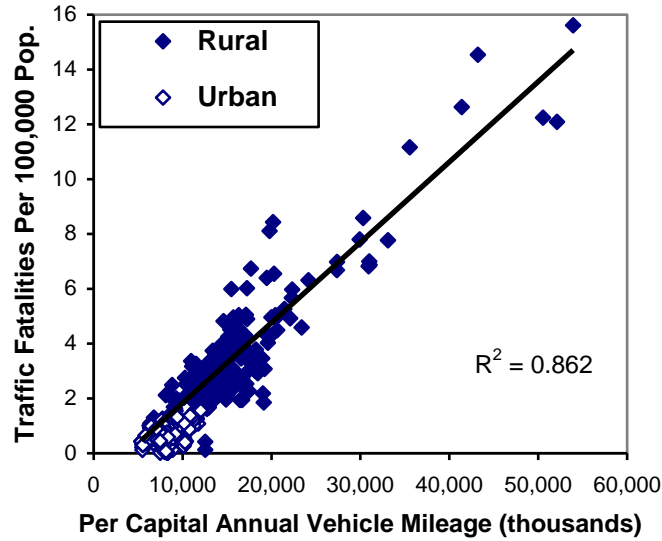
**Figure 6 Vehicle Mileage and Traffic Fatality Rates For U.S. Cities (FHWA 2002)**



*This graph shows a moderate positive relationship between per capita annual vehicle mileage and traffic fatalities in U.S. cities.*

Figures 7 through 10 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).

**Figure 7 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.*

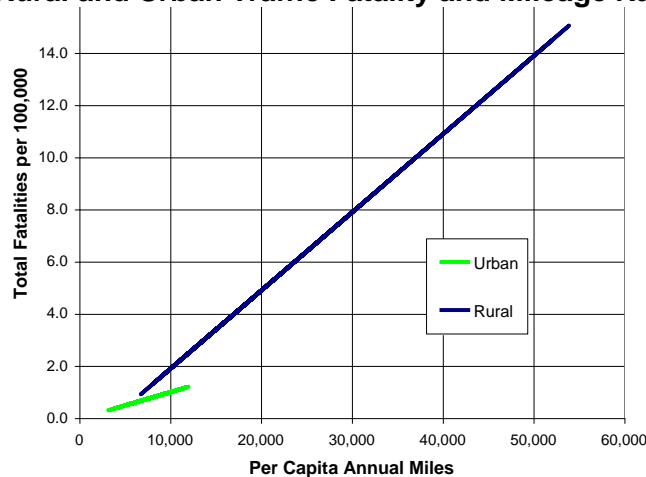
Urban and rural relationships can be calculated separately using the following equations.

$$\text{Rural Traffic Fatalities} = -1.123 + 0.0002998 * \text{Rural Vehicle Mileage} \quad (2)$$

$$\text{Urban Traffic Fatalities} = -0.03465 + 0.0001022 * \text{Urban Vehicle Mileage} \quad (3)$$

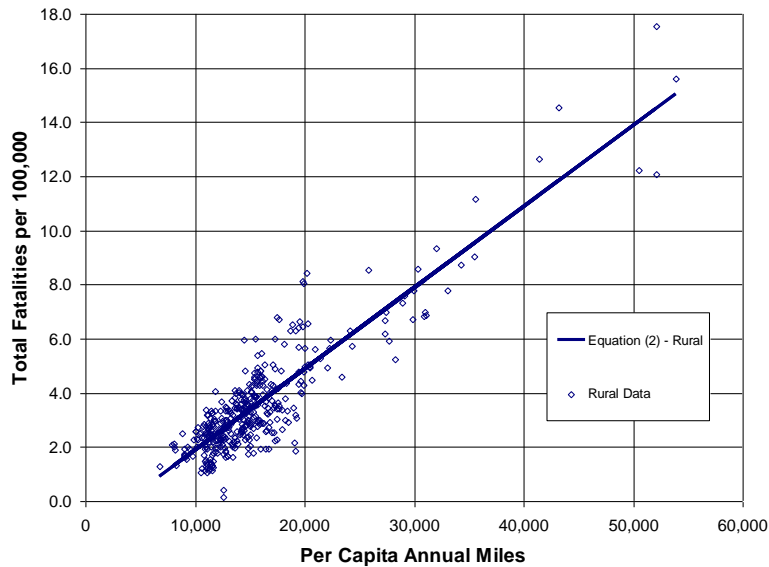
Figure 8 illustrates these equations. The rural area slope is about three times steeper than for urban areas, indicating that mileage has a stronger effect on fatalities in rural conditions, probably due to factors such as increased traffic speeds and emergency response time, less seatbelt and helmet use, and more higher-risk driving (such as young and elderly drivers) due to fewer transport alternatives (Rakauskas and Ward 2007).

**Figure 8 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.*

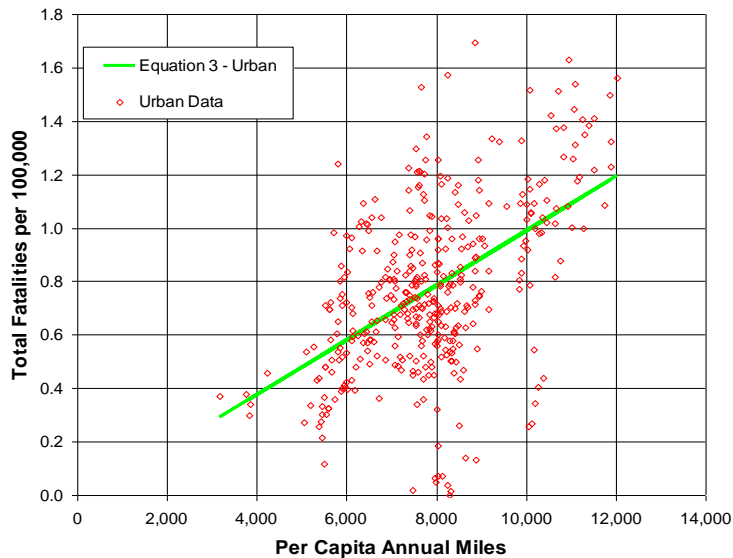
**Figure 9** Rural Traffic Fatality and Mileage Rates (FHWA 1995-2002 data)



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

Figure 9 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 10 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 (Zhou and Sisipiku 1997; Shefer and Rietvald 1997).

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

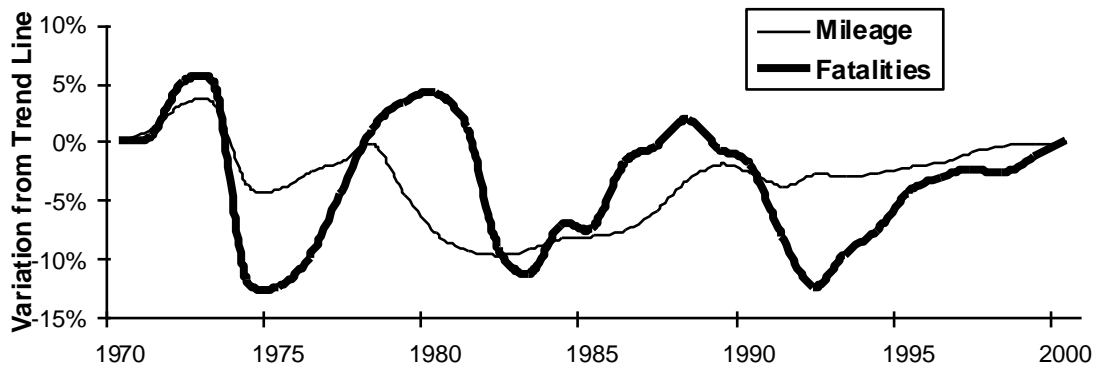


*This graph shows a weaker relationship between annual mileage and crash rates in urban areas.*

There are other indications of positive relationships between mileage and crash 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.

In 2008, vehicle travel declined about 3.4% and traffic fatalities about 10% compared with previous years (Copeland 2009). Chu and Nunn (1976) estimated that during the 1994 fuel price spike, California traffic fatalities declined 25% due to a combination of reduced vehicle travel (29%), slower traffic speeds (39%), and daylight saving time (8%). Grabowski and Morrissey (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.

**Figure 11** Vehicle Mileage and Crash Fatality Variation (FHWA Data)



*This figure indicates a correlation between annual mileage and crash fatalities. When vehicle travel declined in 1973-76, 1978-83 and 1990, fatalities also declined. When vehicle travel increased after 1976-78 and 1986-90, fatalities also increased.*

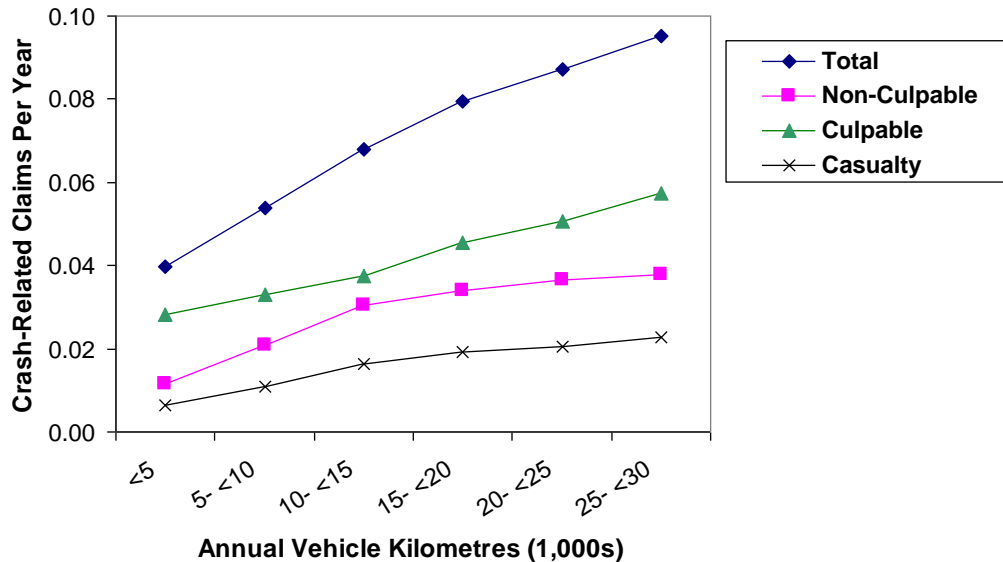
Balkin and Ord (2001) found seasonal highway fatality cycles, with annual peaks during holiday seasons when VMT increases. Reductions in annual mileage during economic recessions due to reduced employment and incomes often reduce per capita crash rates. For example, a recession in 1981-82 caused a 10% reduction in vehicle travel and a 12% reduction in insurance claims in British Columbia (ICBC data). A study of young drivers found that “the consistently significant factor influencing risk of motor vehicle crash involvement was *quantity* of kilometres driven” (Bath 1993, p. 5). 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).

Elderly drivers tend to have high per-mile crash rates but low vehicle-year crash rates due to low annual mileage. 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 based on odometer readings collected during mandatory safety checks with insurance claim costs, for 2.87 million vehicle exposure-years 34 billion miles of travel in f Massachusetts during the 2006 policy year. 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):

- Motorists who are higher-risk per vehicle-mile due to inexperience or disability tend to drive lower annual mileage, 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 2002 and 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, divides 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>B</b>	<b>C</b>	D

*Changes in 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. First, drivers may be more cautious in denser traffic. Second, density increases congestion, which reduces speed and therefore crash severity, which explains why urban areas tend to have low fatality rates (Zhou and Sisiopiku 1997; Shefer and Rietvald 1997). Third, increased mileage may justify roadway improvements, such as grade separation, which reduces 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 (2002) 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 qualify 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:

1. 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.
2. 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.
3. Improved travel options may shift public attitudes, making it easier for courts to revoke driving privileges of higher-risk drivers.
4. Traffic management strategies, such as traffic calming and new urbanist roadway design, reduce traffic speeds and therefore crash frequency and severity.
5. Smart growth land use strategies increase land use density, which tends to increase crash frequency but reduces crash severity.

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 the risks facing motorists, for example, from road rage or attacks in parking lots.

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).

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.

### *Vehicle Ownership Reductions*

Some mobility management strategies reduce vehicle ownership by changing the cost structure or improving alternatives. These include unbundled residential parking (residents pay directly for each parking space they use, rather than having parking costs included with vehicle rents), carsharing, transit improvements, pricing reforms, location-efficient mortgages (which improves mortgage options for home buyers who choose a less automobile-oriented location), and transit oriented development (VTPI 2004). 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 to 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*

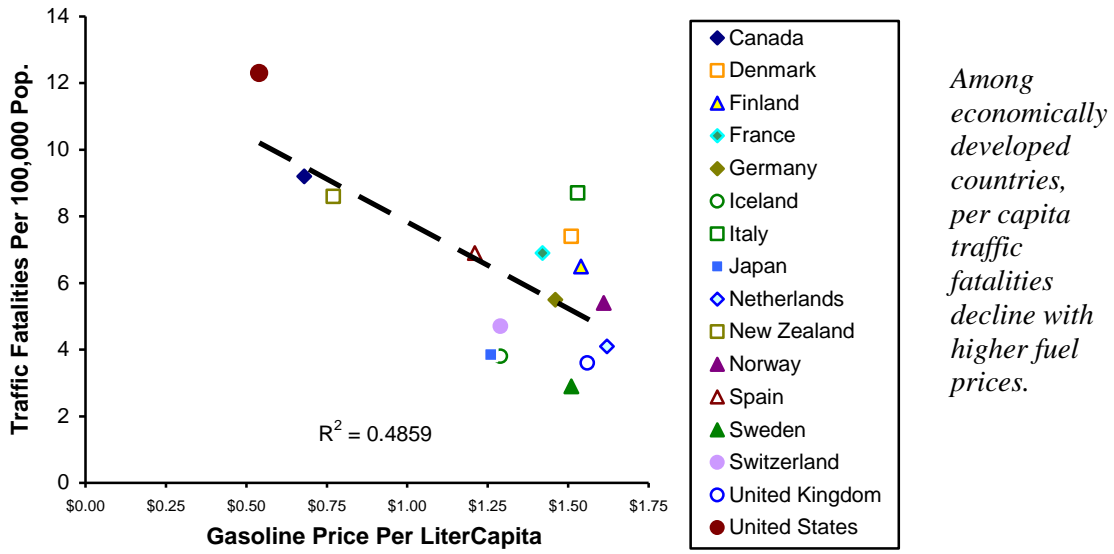
Various transportation price reforms are advocated to achieve various objectives, including road and parking congestion reduction, emission reductions, and increased fairness (Litman 2011; “Market Reforms,” VTPI, 2004). These reforms can cause various travel changes, including shifts in route, travel time, mode, destination and trip frequency (“Transportation Elasticities,” VTPI 2004), which have a variety of safety impacts. Individual pricing reforms are discussed below.

### **Fuel Price Increases** ([www.vtpi.org/tdm/tdm17.htm](http://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<sup>2</sup>**



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. Chu and Nunn (1976) estimate that during the 1974 oil crisis, when fuel prices spiked, California traffic fatalities declined 25% from what would be expected. Their model predicts that under normal conditions the state would have had 2,303 fatalities during the first half of 1974 but only experienced 1,726. They estimate that reduced travel accounted for 29%, slower driving speed for 39%, and permanent daylight saving time for 8% of the 577 total fatality reduction estimated to have occurred. 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.

Studies by Chi, et al. (2010a, 2010b, 2011a and 2011b) quantify fuel price impacts on traffic safety in various U.S. regions. 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 increases cause larger short-term crash reductions by younger drivers, and larger intermediate-term reductions by older drivers and male drivers (2010a; 2011b), and tend to have particularly large effects on drunk driving crash (2010b).

<sup>2</sup> Gerhard Metschies (2005), *International Fuel Prices 2005*, International Fuel Prices at [www.international-fuel-prices.com/downloads/FuelPrices2005.pdf](http://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](http://en.wikipedia.org/wiki/List_of_countries_by_traffic-related_death_rate) (9 February 2011).

Schuffham and Langley (2002) analyzed New Zealand traffic fatality rates, taking into account vehicle travel (automobile and motorcycle ownership and mileage), economic activity (GDP) and behaviour (seatbelt use, alcohol drinking). They found that per capita crash fatalities have declined overall, likely due to safety strategies such as seatbelts and improved emergency response, but within this trend, per capita crash rates varied with changes in per capita vehicle mileage, with crash reductions when fuel price increases reduced per capita vehicle travel. 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.

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](http://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 (“Road Pricing,” VTPI 2004), 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% (“Parking Pricing,” VTPI 2004). Experience indicates that crashes typically decline proportionately or more. For example, the city of London’s congestion fee reduced city center vehicle trips by 20%, and crashes in that area declined about 25% (TfL 2004). Analyzing crash rates at a fine geographic scale, Lovegrove and Litman (2008) concluded that a typical congestion pricing program that encourages shifts to alternative modes is likely to reduce neighbourhood collision frequency by approximately 19% (total) and 21% (severe). However, specific impacts may vary; in some situations a portion of the reduced demand consists of travel shifted to other routes or times, which provides no safety benefit.

**Distance-Based Pricing** ([www.vtpi.org/tdm/tdm10.htm](http://www.vtpi.org/tdm/tdm10.htm))

*Distance-based* (also called *Pay-As-You-Drive* or *Per-mile*) pricing 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). However, 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 about 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 User Fatality Rate By Mode (DfT 2003)**

	Total Deaths	Miles*	Deaths Per Bil. Miles	Trips*	Deaths Per Bil. Trips	Hours*	Deaths Per Billion Hours
Walk	767	192	69	245	54	64	208
Bicycle	129	34	66	14	155	5	467
Motorcycle/moped	609	36	297	3	3,170	1	7,777
Car/Van/Lorry	1,880	5,540	6.0	627	52	222	147
Public Transit	19	1,031	0.32	101	3.3	69	4.8
Totals	3,404	6,833	8.7	990	59.8	361	163.8

(\* = Annual Per Capita) This table compares traffic fatality rates for various modes, using mileage, trips and hours as denominators. This only indicates risk to users, not to others.

Traffic risks varies by mode and how risk is measured, as indicated in Table 7. 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<sup>3</sup>**

	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	-

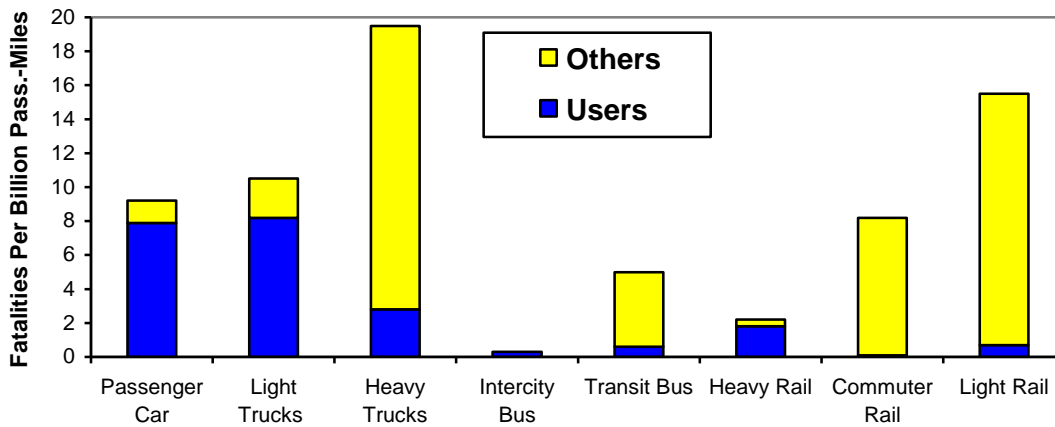
This table indicates traffic fatality rates per billion miles of travel for various modes.

<sup>3</sup> Based on BTS, *National Transportation Statistics* ([www.bts.dot.gov](http://www.bts.dot.gov)), 2003, Tables 1-32, 2-1 and 2-4; APTA, *Safety Summary By Mode* ([www.apta.com](http://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](http://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 risks imposed on others. Table 8 indicates risk to both *user* and *others* (other road users). 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)



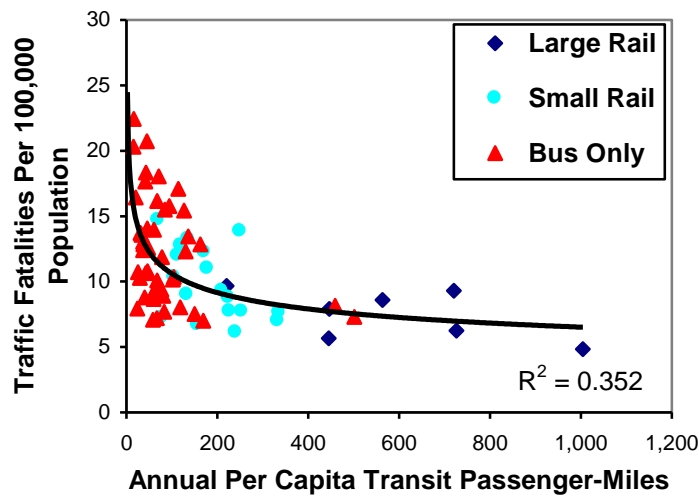
*Transit travel tends to have lower crash rates than automobile travel, even taking into account risks to other road users.*

Analysis by Lovegrove and Litman (2008) using a 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).

## Transit

Public transit is a relatively safe mode, particularly for users, as indicated in Figure 15.<sup>4</sup> Transit passengers have about one-tenth the fatality rate as car occupants, and even considering external risks, transit causes less than half the total deaths per passenger-mile as automobile travel. Total crash rates per passenger-mile (including risks to transit vehicle occupants and other road users) are relatively high in some jurisdictions due to low average transit vehicle occupancies and because a large portion of transit vehicle mileage occurs in congested urban conditions, but as transit ridership increases crash casualty rates per passenger-mile decline. Mobility management strategies that encourage transit ridership and increase average transit vehicle occupancy impose little incremental external risk and reduce crash rates per passenger-mile.

**Figure 15** U.S. Traffic Deaths (Litman 2004)

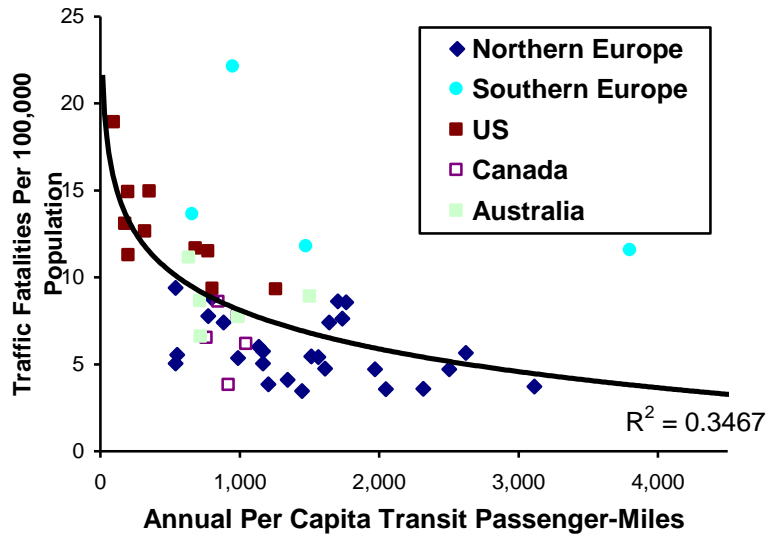


*Per capita traffic fatalities (including automobile occupants, transit occupants and pedestrians) tend to decline with increased transit ridership.*

Per capita crash rates tend to decline as transit ridership increases in a community, and are particularly low in cities with large rail transit systems as indicated in figures 15 and 16. Table 9 indicates very low fatality and injury rates for transit passengers in the UK. Lim, et al (2006) describes how Bus Rapid Transit improvements in Seoul, South Korea increased transit ridership more than 20%, but reduced bus casualties by 11% and total traffic crashes by 26%. Multiple regression analysis found that bus accident rates were influenced by factors such as the extent of bus driving experience, driver wages, number of repair personnel, vehicle age, and the ratio of bus exclusive lanes to the length of total bus routes.

<sup>4</sup> The exception is U.S. light rail transit (LRT), which has unique accident risks (TCRP, 2001). They operate in dense urban conditions where crash risk is high. Other travel modes also have a relatively high crash rates under these conditions. Many LRT systems are new, and so have relatively low ridership, and limited experience by both operators and motorists. Some “accidental” rail transit deaths are probably suicides, and since the number of LRT deaths is small, even a few miss-categorized deaths significantly increases the fatality rate.

**Figure 16** Traffic Fatalities Vs. Transit Travel (Kenworthy and Laube 2000)



*International data indicate that crash rates decline with increased transit ridership.*

**Table 9** UK Crash Rates Per Billion Pass-Kms (Steer Davies Gleave 2005, Table 7.3)

Mode	Killed	Killed and Injured
Motorcycle	112	5,549
Cycling	33	4,525
Walking	48	2,335
Private car	3	337
Bus or Coach	0.1	196
Heavy Rail	0.1	13
Light Rail	0.00002	0.00007

These traffic fatality reductions result not just from automobile vehicle-miles shifted to transit passenger-miles, but also from the leverage effects transit can have on transportation and land use patterns (Litman 2004). Residents of cities with high quality transit tend to own fewer automobiles, drive less (due to reduced vehicle ownership and more compact and mixed land use patterns), have lower traffic speeds (due to more compact urban development), and have less high-risk driving (for example, teenagers and elderly people may be less likely to have a drivers license and own a vehicle in communities with better travel alternatives). The traffic safety impacts of more accessible land use patterns are discussed in more detail later.

### **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 decline by 10%, and the elasticity of crashes to mileage is 1.5 as suggested earlier, total crashes should decline by 15%, but the casualty rate per crash should increase by 10%, so total casualties would only decline by 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).

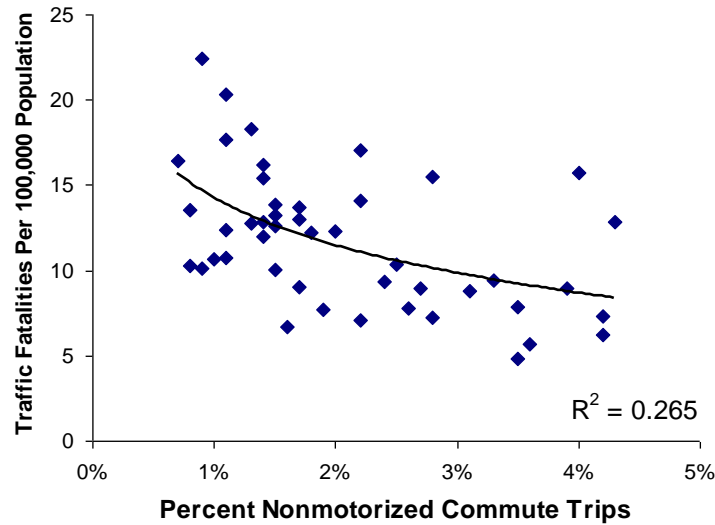
### **Nonmotorized Transport**

Walking and cycling tend to have higher user crash rates per-mile than motorized modes, as indicated in Table 8. But mobility management strategies that increase nonmotorized do not necessarily increase total risk because (Rabl and de Nazelle 2012; WHO 2008a):

1. Nonmotorized travel imposes minimal risk to other road users.
2. High crash and casualty rates for pedestrians and cyclists result, in part, because people with particular risk factors tend to use these modes, including children, people with disabilities and elderly people. A skilled and responsible adult who shifts from driving to nonmotorized travel is likely to experience less additional risk than these average values suggest.
3. Drivers tend to be more cautious in areas where they expect to encounter walkers and cyclists.
4. Increased walking and cycling may stimulate nonmotorized travel improvements.
5. Nonmotorized trips tend to be shorter than motorized trips, so total per capita mileage declines. A local walking trip often substitutes for a longer automobile trip.
6. Some walking and cycling promotion programs include education and facility improvements that reduce per-mile bicycle crash rates.
7. Walking and cycling provide health benefits, including physical fitness and air pollution emission reductions, that may offset increased accident risks.

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.

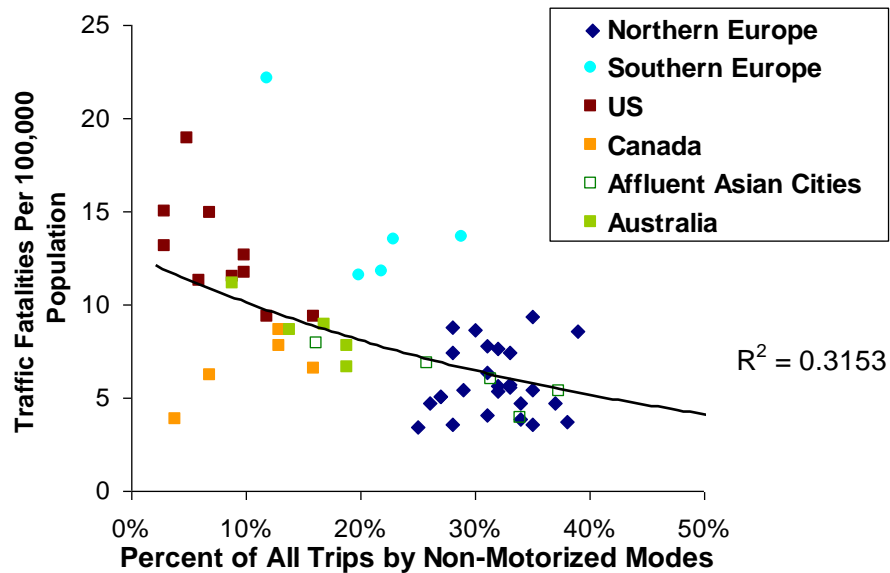
**Figure 17** Traffic Fatalities Vs. Non-Motorized Transport (US Census 2000)



*Per capita traffic fatality rates tend to decline as nonmotorized travel increases in a city. This equation has a low R-square (0.265), but the estimate coefficients are significant.*

As nonmotorized travel increases in a community, both total per capita traffic casualty rates and per-mile pedestrian and cyclist crash rates tend to decline (ABW 2010), as indicated in figures 15 and 16, an effect sometimes called *safety in numbers* (Jacobsen 2003). Economically developed countries with high rates of nonmotorized travel, such as Germany and the Netherlands, have pedestrian fatality rates per billion kilometers walked a tenth as high, and bicyclist fatalities rates only a quarter as high, as in the United States (Pucher and Dijkstra 2000; Fietsberaad 2008).

**Figure 18** 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 nonmotorized travel increases.*

Wardlaw (2001) finds that in various geographic conditions, doubling cycling mileage only increases cycling deaths by 25%. He hypothesizes that this results from a combination of reduced automobile travel (which reduces risk to cyclists), increased cycling skill, and increased caution by drivers. Wittink (2003), Jacobsen (2003), Robinson (2005), Geyer, Raford and Ragland (2006), and Turner, Roozenburg and Francis (2006) also find that shifts from driving to nonmotorized modes by sober, responsible adults are unlikely to significantly increase total accidents, and that per capita collisions between motorists and nonmotorized road users decline as nonmotorized transport activity increases.

Jacobsen calculates that the number of collisions between motorists and nonmotorists increases at roughly the 0.4 power of the amount of walking and cycling that occurs in a community (e.g., doubling nonmotorized travel increases pedestrian/cycling injuries by 32%), and the probability that a motorist will strike a nonmotorized traveler declines with the roughly -0.6 power of the amount of nonmotorized travel (e.g., risk of a pedestrian being hit by a motorist declines 34% if walking and cycling double in a community). 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%. Modeling by Elvik (2009) indicates that shifting travel from motor vehicles to walking or cycling can reduce total traffic accidents.

The *Health Economic Assessment Tool for Cycling* (HEAT for Cycling) is a World Health Organization computer program that estimates the economic savings resulting from reduced mortality due to cycling. Lindsay, Woodward and Macmillan (2008) used the HEAT model to estimate the effects on air pollution and health of replacing light vehicles with bicycles for varying proportions of short trips ( $\leq 7$  km) for adults in urban settings in New Zealand. 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 split 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 goal for walking and cycling in the New Zealand Transport Strategy (30% of urban trips by 2040), and would return 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.

Nonmotorized travel provides physical exercise which can have substantial health benefits (AJHP 2004; “Health and Fitness,” VTPI 2004). 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 1300 € annually, and about 20 €/yr additional air pollution 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 nonmotorized travel is more hazardous to users per mile of travel, for various reasons increased nonmotorized travel tends to reduce total traffic risk in a community. There is no evidence that shifting travel from driving to nonmotorized 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 (“Telework,” VTPI, 2004). 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.

### *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; 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 reductions tend to reduce collision rates and crash severity, and are particularly effective at reducing injuries to pedestrians and cyclists (Leaf and Preusser 1998; “Speed Reductions” VTPI 2004; WHO 2004). One major study concluded that speeding is a major road safety problem in many countries, and reducing average speeds on the roads by only 5% would reduce fatalities approximately 20% (OECD/ECMT 2006).

The *Power Model* states that a given relative change in the mean speed of traffic is associated with a relative change in the number of accidents or accident victims by an exponential function (Elvik 2005). This indicates that a 10% change in the mean speed of traffic is likely to have a greater impact on traffic fatalities than a 10% change in traffic volume. Even modest speed reductions can prevent many collisions, and reduce the severity of damages and injuries that result when crashes occur, and are particularly effective at reducing injuries to pedestrians and cyclists (IIHS 2000; Elvik 2005; Kloeden, McLean, and Ponte 2001; Racioppi, et al. 2004). Based on analysis of several data sets that relate collision speeds and pedestrian injury severity, Pasanen (1992) estimated that about 5% of pedestrians would 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.

Analysis by Redelmeier and Bayoumi (2010) using U.S. data suggested that 1 hour spent driving was 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 by decreasing their average speed slightly.

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.

### *Streetscaping, Traffic Calming and Road Diets*

Streetscaping and traffic calming include various roadway design features that control traffic speeds and volumes, accommodate alternative modes (sidewalks, bike lanes, high-occupant vehicle lanes, etc.) and improve roadway aesthetics. *Traffic calming* (roadway design strategies to reduce traffic speeds on a particular roadway) and increased traffic law enforcement tends to increase safety (“Traffic Calming” VTPI 2004; Ernst and Shoup 2009). Meta-analysis of 33 studies by Elvik (2001a) concluded that area-wide traffic calming reduces injury accidents about 15%, with the largest reduction on residential streets (25%), and smaller reductions on main roads (10%).

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. Analysis using standard road safety analysis methodology further revealed that 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. U.S. Highway Safety Research System research (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.

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.

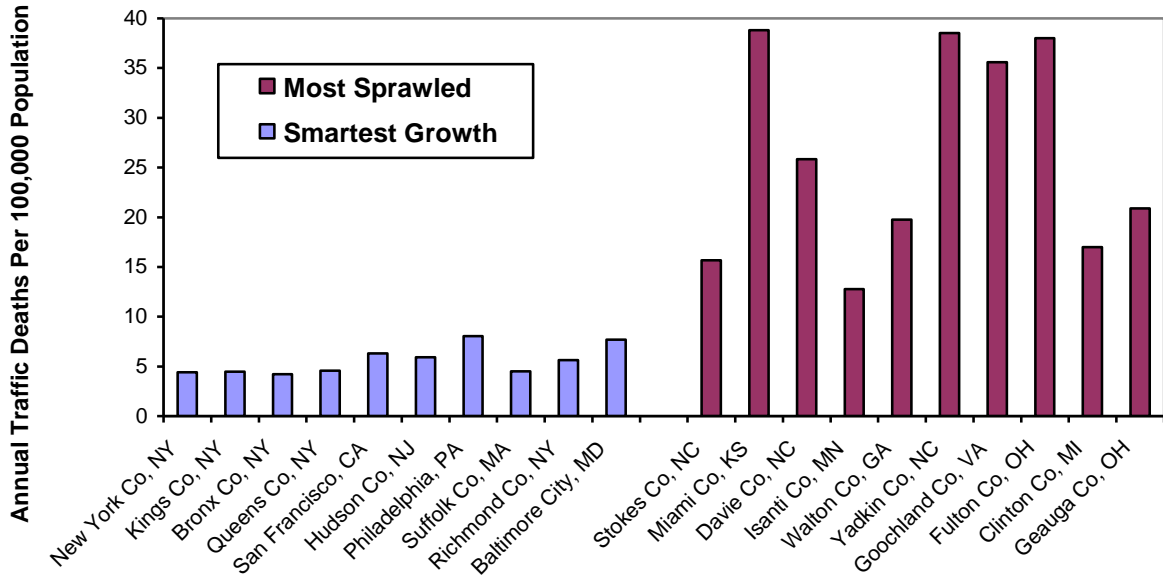
### *Vehicle Use Restrictions*

Some communities restrict vehicle use, such as *No-Drive Days* during which a certain vehicles are prohibited from operating a particular areas, and prohibitions on driving on certain streets at certain times. 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 No-Drive Days 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.

**Smart Growth Land Use Policies**

Smart growth (also called *new urbanism* and *transit oriented development*) consists of land use development policies that more compact, mixed use, multi-modal communities (“Smart Growth” VTPI 2004). This is an alternative to dispersed, automobile-dependent, urban fringe development, commonly called *sprawl*.

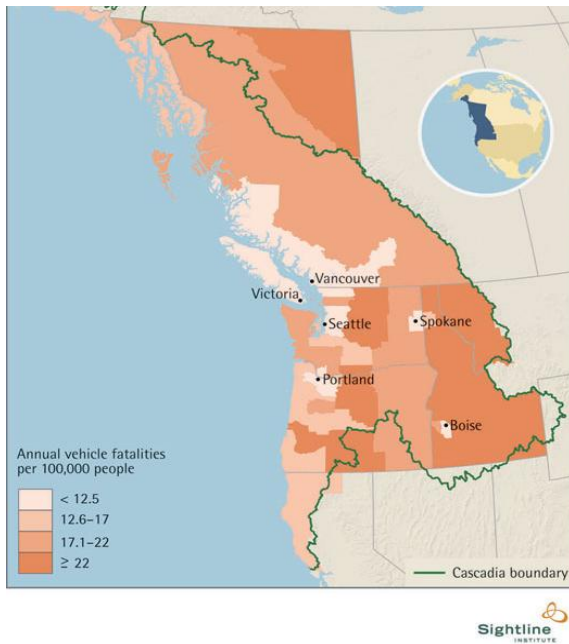
**Figure 19 Annual Traffic Death Rate (Ewing, Schieber and Zegeer 2003)**



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

Land use patterns have various impacts on travel and traffic crash risk (“Land Use Impacts On Transportation,” VTPI 2004). Increased density tends to increase *crash rates per vehicle-mile*, but reduces *traffic fatalities per capita*, due to less per capita mileage and less severe crashes. Ewing, Schieber and Zegeer (2003) find that per capita traffic fatality rates increase with the degree of sprawl in a community, as indicated in figures 17 and 18. These reflect relatively large geographic scales; similar effects probably exist between neighborhoods. For example, a smart growth neighborhood is likely to have a lower traffic fatality rate than a more sprawled neighborhood within a region or city. Durning (1996) found that per capita traffic casualties are about four times higher for residents of low-density suburbs than for residents of higher-density urban neighborhoods in the Puget Sound region. Ewing, Schieber and Zegeer found that each one percent increase in their index toward smart growth reduces the area’s traffic fatality rate by 1.5%. Fatality rates per pedestrian travel mile also declined with an increase in this index.

**Figure 20 Annual Traffic Fatality Rate (Sightline 2009)**



*Per capita traffic fatality rates are much higher in rural areas than in cities. Automobile-dependent areas have more than twice the traffic fatality rates as more multi-modal, urban areas.*

Dumbaugh and Rae (2009) performed regression analysis of crash rates in San Antonio, Texas neighborhoods. Accounting for various demographic and geographic factors they 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 mile of arterial roadway is associated with a 15% increase in total crashes.
- Each additional arterial-oriented retail or commercial parcel increased total crashes 1.3%, and each additional big box store increased total crashes 6.6%, while pedestrian-scaled commercial or retail uses were associated with a 2.2% reduction in crashes.
- The numbers of both young and older drivers were associated with increased total crashes.
- Each additional freeway mile within a neighborhood is associated with a 5% increase in *fatal* crashes, and each additional arterial mile is associated with a 20% increase in *fatal* crashes.
- Three- and four-leg intersections were associated with significantly reduced fatal crash rates.

The authors conclude that many of the urban planning and roadway planning practices previously recommended to increase traffic safety, such as separation of residential, commercial and recreational activities, 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.

Analysis by Lovegrove and Litman (2008) using a community-based, macro-level collision prediction models suggests that a smart growth strategy of more compact, multi-modal land use development patterns can reduce per capita neighbourhood collision frequency by 20% (total) and 29% (severe). Scheiner and Holz-Rau (2011) find considerably lower per capita crash injury rates and costs in urban centers than for suburban and rural locations in Germany. Garrick and Marshall (2008) analyzed road connectivity, network configuration, land use density, severe vehicle crashes, and mode choice in twenty-four California cities; half were classified as “safe cities” (severe/fatal crash rates one-third the state average), and half as “less safe cities” (severe/fatal crash rates close to the state average).

#### **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.

The safer cities were mainly established prior to 1950, while less safe cities tend to be newer. 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. The results were consistent across the board, with highly connected networks of small blocks exhibiting the best performance in all categories.

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, in smart growth communities, young men and people with disabilities (such as seniors with poor eyesight) drive less, it is common for residents to travel by walking, taxi or public transit when they may be drinking alcohol, teenagers are less likely to have drivers licenses and vehicles, elderly people more easily give up driving, and authorities can more easily revoke driving privileges. In the U.S., the portion of 16-19 year olds with drivers licenses peaked in 1983 and declined about 20% since (Brown 2010). 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, and better travel options (walking, cycling, taxi and public transport). Overall, city residents are safer, taking into account risks that increase with urban living, such as pedestrian fatalities and homicides (Durning 1996; Lucy 2002 and 2003).

**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
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.
PAYD insurance.	Reduces mileage in proportion to motorist risk class.	Large potential safety benefits. Reduces total traffic and gives high-risk motorists an extra incentive to reduce mileage.	Some shifts to alternative modes which reduces total pollution emissions and increases physical fitness.
Transit improvements, HOV priority, park & ride	Shifts automobile travel to transit	Moderate to large safety benefits. Shifts from automobile to transit reduce per-mile crash rates, and tend to reduce total automobile travel.	Reduced total pollution emissions, and tends to increase nonmotorized travel and therefore physical fitness.
Ridesharing, HOV priority	Shifts to 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 nonmotorized travel and therefore physical fitness.
Walking and cycling improvements, traffic calming	Shifts motorized travel to nonmotorized modes	Mixed safety impacts. Can increase per-mile to users, but reduces risk to others, reduces total person-miles and increases driver caution.	Can provide significant health benefits. Reduces total pollution emissions.
Telework, delivery services	Reduces total vehicle travel	Modest safety benefits. Reduced vehicle travel reduces crashes, but benefits may be partly offset by rebound effects.	Uncertain health impacts. Reduces total pollution emissions.
Flextime, congestion pricing	Shifts travel from peak to off-peak	Mixed. Reducing congestion tends to reduce crashes, but increased speed increases crash severity.	Uncertain impacts on health and pollution emissions.
Streetscaping, traffic calming, speed enforcement	Reduces traffic speeds	Large safety benefits where applied. Increases safety by reducing crash frequency and severity, and reducing total vehicle mileage.	Tends to improve walking and cycling conditions, providing health benefits.
Time and location driving restrictions.	Vehicle Use Restrictions	Mixed. Provides safety benefits if total vehicle travel declines, but not if vehicle travel shifts to other times and routes.	Provides pollution reduction and fitness benefits if total vehicle travel declines and use of non-motorized travel increases.
Land use management (Smart Growth, New Urbanism, etc.)	Reduces per capita vehicle travel and traffic speeds.	Large safety benefits. Increases safety by reducing per capita vehicle travel. Increases congestion, which increases crash frequency but reduces crash severity.	Reduces total pollution emissions but may increase exposure increasing density. Tends to increase nonmotorized 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 in mileage to other road users.
- If motorists primarily reduce higher-risk vehicle travel (drunk, weekend-nights, surface streets) a mileage reduction should provide an even larger reduction in crashes and fatalities.

Experts often assume that mobility management strategies mainly reduce lower-risk vehicle travel, for example, commuting, and so are an inefficient way to increase traffic safety. They point to statistics indicating that a large portion of crashes (about half) result from specific high-risk behaviors (drivers under the influence of alcohol or drugs, using a mobile telephone, street racing), or higher risk (young men or very old) drivers. This perspective (it could even be considered an ideology) 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.

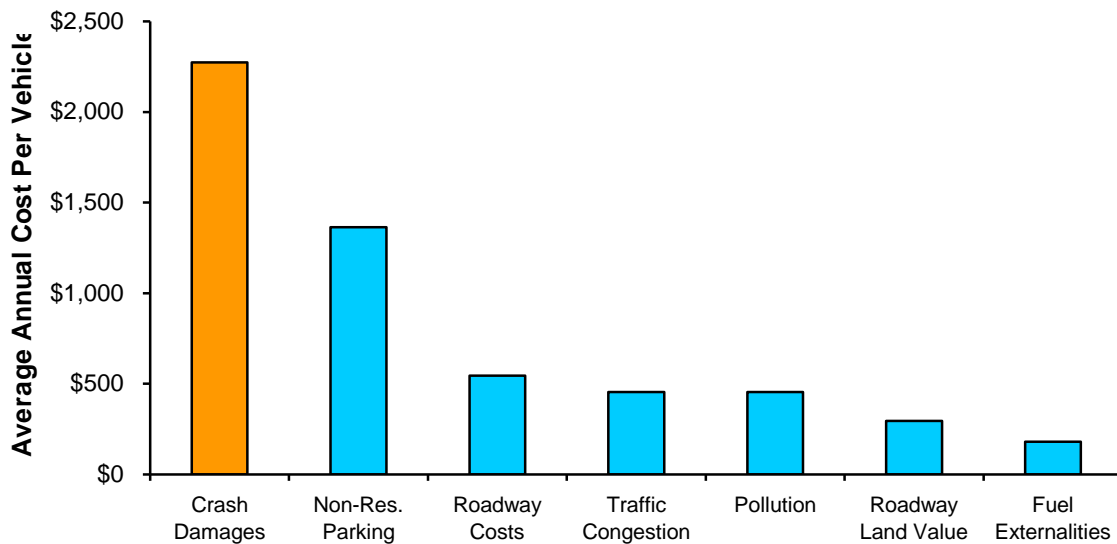
First, a significant portion of crashes (about half) involve normal drivers under normal driving conditions, without any specific risky behaviors. Second, reductions in error-free driving reduce crashes because those vehicles are no longer targets when other motorists make a mistake. Third, safe driving 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; Murphy and Delucchi 1998; Wang, Knipling and Blincoe 1999; 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 21.<sup>5</sup>

**Figure 21** 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

<sup>5</sup> 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.

the other hand, a congestion reduction strategy provides much greater total benefits if it causes even small reductions in crashes. A 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  $80\% \times 85\% = 68\%$ , 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 patterns), 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, the travel reduced consists of lower-value trips that consumers are most willing to forego when given modest incentives (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 nonmotorized 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. Nonmotorized 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. 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.

## Acknowledgements

I would like to thank the following people for providing information and encouragement: Professor Jean Andrey, Dr. Patrick Butler, Alan Durning, Aaron Edlin, Peter Jacobsen, Dr. Ted Miller, Professor Robert Noland and Sergio Pastrana.

## References

ABW (2010), *Bicycling and Walking in the U.S.: 2010 Benchmarking Report*, Alliance for Biking & Walking, ([www.peoplepoweredmovement.org](http://www.peoplepoweredmovement.org)); at [www.peoplepoweredmovement.org/site/index.php/site/memberservices/C529](http://www.peoplepoweredmovement.org/site/index.php/site/memberservices/C529).

AJHP (2003), "Special Issue: Health Promoting Community Design," *American Journal of Health Promotion* ([www.healthpromotionjournal.com](http://www.healthpromotionjournal.com)), Vol. 18, No. 1, Sept./Oct. 2003.

Jean Andrey (2000) "The Automobile Imperative: Risks of Mobility and Mobility-Related Risks," *The Canadian Geographer*, Vol. 44, No. 4, pp. 387-400.

APHA (2010), *The Hidden Health Costs of Transportation: Background*, American Public Health Association ([www.apha.org](http://www.apha.org)); at [www.apha.org/advocacy/reports/reports](http://www.apha.org/advocacy/reports/reports)

APTA (annual reports), *Transit Statistics*, American Public Transportation Association ([www.apta.com](http://www.apta.com)).

APTA (2003), *Public Transportation Fact Book*, American Public Transportation Association; at [www.apta.com/resources/statistics/Documents/FactBook/APTA\\_2003\\_Fact\\_Book.pdf](http://www.apta.com/resources/statistics/Documents/FactBook/APTA_2003_Fact_Book.pdf)

ATSB (2007), *International Road Safety Comparisons: The 2005 Report A Comparison of Road Safety Statistics in OECD Nations and Australia*, Australian Transport Safety Bureau ([www.atsb.gov.au](http://www.atsb.gov.au)); at [www.atsb.gov.au/publications/2007/pdf/Int\\_comp\\_05.pdf](http://www.atsb.gov.au/publications/2007/pdf/Int_comp_05.pdf).

Sandy Balkin and J. Keith Ord (2001) "Assessing the Impact of Speed-Limit Increases on Fatal Interstate Crashes," *Journal of Transportation and Statistics*, Vol. 4, No. 1 ([www.bts.gov](http://www.bts.gov)), pp. 1-26, April.

J. Ball, M. Ward, L. Thornley, and R. Quigley (2009), *Applying Health Impact Assessment To Land Transport Planning*, Research Report 375, New Zealand Transport Agency ([www.landtransport.govt.nz](http://www.landtransport.govt.nz)); at [www.landtransport.govt.nz/research/reports/375.pdf](http://www.landtransport.govt.nz/research/reports/375.pdf).

Stephen Bath (1993) *Influence of Socioeconomic Factors on the Exposure to Crash Risk for Young Drivers*, Traffic Safety Research Dept., ICBC ([www.icbc.com](http://www.icbc.com)).

Judith Bell and Larry Cohen (2009), *The Transportation Prescription: Bold New Ideas for Healthy, Equitable Transportation Reform in America*, PolicyLink and the Prevention Institute Convergence Partnership ([www.convergencepartnership.org/transportationhealthandequity](http://www.convergencepartnership.org/transportationhealthandequity)).

Lawrence Blincoe, et al. (2002), *Economic Cost of Motor Vehicle Crashes 2000*, USDOT DOT HS 809 446 NHTSA ([www.nhtsa.dot.gov](http://www.nhtsa.dot.gov)); at [www.nhtsa.gov/DOT/NHTSA/Communication%20&%20Consumer%20Information/Articles/Associated%20Files/EconomicImpact2000.pdf](http://www.nhtsa.gov/DOT/NHTSA/Communication%20&%20Consumer%20Information/Articles/Associated%20Files/EconomicImpact2000.pdf).

Laura K. Brennan Ramirez, et. al (2006), “Indicators of Activity-Friendly Communities: An Evidence-Based Consensus Process,” *American Journal of Preventive Medicine*, Vol. 31, No. 6, December.

Lester Brown (2010), *U.S. Car Fleet Shrank by Four Million in 2009*, Earth Policy Institute ([www.earth-policy.org](http://www.earth-policy.org)); at [www.earth-policy.org/index.php?/plan\\_b\\_updates/2010/update87](http://www.earth-policy.org/index.php?/plan_b_updates/2010/update87).

BTS (2000) *Transportation Safety Data*, Bureau of Transportation Statistics, USDOT ([www.bts.gov/programs/btsprod/nts/chp3v.html](http://www.bts.gov/programs/btsprod/nts/chp3v.html)).

Patrick Butler (1996) “Automobile Insurance Pricing,” National Organization for Women ([www.now.org](http://www.now.org)), presented at National Conference on Women’s Travel Issues, Baltimore, National Organization for Women CentsPerMileNow ([www.centspermilenow.org/publicat.htm](http://www.centspermilenow.org/publicat.htm)).

Ruy Cardoso and Richard Woll (1993), “Discussion of Patrick Butler’s ‘Cost-Based Pricing of Individual Automobile Risk Transfer: Car-Mile Exposure Unit Analysis,’” *Journal of Actuarial Practice*, Vol. 1, No. 1, pp. 69-71; at [www.centspermilenow.org/Reprints/516.pdf](http://www.centspermilenow.org/Reprints/516.pdf).

CAS (1996) *Foundations of Casualty Actuarial Science*, 3<sup>rd</sup> Edition, Casualty Actuarial Society (Arlington; [www.casact.org](http://www.casact.org)).

CBO (2003) *Fuel Economy Standards Versus A Gasoline Tax*, Congressional Budget Office ([www.cbo.gov](http://www.cbo.gov)); at [www.cbo.gov/ftpdocs/51xx/doc5159/03-09-CAFEbrief.pdf](http://www.cbo.gov/ftpdocs/51xx/doc5159/03-09-CAFEbrief.pdf).

CDC (2003) “Deaths: Preliminary Data for 2001,” *National Vital Statistics Reports*, Vol. 51, No 5, National Center of Health Statistics, National Center of Disease Control and Prevention ([www.cdc.gov/nchs](http://www.cdc.gov/nchs)).

G. Chi, et. al. (2010a), “Gasoline Prices and Traffic Safety in Mississippi,” *Journal of Safety Research*, Vol. 41(6), pp. 493–500; at <http://nexus.umn.edu/Papers/GasPricesAndTrafficSafety.pdf>.

G. Chi, et al. (2010b). “Gasoline Prices And Their Relationship To Drunk-Driving Crashes,” *Accident Analysis and Prevention*, Vol. 43(1), pp. 194–203; at <http://nexus.umn.edu/Papers/GasPricesAndDrunkDriving.pdf>.

G. Chi, et al. (2011a), *Gasoline Price Effects on Traffic Safety in Urban and Rural Areas: Evidence from Minnesota, 1998–2007*, presented at the Transportation Research Board Annual Meeting ([www.trb.org](http://www.trb.org)); at <http://nexus.umn.edu/Papers/GasolinePricesAndTrafficSafetyMinnesota.pdf>.

G. Chi, et al. (2011b), *A Time Geography Approach to Understanding the Impact of Gasoline Price Changes on Traffic Safety*, presented at the Transportation Research Board Annual Meeting ([www.trb.org](http://www.trb.org)); at <http://nexus.umn.edu/Papers/TimeGeography.pdf>.

Robert Chirinko and Edward Harper Jr. (1993) “Buckle Up or Slow Down? New Estimates of Offsetting Behavior and their Implications for Automobile Safety Regulation,” *Journal of Policy Analysis and Management*, Vol. 12, No. 2, pp. 270-296.

Betty Yei-Chou Chu and Geoffrey E. Nunn (1976), "An Analysis Of The Decline In California Traffic Fatalities During The Energy Crisis," *Accident Analysis & Prevention* ([www.sciencedirect.com/science/journal/00014575](http://www.sciencedirect.com/science/journal/00014575)), Vol. 8, Is. 3, September, Pages 145-150.

Xuehao Chu (2003), *The Fatality Risk of Walking in America: A Time-Based Comparative Approach*, Walk21 Conference - Health, Equity and the Environment, Portland, Oregon ([www.americawalks.org/PDF\\_PAPE/Chu.pdf](http://www.americawalks.org/PDF_PAPE/Chu.pdf)).

Xuehao Chu (2006), *The Relative Risk between Walking and Motoring In the United States*, Transportation Research Board 85th Annual Meeting ([www.trb.org](http://www.trb.org)); at [www.mdt.mt.gov/research/docs/trb\\_cd/Files/06-0277.pdf](http://www.mdt.mt.gov/research/docs/trb_cd/Files/06-0277.pdf).

David E. Clark, and Brad M. Cushing (2004), "Rural and Urban Traffic Fatalities, Vehicle Miles, and Population Density," *Accident Analysis and Prevention*, Vol. 36, pp. 967-972.

*Community Road Accident Database* (<http://europa.eu.int/comm/transport/care>), detailed data on individual accidents in participating European countries.

Larry Copeland (2009), "Traffic Deaths Down On America's Roads," *USA Today*, 5 February 2009 ([www.usatoday.com/news/nation/2009-02-04-traffic-deaths\\_N.htm](http://www.usatoday.com/news/nation/2009-02-04-traffic-deaths_N.htm)).

A. Scott Cothron, Stephen E. Ranft, Carol H. Walters, David W. Fenno, and Dominique Lord (2005), *Crash Analysis of Selected High-Occupancy Vehicle Facilities in Texas: Methodology, Findings, and Recommendations*, Report 0-4434-1, Texas Transportation Institute (<http://tti.tamu.edu>).

Charles Courtemanche (2008), *Silver Lining? The Connection between Gasoline Prices and Obesity*, Greensboro - Department of Economics, University of North Carolina (UNC); at <http://ssrn.com/abstract=982466>

DfT (2003), *2003 National Travel Survey and Road Casualties Great Britain*, UK Dept. for Transport ([www.transtat.dft.gov.uk](http://www.transtat.dft.gov.uk)).

DfT (2004), "International Comparison," *Transportation Statistics for Great Britain*, UK Department For Transport ([www.dft.gov.uk/stellent/groups/dft\\_transstats/documents/page/dft\\_transstats\\_031999.hcsp](http://www.dft.gov.uk/stellent/groups/dft_transstats/documents/page/dft_transstats_031999.hcsp)).

DHHS (2008), *Physical Activity Guidelines For Americans*, Physical Activity Guidelines Advisory Committee Report, Department of Health and Human Services ([www.health.gov](http://www.health.gov)); at [www.health.gov/paguidelines/report](http://www.health.gov/paguidelines/report).

Andrew Dickerson, John Peirson and Roger Vickerman (1998), *Road Accidents and Traffic Flows: An Econometric Investigation*, Department of Economics, University of Kent; at [www.kent.ac.uk/economics/papers/papers-pdf/1998/9809.pdf](http://www.kent.ac.uk/economics/papers/papers-pdf/1998/9809.pdf).

Rayola Dougher and Thomas Hogarty (1994), *Paying for Automobile Insurance at the Pump: A Critical Review*, Research Study #076, American Petroleum Institute, ([www.api.org](http://www.api.org)).

Eric Dumbaugh (2005), "Safe Streets, Livable Streets," *Journal of the American Planning Association* ([www.planning.org](http://www.planning.org)), Vol. 71, No. 3, Summer, pp. 283-300; at [www.naturewithin.info/Roadside/TransSafety\\_JAPA.pdf](http://www.naturewithin.info/Roadside/TransSafety_JAPA.pdf).

Eric Dumbaugh and Robert Rae (2009), "Safe Urban Form: Revisiting the Relationship Between Community Design and Traffic Safety," *Journal of the American Planning Association*, Vol. 75, No. 3, Summer 2009; at [http://pdfserve.informaworld.com/891216\\_911996851.pdf](http://pdfserve.informaworld.com/891216_911996851.pdf).

Alan Durning (1996), *The Car and the City*, Northwest Environment Watch ([www.northwestwatch.org](http://www.northwestwatch.org)).

Aaron Edlin (1998), *Per-Mile Premiums for Auto Insurance*, Dept. of Economics, University of California at Berkeley (<http://emlab.berkeley.edu/users/edlin>).

Aaron Edlin and Pena Karaca-Mandic (2002), *The Accident Externality from Driving*, The Berkeley Electronic Press ([www.bepress.com](http://www.bepress.com)), March. Also published in the *Journal of Political Economy*, Vol. 114, No. 5, 2006, pp. 931-955.

Rune Elvik (1994), "The External Costs of Traffic Injury: Definition, Estimation, and Possibilities for Internalization," *Accident Analysis and Prevention*, Vol. 26, No. 6, pp. 719-732.

Rune Elvik (1995), "An Analysis of Official Economic Valuations of Traffic Accident Fatalities in 20 Motorized Countries," *Accident Analysis and Prevention*, Vol. 27, No 2, 237-247.

Rune Elvik (2001a), "Area-Wide Urban Traffic Calming Schemes: A Meta-Analysis of Safety Effects," *Accident Analysis and Prevention*, Vol. 33 ([www.elsevier.com/locate/aap](http://www.elsevier.com/locate/aap)), pp. 327-336.

Rune Elvik (2001b), "Zero Killed in Traffic – from Vision to Implementation," *Nordic Road & Transport Research*, No. 1, 2001 ([www.vti.se/nordic/1-01mapp/toi1.htm](http://www.vti.se/nordic/1-01mapp/toi1.htm)).

Rune Elvik (2005), *Speed And Road Safety: Synthesis Of Evidence From Evaluation Studies*, *Transportation Research Record 1908*, TRB ([www.trb.org](http://www.trb.org)), pp. 59-69; <http://pubsindex.trb.org/view.aspx?id=762266>.

Rune Elvik (2009), "The Non-Linearity of Risk and the Promotion of Environmentally Sustainable Transport," *Accident Analysis and Prevention*, Vol. 41, pp. 849–855.

Michelle Ernst and Lilly Shoup (2009), *Dangerous by Design: Solving the Epidemic of Preventable Pedestrian Deaths (and Making Great Neighborhoods)*, Transport for America (<http://t4america.org>); at [http://t4america.org/docs/dangerousbydesign/dangerous\\_by\\_design.pdf](http://t4america.org/docs/dangerousbydesign/dangerous_by_design.pdf).

Leonard Evans (2005), *Traffic Safety*, Science Serving Society ([www.scienceservingsociety.com](http://www.scienceservingsociety.com)).

Reid Ewing and Eric Dumbaugh (2009), "The Built Environment and Traffic Safety: A Review of Empirical Evidence," *Journal of Planning Literature*, Vol. 23 No. 4, May 2009, pp. 347-367.

Reid Ewing, R. Pendall and Don Chen (2002), *Measuring Sprawl and Its Impacts*, Smart Growth America ([www.smartgrowthamerica.org](http://www.smartgrowthamerica.org)).

Reid Ewing, Richard Schieber and Charles V. Zegeer (2003), "Urban Sprawl As A Risk Factor In Motor Vehicle Occupant And Pedestrian Fatalities," *American Journal of Public Health*, Vol. 93, No. 9 ([www.ajph.org](http://www.ajph.org)), Sept. 2003, pp. 1541-1545.

Joseph Ferreira Jr. and Eric Minike (2010), *A Risk Assessment of Pay-As-You-Drive Auto Insurance*, Department of Urban Studies and Planning, Massachusetts Institute of Technology (<http://dusp.mit.edu>); at [www.clf.org/wp-content/uploads/2010/12/CLF-PAYD-Study\\_November-2010.pdf](http://www.clf.org/wp-content/uploads/2010/12/CLF-PAYD-Study_November-2010.pdf).

FHWA (1994), *Motor Vehicle Accident Costs - Technical Advisory*, T 7570.2, Federal Highway Administration, USDOT ([www.fhwa.dot.gov/legsregs/directives/techadv/t75702.htm](http://www.fhwa.dot.gov/legsregs/directives/techadv/t75702.htm)).

FHWA (Annual Reports), *Highway Statistics*, Federal Highway Administration ([www.fhwa.dot.gov/ohim](http://www.fhwa.dot.gov/ohim)).

Fietsberaad (2008), *Cycling in the Netherlands*, Ministry of Transport, Public Works and Water Management, The Netherlands; at [www.fietsberaad.nl/library/repository/bestanden/Cycling%20in%20the%20Netherlands%20VenW.pdf](http://www.fietsberaad.nl/library/repository/bestanden/Cycling%20in%20the%20Netherlands%20VenW.pdf).

Larry Frank (2004), “Obesity Relationships with Community Design, Physical Activity and Time Spent in Cars,” *American Journal of Preventive Medicine* ([www.ajpm-online.net/home](http://www.ajpm-online.net/home)), Vol. 27, No. 2, June, 2004, pp. 87-97.

Lawrence Frank, Sarah Kavage and Todd Litman (2006), *Promoting Public Health Through Smart Growth: Building Healthier Communities Through Transportation And Land Use Policies*, Smart Growth BC ([www.smartgrowth.bc.ca](http://www.smartgrowth.bc.ca)); at [www.vtppi.org/sgbc\\_health.pdf](http://www.vtppi.org/sgbc_health.pdf).

Howard Frumkin, Lawrence Frank and Richard Jackson (2004), *Urban Sprawl and Public Health: Designing, Planning, and Building For Healthier Communities*, Island Press ([www.islandpress.org](http://www.islandpress.org)).

Norman W. Garrick and Wesley Marshall (2008), *Network, Placemaking and Sustainability*, Center for Transportation and Urban Planning, University of Connecticut ([www.ctup.uconn.edu](http://www.ctup.uconn.edu)); at [www.cnu.org/sites/files/network\\_placemaking\\_sustainability.pdf](http://www.cnu.org/sites/files/network_placemaking_sustainability.pdf).

Ted Gayer (2001), *The Fatality Risks of Sport-Utility Vehicles, Vans, and Pickups*, Economics Department, University of California, Berkeley (<http://repositories.cdlib.org/iber/econ/E01-297>), Working Paper E01-297.

Judy Geyer, Noah Raford and David Ragland (2006), *The Continuing Debate about Safety in Numbers—Data From Oakland, CA*, Transportation Research Board 85th Annual Meeting ([www.trb.org](http://www.trb.org)); at [www.mdt.mt.gov/research/docs/trb\\_cd/Files/06-2616.pdf](http://www.mdt.mt.gov/research/docs/trb_cd/Files/06-2616.pdf).

David C. Grabowski and Michael A. Morrissey (2004), “Gasoline Prices and Motor Vehicle Fatalities,” *Journal of Policy Analysis and Management* ([www.appam.org/publications/jpam/about.asp](http://www.appam.org/publications/jpam/about.asp)), Vol. 23, No. 3, pp. 575–593. For more recent analysis see “As Gas Prices Go Up, Auto Deaths Drop,” Associated Press, 11 July 2008; at [http://news.yahoo.com/s/ap/20080711/ap\\_on\\_he\\_me/auto\\_deaths\\_gas\\_prices](http://news.yahoo.com/s/ap/20080711/ap_on_he_me/auto_deaths_gas_prices); and “10 Things You Can Like About \$4 Gas,” *Time Magazine*, July 2008; [www.time.com/time/specials/packages/article/0,28804,1819594\\_1819592\\_1819582,00.htm](http://www.time.com/time/specials/packages/article/0,28804,1819594_1819592_1819582,00.htm).

David C. Grabowski and Michael A. Morrissey (2006), Do Higher Gasoline Taxes Save Lives? *Economics Letters* ([www.elsevier.com/locate/econbase](http://www.elsevier.com/locate/econbase)), Vol. 90, pp. 51–55.

Fanis Grammenos (2011), *Healthy Travel Modes: Correlations, Causality and Caution*, Planetizen ([www.planetizen.com/node/51851](http://www.planetizen.com/node/51851)).

Frank Haight (1994), "Problems in Estimating Comparative Costs of Safety and Mobility," *Journal of Transport Economics and Policy*, January, p. 14-17; at [www.bath.ac.uk/e-journals/jtep/pdf/Volume\\_XXV111\\_No\\_1\\_7-30.pdf](http://www.bath.ac.uk/e-journals/jtep/pdf/Volume_XXV111_No_1_7-30.pdf).

HSIS (2010), *Evaluation of Lane Reduction "Road Diet" Measures on Crashes Summary Report Research, Development, and Technology*, Highway Safety Information System ([www.hsisinfo.org](http://www.hsisinfo.org)); summary report at [www.hsisinfo.org/pdf/10-053.pdf](http://www.hsisinfo.org/pdf/10-053.pdf).

ICBC (various dates), Insurance Corporation of British Columbia ([www.icbc.com](http://www.icbc.com)).

IHS (2003), *IHS Status Report, Special Issue: Speeding*, Insurance Institute for Highway Safety ([www.hwysafety.org/srpdfs/sr3810.pdf](http://www.hwysafety.org/srpdfs/sr3810.pdf)).

Simon Ilyushchenko (2010), *Fatal US Car Collisions, 2005-2007*, Blogroll: The Days Are Numbered ([www.thedaysarenumbered.com](http://www.thedaysarenumbered.com)); at [www.thedaysarenumbered.com/2008/11/fatal-us-car-collisions-2005-2007.html](http://www.thedaysarenumbered.com/2008/11/fatal-us-car-collisions-2005-2007.html).

Peter L. Jacobsen (2003), "Safety In Numbers: More Walkers and Bicyclists, Safer Walking and Bicycling," *Injury Prevention* (<http://ip.bmjournals.com>), Vol. 9, pp. 205-209; at <http://injuryprevention.bmj.com/cgi/content/full/9/3/205>.

Mary Janke (1991), "Accidents, Mileage, and the Exaggeration of Risk," *Accident Analysis and Prevention*, Vol. 23, No. 3, pp. 183-188.

Jan Jansson (1994), "Accident Externality Charges," *Journal of Transport Economics and Policy*, Vol. 28.

Jeffrey Kenworthy and Felix Laube (2000), *Millennium Cities Database For Sustainable Transport*, Institute for Sustainability and Technology Policy, Distributed by the International Union of Public Transport ([www.uitp.com](http://www.uitp.com)).

Richard E. Killingsworth and Jean Lamming (2001), "Development and Public Health; Could Our Development Patterns be Affecting Our Personal Health?" *Urban Land*, Urban Land Institute ([www.uli.org](http://www.uli.org)), pp. 12-17, July.

C.N. Kloeden, A.J. McLean, and G. Ponte (2001), *Travelling Speed and the Risk of Crash Involvement On Rural Roads*, Federal Office of Road Safety, CR 204 (<http://www.atsb.gov.au/road/rpts/cr204/index.cfm>).

Patsy Klus (1999), *Carjackings in the United States, 1992-96*, Bureau of Justice Statistics; at [www.ojp.usdoj.gov/bjs/pub/pdf/cus96.pdf](http://www.ojp.usdoj.gov/bjs/pub/pdf/cus96.pdf).

Elizabeth Kopits and Maureen Cropper (2003), *Traffic Fatalities and Economic Growth*, World Bank ([www-wds.worldbank.org](http://www-wds.worldbank.org)).

Kevin J. Krizek, et al (2006), *Guidelines for Analysis of Investments in Bicycle Facilities*, Transportation Research Board, NCHRP Report 552 ([www.trb.org](http://www.trb.org)); at [http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_552.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_552.pdf).

Young-Jun Kweon and Kara M. Kockelman (2003), "Overall Injury Risk to Different Drivers: Combining Exposure, Frequency, and Severity Models," *Accident Analysis and Prevention*, Vol. 35, No. 4, pp. 313-321; at

[www.ce.utexas.edu/prof/kockelman/public\\_html/TRB02CrashRates.pdf](http://www.ce.utexas.edu/prof/kockelman/public_html/TRB02CrashRates.pdf).

W.A. Leaf and D.F. Preusser, D.F. (1998), *Literature Review on Vehicle Travel Speeds and Pedestrian Injuries*, National Highway Traffic Safety Administration, USDOT ([www.nhtsa.gov](http://www.nhtsa.gov)); at [www.nhtsa.gov/people/injury/research/pub/hs809012.html](http://www.nhtsa.gov/people/injury/research/pub/hs809012.html).

J. Paul Leigh and Estella M. Geraghty (2008), "High Gasoline Prices and Mortality From Motor Vehicle Crashes and Air Pollution," *Journal of Occupational and Environmental Medicine*, Vol. 50, Is. 3, March, pp. 249-54; at [www.ncbi.nlm.nih.gov/pubmed/18332774](http://www.ncbi.nlm.nih.gov/pubmed/18332774).

LFC (2008), *The Built Environment and Health: A Review*, Lawrence Frank & Company for Plan-It Calgary, City of Calgary ([www.calgary.ca](http://www.calgary.ca)); at [www.calgary.ca/docgallery/BU/planning/pdf/plan\\_it/health\\_and\\_wellness\\_reports.pdf](http://www.calgary.ca/docgallery/BU/planning/pdf/plan_it/health_and_wellness_reports.pdf).

Graeme Lindsay, Alistair Woodward and Alex Macmillan (2008), *Effects On Health And The Environment Of Increasing The Proportion Of Short Urban Trips Made By Bicycle Instead Of Motor Vehicle*, Discussion Paper, School of Population Health, University of Auckland ([www.fmhs.auckland.ac.nz](http://www.fmhs.auckland.ac.nz)).

Samjin Lim, Wonchol Kim, Sangmoon Jung and Myungsoon Chang (2006), "Bus Traffic Accident Analysis: Before and after Transportation Reform in Seoul," *Seoul Studies Journal*, Seoul Development Institute ([www.sdi.re.kr](http://www.sdi.re.kr)).

Todd Litman (1997), "Distance-Based Vehicle Insurance as a TDM Strategy," *Transportation Quarterly*, Vol. 51, No. 3, Summer, pp. 119-138; at [www.vtppi.org/dbvi.pdf](http://www.vtppi.org/dbvi.pdf).

Todd Litman (2003), "Integrating Public Health Objectives in Transportation Decision-Making," *American Journal of Health Promotion*, Vol. 18, No. 1 ([www.healthpromotionjournal.com](http://www.healthpromotionjournal.com)), Sept./Oct. 2003, pp. 103-108; at [www.vtppi.org/AJHP-litman.pdf](http://www.vtppi.org/AJHP-litman.pdf).

Todd Litman (2004), *Rail Transit in America: Comprehensive Evaluation of Benefits*, VTPI ([www.vtppi.org](http://www.vtppi.org)); at [www.vtppi.org/railben.pdf](http://www.vtppi.org/railben.pdf); summarized in "Impacts of Rail Transit on the Performance of a Transportation System," *Transportation Research Record 1930*, Transportation Research Board ([www.trb.org](http://www.trb.org)), pp. 23-29.

Todd Litman (2005), "Terrorism, Transit and Public Safety: Evaluating the Risks," *Journal of Public Transit*, Vol. 8, No. 4 ([www.nctr.usf.edu/jpt/journal.htm](http://www.nctr.usf.edu/jpt/journal.htm)), pp. 33-46.; at [www.vtppi.org/transitrisk.pdf](http://www.vtppi.org/transitrisk.pdf).

Todd Litman (2005b), "Efficient Transportation Versus Efficient Vehicles," *Transport Policy*; at [www.vtppi.org/cafe.pdf](http://www.vtppi.org/cafe.pdf).

Todd Litman (2007), *Socially Optimal Transport Prices and Markets*, Victoria Transport Policy Institute ([www.vtppi.org](http://www.vtppi.org)); at [www.vtppi.org/sotpm.pdf](http://www.vtppi.org/sotpm.pdf).

Todd Litman (2009), *Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications*, Victoria Transport Policy Institute ([www.vtppi.org/tca](http://www.vtppi.org/tca)).

Todd Litman (2009a), “Transportation Policy and Injury Control,” *Injury Prevention*, Vol. 15, Issue 6 (<http://injuryprevention.bmj.com/content/15/6/362.full>); at [www.vtppi.org/tpic.pdf](http://www.vtppi.org/tpic.pdf).

Todd Litman (2009b), “Public Transportation and Health,” in *The Transportation Prescription: Bold New Ideas for Healthy, Equitable Transportation Reform in America*, (Bell and Cohen eds.) PolicyLink and the Prevention Institute Convergence Partnership ([www.convergencepartnership.org/transportationhealthandequity](http://www.convergencepartnership.org/transportationhealthandequity)).

Todd Litman (2010b), *Evaluating Public Transportation Health Benefits*, American Public Transportation Association ([www.apta.com](http://www.apta.com)); at [www.vtppi.org/tran\\_health.pdf](http://www.vtppi.org/tran_health.pdf).

Todd Litman (2011), *Pricing For Traffic Safety: How Efficient Transport Pricing Can Reduce Roadway Crash Risk*, Victoria Transport Policy Institute ([www.vtppi.org](http://www.vtppi.org)); at [www.vtppi.org/price\\_safe.pdf](http://www.vtppi.org/price_safe.pdf).

Gordon Lovegrove and Terek Sayed (2006), “Macro-level Collision Prediction Model For Evaluating Neighborhood Level Traffic Safety,” *Canadian Journal of Civil Engineering*, Vol. 33, No. 5, May, pp. 609-621; at [www.nrcresearchpress.com/doi/pdf/10.1139/106-013](http://www.nrcresearchpress.com/doi/pdf/10.1139/106-013).

Gordon Lovegrove and Todd Litman (2008), *Macrolevel Collision Prediction Models to Evaluate Road Safety Effects of Mobility Management Strategies: New Empirical Tools to Promote Sustainable Development*, Transportation Research Board 87th Annual Meeting ([www.trb.org](http://www.trb.org)); at [www.vtppi.org/lovegrove\\_litman.pdf](http://www.vtppi.org/lovegrove_litman.pdf).

Gord Lovegrove, Clark Lim and Tarek Sayed (2010), “Community-Based, Macrolevel Collision Prediction Model Use with a Regional Transportation Plan,” *Journal Of Transportation Engineering*, Vol. 136, No. 2, February 2010, pp. 120-128; abstract at <http://cedb.asce.org/cgi/WWWdisplay.cgi?253404>.

William Lucy (2002), *Danger in Exurbia: Outer Suburbs More Dangerous Than Cities*, University of Virginia ([www.virginia.edu](http://www.virginia.edu)); summarized in [www.virginia.edu/topnews/releases2002/lucy-april-30-2002.html](http://www.virginia.edu/topnews/releases2002/lucy-april-30-2002.html).

William H. Lucy (2003), “Mortality Risk Associated With Leaving Home: Recognizing the Relevance of the Built Environment,” *American Journal of Public Health*, Vol 93, No. 9, September 2003, pp. 1564-1569; at [www.ajph.org/cgi/content/full/93/9/1564](http://www.ajph.org/cgi/content/full/93/9/1564).

William Lucy and David L. Phillips (2006), *Tomorrow’s Cities, Tomorrow’s Suburbs*, Planners Press ([www.planning.org](http://www.planning.org)).

Buzzacchi Luigi and Tommaso M. Valletti (2002) *Strategic Price Discrimination in Compulsory Insurance Markets*, Imperial College London ([www.ms.ic.ac.uk/tommaso/discr.pdf](http://www.ms.ic.ac.uk/tommaso/discr.pdf)).

Elizabeth MacDonald, Rebecca Sanders and Paul Supawanich (2008), *The Effects Of Transportation Corridors’ Roadside Design Features On User Behavior And Safety, And Their Contributions To Health, Environmental Quality, And Community Economic Vitality: A Literature Review*, University of California Transportation Center ([www.uctc.net](http://www.uctc.net)).

Roger L Mackett and Belinda Brown (2011), *Transport, Physical Activity and Health: Present Knowledge and the Way Ahead*, Centre for Transport Studies, University College London ([www.ucl.ac.uk/news/pdf/transportactivityhealth.pdf](http://www.ucl.ac.uk/news/pdf/transportactivityhealth.pdf)).

Murray May, Paul J. Tranter and James R. Warn (2008), "Towards a Holistic Framework for Road Safety in Australia," *Journal of Transport Geography*, Vol. 16.

Murray May, Paul J. Tranter and James R. Warn (2011), "Progressing Road Safety Through Deep Change And Transformational Leadership," *Journal of Transport Geography*, Vol. 19, pp. 1423-1430; abstract at [www.sciencedirect.com/science/article/pii/S0966692311001098](http://www.sciencedirect.com/science/article/pii/S0966692311001098).

G. Maycock and C.R. Lockwood (1993), "The Accident Liability of British Car Drivers." *Transport Reviews*, Vol. 13, No. 3, pp. 231-245.

Tom Maze, et al (2005), "Safety Performance of Divided Expressways," *ITE Journal*, Vol. 75, No. 5 ([www.ite.org](http://www.ite.org)), May 2005, pp. 48-53.

G. William Mercer (1987), "Influences on Passenger Vehicle Casualty Accident Frequency and Severity: Unemployment, Driver Gender, Driver Age, Drinking Driving and Restraint Device Use," *Accident Analysis and Prevention*, Vol. 19, 1987, pp. 231-236.

Ted Miller (1991), *The Costs of Highway Crashes*. FHWA (Washington DC), Publication No. FHWA-RD-055, 1991.

Louis Mizell (1995), *Aggressive Driving*, AAA Foundation for Traffic Safety ([www.aaafoundation.org](http://www.aaafoundation.org)); at [www.aaafoundation.org/resources/index.cfm?button=agdrtext](http://www.aaafoundation.org/resources/index.cfm?button=agdrtext).

J. Murphy and Mark Delucchi (1998), "A Review of the Literature on the Social Cost of Motor Vehicle Use in the U.S.," *Journal of Transportation And Statistics*. Vol. 1, No. 1 ([www.bts.gov](http://www.bts.gov)), January, pp. 15-42.

Christopher Murray (1996), *Global Burden of Disease and Injury*, Center for Population and Development Studies, Harvard University School of Public Health ([www.hsph.harvard.edu](http://www.hsph.harvard.edu)).

Dan Nabors, et al. (2007), *Pedestrian Road Safety Audit Guidelines and Prompt Lists*, Pedestrian and Bicycle Information Center ([www.pedbikeinfo.org](http://www.pedbikeinfo.org)), Federal Highway Administration Office of Safety; at <http://www.walkinginfo.org/library/details.cfm?id=3955>.

NCIPC (2001), *National Strategies for Advancing Child Pedestrian Safety*, National Center for Injury Prevention and Control, Center for Disease Control ([www.cdc.gov](http://www.cdc.gov)); at [www.cdc.gov/ncipc/pedestrian/contents.htm](http://www.cdc.gov/ncipc/pedestrian/contents.htm).

Peter Newman and Jeffrey Kenworthy (1999), *Sustainability and Cities; Overcoming Automobile Dependency*, Island Press ([www.islandpress.org](http://www.islandpress.org)).

NHTSA (2001), "NHTAS Warns of Van Rollover Dangers." cited in *Metro Magazine*, June/July.

NHTSA (2002), *Safety Belt and Helmet Use in 2002 – Overall Results*. National Highway Traffic Safety Administration ([www.buckleupamerica.org/research/files/2002NOPUS.pdf](http://www.buckleupamerica.org/research/files/2002NOPUS.pdf)).

NHTSA (2003), *Traffic Safety Facts 2001*. National Highway Traffic Safety Administration ([www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2001.pdf](http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2001.pdf)).

NHTSA (2005), *Motor Vehicle Traffic Crashes as a Leading Cause of Death in the U.S., 2002 – A Demographic Perspective*, National Center for Statistics and Analysis; National Highway Traffic Safety Administration, DOT HS 809 843 ([www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2005/809843.pdf](http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2005/809843.pdf)).

Robert Noland (2003), “Traffic Fatalities and Injuries: The Effects of Changes in Infrastructure and Other Trends,” *Journal of Accident Prevention and Analysis* ([www.elsevier.com/locate/aap](http://www.elsevier.com/locate/aap)), Vol. 35, pp. 599-611; at [www.cts.cv.ic.ac.uk/staff/wp22-noland.pdf](http://www.cts.cv.ic.ac.uk/staff/wp22-noland.pdf).

Robert B. Noland and Mohammed A. Quddus (2005), “Congestion and Safety: A Spatial Analysis of London,” *Transportation Research*, Vol. 39A, Issues 7-9 ([www.elsevier.com/locate/tra](http://www.elsevier.com/locate/tra)), Aug-Nov. 2005, pp. 737-754.

OECD (annual reports), *International Road Traffic and Accident Database*, Organization for Economic Cooperation and Development ([www.internationaltransportforum.org/irtad/coverage.html](http://www.internationaltransportforum.org/irtad/coverage.html)).

OECD (annual reports), *OECD Factbook*, Organization for Economic Cooperation and Development ([www.sourceoecd.org/factbook](http://www.sourceoecd.org/factbook)).

OECD/ECMT (2006), *Speed Management*, Joint Transport Research Centre of the Organisation for Economic Co-operation and Development and the European Conference of Ministers of Transport ([www.cemt.org/JTRC/WorkingGroups/SpeedManagement/index.htm](http://www.cemt.org/JTRC/WorkingGroups/SpeedManagement/index.htm)).

Zack O'Malley Greenburg (2009), “America's Safest Cities,” *Forbes Magazine* ([www.forbes.com](http://www.forbes.com)); at [www.forbes.com/2009/10/26/safest-cities-ten-lifestyle-real-estate-metros-msa\\_print.html](http://www.forbes.com/2009/10/26/safest-cities-ten-lifestyle-real-estate-metros-msa_print.html).

Paul Ong (2004), “Auto Insurance Redlining In The Inner City,” *Access 25*, University of California Transportation Center ([www.uctc.net](http://www.uctc.net)), Fall 2004, pp. 40-41.

Yves Page (2001), “A Statistical Model to Compare Road Mortality in OECD Countries,” *Accident Analysis and Prevention*, Vol. 33 ([www.elsevier.com/locate/aap](http://www.elsevier.com/locate/aap)), pp. 371-385.

Ian W.H. Parry (2004), “Comparing Alternative Policies to Reduce Traffic Accidents Article,” *Journal of Urban Economics*, Vol. 54, No. 2 ([www.elsevier.com/locate/jue](http://www.elsevier.com/locate/jue)), Sept., pp. 346-368; at [www.rff.org/Documents/RFF-DP-03-07.pdf](http://www.rff.org/Documents/RFF-DP-03-07.pdf).

E. Pasanen (1992), *Driving Speeds and Pedestrian Safety: A Mathematical Model*, Technical Report No. REPT-77, Helsinki University of Technology, Laboratory of Traffic and Transportation Engineering, Espoo, Finland.

Ulf Persson and Knut Ödegaard (1995), “External Cost Estimates of Road Traffic Accidents; An International Comparison,” *Journal of Transport Economics and Policy*, pp. 291-304, September.

PfP (2011), *Transportation and Health: Policy Interventions for Safer, Healthier People and Communities*, Partnership for Prevention (Safe Transportation Research and Education Center,

Booz Allen Hamilton, and the Centers for Disease Control and Prevention) ([www.prevent.org](http://www.prevent.org)); at [www.prevent.org/Additional-Pages/Transportation-and-Health.aspx](http://www.prevent.org/Additional-Pages/Transportation-and-Health.aspx).

John Pucher and Lewis Dijkstra (2000), "Making Walking and Cycling Safer: Lessons from Europe," *Transportation Quarterly*, Vol. 54, No. 3, Summer; at [www.vtppi.org/puchertq.pdf](http://www.vtppi.org/puchertq.pdf).

Ari Rabl and Audrey de Nazelle (2012), "Benefits of Shift From Car to Active Transport," *Transport Policy*, Vol. 19, pp. 121-131; at [www.citeulike.org/article/9904895](http://www.citeulike.org/article/9904895).

Francesca Racioppi, Lars Eriksson, Claes Tingvall and Andres Villaveces (2004), *Preventing Road Traffic Injury: A Public Health Perspective For Europe*, World Health Organization, Regional Office for Europe ([www.euro.who.int/document/E82659.pdf](http://www.euro.who.int/document/E82659.pdf)).

Michael E. Rakauskas and Nicholas J. Ward (2007), "Identifying Fatality Factors Of Rural And Urban Safety Cultures," *Proceedings of the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*; at [http://ppc.uiowa.edu/driving-assessment/2007/proceedings/papers/033\\_RakauskasWard.pdf](http://ppc.uiowa.edu/driving-assessment/2007/proceedings/papers/033_RakauskasWard.pdf).

Henri Richardson (1997), *Motor Vehicle Traffic Crashes as a Leading Cause of Death in the U.S., 1992*, DOT HS 808 552, National Highway Traffic Safety Administration, USDOT ([www.nhtsa.dot.gov](http://www.nhtsa.dot.gov)).

Ian Roberts and I. Crombie (1995), "Child Pedestrian Deaths: Sensitivity to Traffic Volume-Evidence from the USA," *Journal of Epidemiol Community Health*, Vol. 49, No. 2 (<http://jech.bmjournals.com>), April 1995, pp. 186-188.

Dorothy Robinson (2005), "Safety in Numbers in Australia: More Walkers and Bicyclists, Safer Walking and Bicycling," *Health Promotion Journal of Australia*, Vol. 16, No. 1 ([www.healthpromotion.org.au](http://www.healthpromotion.org.au)), April 2005, pp. 47-51.

David Rojas-Rueda, Audrey de Nazelle, Marko Tainio and Mark J Nieuwenhuijsen (2011), "The Health Risks And Benefits Of Cycling In Urban Environments Compared With Car Use: Health Impact Assessment Study," *BMJ*, 343:d4521 ([www.bmj.com](http://www.bmj.com)); at [www.bmj.com/content/343/bmj.d4521.full](http://www.bmj.com/content/343/bmj.d4521.full).

RSPC (Royal Society of the Prevention of Accidents) (1997), Cited in "Fasten Your Safety Belts," *The Economist*, 11 January 1997, p. 57.

Joachim Scheiner and Christian Holz-Rau (2011), "A Residential Location Approach To Traffic Safety: Two Case Studies From Germany," *Accident Analysis & Prevention* ([www.sciencedirect.com/science/journal/00014575](http://www.sciencedirect.com/science/journal/00014575)), Vol. 43, Is. 1, January, pp. 307-322

P.A. Schuffham and J.D. Langley (2002), "A Model of Traffic Crashes In New Zealand," *Accident Analysis & Prevention*, Vol. 34 ([www.elsevier.com/locate/aap](http://www.elsevier.com/locate/aap)), pp. 673-687.

Maria Segui-Gomez, et al. (2011), "Exposure to Traffic and Risk of Hospitalization Due to Injuries," *Journal of Risk Analysis*, Vol. 31, No. 3, pp. 466-474 (DOI: 10.1111/j.1539-6924.2010.01509.x); at <http://onlinelibrary.wiley.com/doi/10.1111/j.1539-6924.2010.01509.x/abstract>.

SFDPH (2008), *Pedestrian Injury Forecasting Model*, San Francisco Department of Public Health; at [www.dph.sf.ca.us/phes/HIA\\_Tools\\_Ped\\_Injury\\_Model.htm](http://www.dph.sf.ca.us/phes/HIA_Tools_Ped_Injury_Model.htm).

D. Shefer and P. Rietvald (1997), "Congestion and Safety on Highways: Towards an Analytical Model," *Urban Studies*, Vol. 34, No. 4, pp. 679-692.

Sightline (2009), *Traffic Fatalities in Cascadia Map*, Sightline Institute; at [www.sightline.org/maps/maps/Sprawl-Traffic-CS06m](http://www.sightline.org/maps/maps/Sprawl-Traffic-CS06m).

Michael Sivak (2008), *Is The U.S. On The Path To The Lowest Motor Vehicle Fatalities In Decades?*, Report UMTRI-2008-39, University of Michigan Transportation Research Institute ([www.umtri.umich.edu](http://www.umtri.umich.edu)); at <http://deepblue.lib.umich.edu/bitstream/2027.42/60424/1/100969.pdf>.

Michael Sivak (2009), "Mechanisms Involved In The Recent Large Reductions In US Road Fatalities," *Injury Prevention* ([www.injuryprevention.bmj.com](http://www.injuryprevention.bmj.com)), Vol. 15, pp. 205–206; summary at <http://injuryprevention.bmj.com/content/15/3/205.abstract>.

Michael Sivak and Brandon Schoettle (2010), *Toward Understanding The Recent Large Reductions In U.S. Road Fatalities*, University of Michigan Transportation Research Institute ([www.umich.edu/~umtriswt](http://www.umich.edu/~umtriswt)); at <http://deepblue.lib.umich.edu/bitstream/2027.42/71390/1/102304.pdf>.

Michael Sorensen and Marjan Mosslemi (2009), *Subjective and Objective Safety - The Effect of Road Safety Measures on Subjective Safety Among Vulnerable Road Users*, Institute of Transport Economics (TØI) of the Norwegian Centre for Transport Research ([www.toi.no](http://www.toi.no)); at [www.toi.no/getfile.php/Publikasjoner/T%D8I%20rapporter/2009/1009-2009/1009-2009-nett.pdf](http://www.toi.no/getfile.php/Publikasjoner/T%D8I%20rapporter/2009/1009-2009/1009-2009-nett.pdf).

Steer Davies Gleave (2005), *What Light Rail Can Do For Cities: A Review of the Evidence*, UK Passenger Transport Executive Committee ([www.pteg.net](http://www.pteg.net)); at [www.eukn.org/unitedkingdom/themes/Urban\\_Policy/Transport\\_and\\_infrastructure/Public\\_transport/Trams\\_and\\_light\\_rail/Light-rail-and-cities\\_1001.html](http://www.eukn.org/unitedkingdom/themes/Urban_Policy/Transport_and_infrastructure/Public_transport/Trams_and_light_rail/Light-rail-and-cities_1001.html).

Jack Stuster and Zail Coffman (1998), *Synthesis of Safety Research Related to Speed and Speed Limits*, FHWA-RD-98-154 Federal Highway Administration ([www.tfhr.gov/safety/speed/speed.htm](http://www.tfhr.gov/safety/speed/speed.htm) and [www.tfhr.gov/safety/speed/speed.htm](http://www.tfhr.gov/safety/speed/speed.htm)).

SUPREME (2005), *Best Practices In Road Safety*, Summary And Publication Of Best Practices In Road Safety In The Member States, European Commission (<http://ec.europa.eu>); at [http://ec.europa.eu/transport/supreme/index\\_en.htm](http://ec.europa.eu/transport/supreme/index_en.htm).

Peter Swift, Dan Painter and Matthew Goldstein (2006), *Residential Street Typology and Injury Accident Frequency*, Swift and Associates, originally presented at the Congress for the New Urbanism, 1997; at <http://massengale.typepad.com/venustas/files/SwiftSafetyStudy.pdf>.

M. Taylor, D. Lynam and A. Baruya (2000), *The Effects Of Drivers Speed On The Frequency Of Road Accidents*, TRL Report 421, Transport Research Laboratory ([www.trl.co.uk](http://www.trl.co.uk)).

TCRP (2001), *Light Rail Service: Pedestrian and Vehicular Safety*, Transit Cooperative Research Program, Report 69, Transportation Research Board ([www.trb.org](http://www.trb.org)).

TfL (2004), *Congestion Charging Monitoring*, Transport for London, ([www.cclondon.com](http://www.cclondon.com)).

*TravelSmart* ([www.travelsmart.transport.wa.gov.au](http://www.travelsmart.transport.wa.gov.au)).

TTI (2001), *Urban Mobility Study*, Texas Transportation Institute (<http://mobility.tamu.edu/study>).

S.A. Turner, A. P. Roozenburg and T. Francis (2006), *Predicting Accident Rates for Cyclists and Pedestrians*, Land Transport New Zealand Research Report 289 ([www.ltsa.govt.nz](http://www.ltsa.govt.nz)); at [www.ltsa.govt.nz/research/reports/289.pdf](http://www.ltsa.govt.nz/research/reports/289.pdf).

UITP (2000), *Millennium Cities Database for Sustainable Transport and the Mobility In Cities Database*, International Association of Public Transport ([www.uitp.com/Project/index32.htm](http://www.uitp.com/Project/index32.htm)).

William Vickrey (1968), "Automobile Accidents, Tort Law, Externalities, and Insurance: An Economist's Critique," *Law and Contemporary Problems*, 33, pp. 464-487; at [www.vtppi.org/vic\\_acc.pdf](http://www.vtppi.org/vic_acc.pdf).

Hans-Joachim Vollpracht (2010), "They Call Them Coffin Roads," *Routes-Roads*, N° 347, World Road Association ([www.piarc.org](http://www.piarc.org)); at [www.vtppi.org/Vollpracht.pdf](http://www.vtppi.org/Vollpracht.pdf).

VTPI (2004), *Online TDM Encyclopedia*, Victoria Transport Policy Institute ([www.vtppi.org](http://www.vtppi.org)).

Jing-Shiarn Wang, Ronald R. Knipling and Lawrence J. Blincoc (1999), "The Dimensions of Motor Vehicle Crash Risk," *Journal of Transportation and Statistics* ([www.bts.gov](http://www.bts.gov)), Vol. 2, No. 1, May, pp. 19-43.

Malcolm Wardlaw (2001), *Stepping Stones to a Better Cycling Future*, British CTC/CCN Conference, Chesterfield, England, 13th October 2001; at [www.bicyclinglife.com/library/steppingstones.htm](http://www.bicyclinglife.com/library/steppingstones.htm).

Vicky Feng Wei and Gord Lovegrove (2010), "Sustainable Road Safety: A New (?) Neighbourhood Road Pattern That Saves VRU (Vulnerable Road Users) Lives," *Accident Analysis & Prevention* ([www.sciencedirect.com/science/journal/00014575](http://www.sciencedirect.com/science/journal/00014575)).

WHO (2004), *World Report on Road Traffic Injury Prevention*, World Health Organization and the World Bank ([www.who.int](http://www.who.int)); at [www.who.int/violence\\_injury\\_prevention/publications/road\\_traffic/world\\_report/en/index.html](http://www.who.int/violence_injury_prevention/publications/road_traffic/world_report/en/index.html).

WHO (2008a), *Transport and Health Programme*, World Health Organization Region Office Europe ([www.euro.who.int](http://www.euro.who.int)); at [www.euro.who.int/transport](http://www.euro.who.int/transport).

WHO (2008b), *Health Economic Assessment Tool for Cycling (HEAT for Cycling)*, World Health Organization Region Office Europe ([www.euro.who.int](http://www.euro.who.int)); at [www.euro.who.int/transport/policy/20070503\\_1](http://www.euro.who.int/transport/policy/20070503_1).

WHO (2011), *Health Co-Benefits Of Climate Change Mitigation - Transport Sector: Health In The Green Economy*, Health Impact Assessment, World Health Organization ([www.who.int/hia](http://www.who.int/hia)); at [www.who.int/hia/examples/trspt\\_comms/transport\\_sector\\_health\\_co-benefits\\_climate\\_change\\_mitigation/en/index.html](http://www.who.int/hia/examples/trspt_comms/transport_sector_health_co-benefits_climate_change_mitigation/en/index.html).

Wikipedia (2009), *List Of OECD Countries By Traffic-Related Death Rate; Based on WHO and OECD Data*, [http://en.wikipedia.org/wiki/List\\_of\\_OECD\\_countries\\_by\\_traffic-related\\_death\\_rate](http://en.wikipedia.org/wiki/List_of_OECD_countries_by_traffic-related_death_rate).

Gerald Wilde (1984), "On the Choice of the Denominator in the Calculation of Crash Rates," *Transport Risk Assessment*, University of Waterloo Press (Waterloo).

Gerald Wilde, (1994), *Target Risk*, PDE Publications (Toronto; <http://psyc.queensu.ca/target>).

Allan F. Williams (2003), "Views of U.S. Drivers About Driving Safety," *Journal of Safety Research*, Vol. 34, Is. 5, pp. 491-494.

Roelof Wittink (2003), "Planning For Cycling Supports Road Safety," *Sustainable Transport: Planning for Walking and Cycling In Urban Environments*, (Rodney Tolley Ed.) Woodhead Publishing ([www.woodhead-publishing.com](http://www.woodhead-publishing.com)), pp. 172-188.

Janes Woodcock, et al. (2007), "Energy and Health 3," *The Lancet* ([www.thelancet.com](http://www.thelancet.com)), Vol 370, 22 September 2007, pp. 1078-1088.

Sany R. Zein, et al. (1996), "Safety Benefits of Traffic Calming," *Transportation Research Record 1578*, TRB ([www.trb.org](http://www.trb.org)), pp. 3-10.

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

Charles V. Zegeer, et al. (1994), "Accident Relationships of Roadway Width on Low-Volume Roads," *Transportation Research Record 1445* ([www.trb.org](http://www.trb.org)), pp. 160.

[www.vtppi.org/safetrav.pdf](http://www.vtppi.org/safetrav.pdf)