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A New Traffic Safety Paradigm

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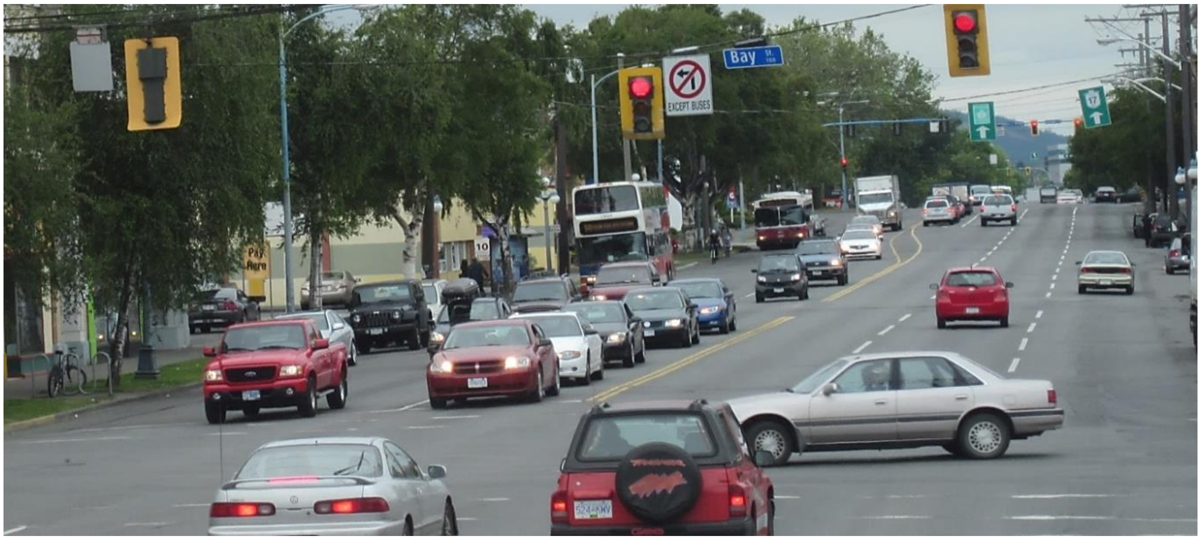

*A new traffic safety paradigm recognizes **exposure**, total vehicle travel, as a risk factor, and therefore the safety benefits of vehicle travel reduction strategies such as multi-modal planning, more efficient transport pricing, Smart Growth development policies and Transportation Demand Management (TDM) programs.*

Abstract

Despite large investments in traffic safety programs and technologies vehicle crashes continue to impose high social costs and recently increased. New strategies are needed to achieve ambitious safety targets such as Vision Zero. Recent research improves our understanding of factors that affect crash risks and identifies new safety strategies. Applying this knowledge requires a paradigm shift, a change in the way problems are defined and solutions evaluated. The old paradigm assumed that driving is generally safe, and so favored safety programs that target special risks such as youth, senior, impaired and distracted driving. The new paradigm recognizes that all vehicle travel carries risk, so *exposure* (total vehicle travel) is a risk factor, and vehicle travel reduction strategies provide safety benefits. This report examines our emerging understanding of traffic risks and new safety strategies, and the importance of more comprehensive safety analysis.

Summarized in

Todd Litman (2022), "Driving as a Risk Factor: A New Paradigm for Vision Zero," *Vision Zero Cities Journal*; at https://medium.com/vision-zero-cities-journal/driving-as-a-risk-factor.

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

Todd Litman (2018), "A New Traffic Safety Paradigm," *Transportation Talk* (Journal of the Canadian Institute of Transportation Engineers), Winter, pp. 12-18; at https://bit.ly/2Febrwx.

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Introduction

Despite many efforts to increase traffic safety, motor vehicle crashes continue to impose huge social costs. According to a National Highway Traffic Safety Administration study, in 2010 United States motor vehicle crashes caused damages cost $242-836 billion or $800-2,700 per capita (Blincoe, et al. 2015). International studies show similar results (Wismans, et al. 2017), with traffic crash costs estimated at 5% of GDP in lower- and middle-income countries (Welle, et al. 2018, p. 31).

Although traffic casualty rates declined during most of the Twentieth Century, they have recently increased, indicating that current traffic safety strategies have fulfilled their potential. Commonly-used safety strategies can be ineffective or counterproductive (Hall and Madsen 2022). New safety strategies are needed to achieve ambitious crash reduction goals such as *Road to Zero* (NSC 2017). This requires a paradigm shift, a change in the ways risks are measured and potential safety strategies are evaluated (Horrox, et al 2021; Hughes 2017; May, Tranter and Warn 2011; Litman 2013).

The old paradigm assumed that driving is safe overall, and most crashes are caused by special risks such as youth, senior, impaired and distracted driving. This favored targeted safety strategies. The new paradigm recognizes that all vehicle travel imposes risks, so *exposure* – total vehicle travel – is a risk factor. It recognizes the additional crashes caused by planning decisions that induce additional vehicle travel, and the safety benefits of vehicle travel reduction strategies such as multi-modal planning, efficient transport pricing, transportation demand management (TDM) programs, and Smart Growth development policies. Since these strategies tend to provide large co-benefits, in addition to safety, the new paradigm supports more comprehensive analysis that considers these impacts. Table 1 compares the old and new safety paradigms.

Table 1 **Comparing the Old and New Traffic Safety Paradigms**

Factor	Old	New
Goal	Make driving safer.	Make transportation systems safer.
Risk measurement	Occupant risks, measured by distance (e.g., occupant deaths per 100,000 million vehicle-miles).	Total risks, including risks to occupants and other road users, measured by distance and per capita.
Solutions considered	Roadway and vehicle design improvements. Graduated licenses and senior driver testing. Seatbelt and helmet requirements. Anti-impaired and distracted driving campaigns.	Walking, bicycling and public transit improvements. Road, parking, fuel and insurance pricing reforms. More connected and complete streets. Smart Growth development policies. Transportation demand management programs. Traffic speed reductions.
Analysis scope	Program costs and traffic safety benefits.	All economic, social and environmental impacts.

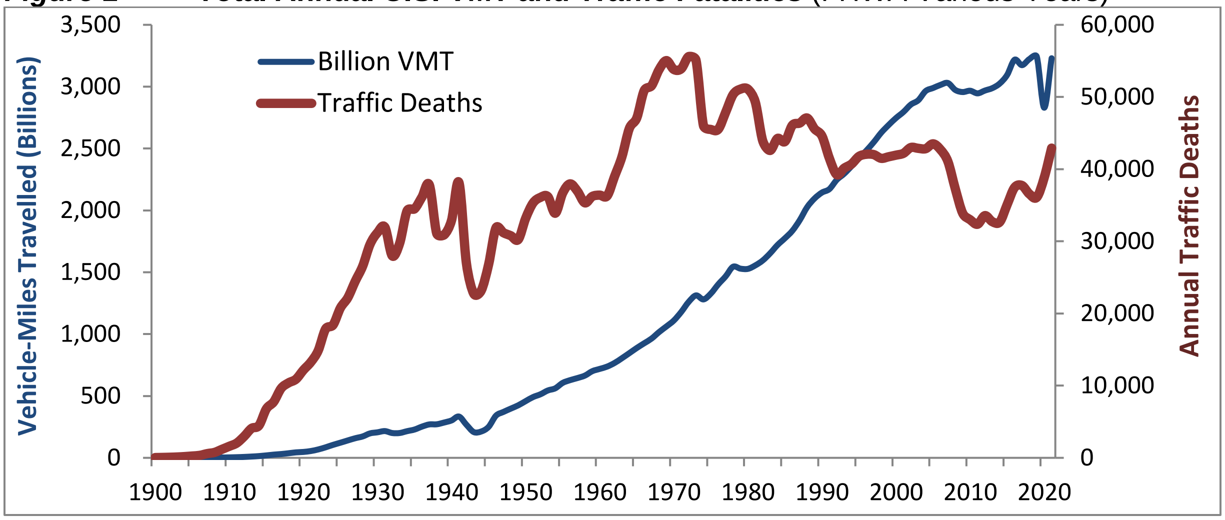
The old and new safety paradigms differ in many ways. The new paradigm considers more impacts and solutions.

This report explores these issues. It describes traffic casualty trends and the need for a new safety paradigm, summarizes recent research on traffic risk factors and innovative safety strategies, evaluates the degree that current safety programs consider these factors, and provides recommendations for implementing new strategies to achieve safety goals. It should be of interest to anybody who wants to identify the most efficient and cost effective ways to improve traffic safety.

Why a New Paradigm?

This section describes why a new approach is needed for traffic safety.

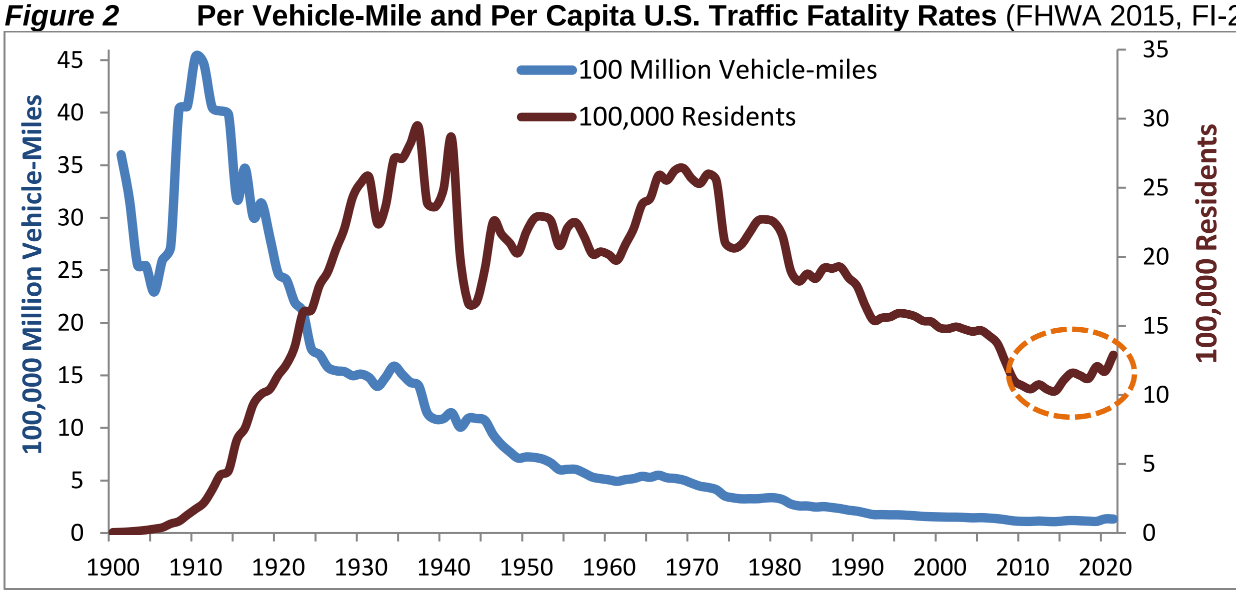
Figure 1 **Total Annual U.S. VMT and Traffic Fatalities** (FHWA Various Years)



Total traffic death peaked in 1973 and subsequently declined, but increased after 2011.

Figure 1 shows U.S. traffic death and vehicle miles travelled (VMT) trends. Vehicle travel increased steadily during the Twentieth Century, but the growth rate slowed after 2000. Total deaths peaked in 1973 and subsequently declined, but increased after 2011. The figure below shows distance-based and per capita traffic fatality rates. These declined for most of the last century but have recently started to rise. This suggests that the most effective traffic safety strategies, such as more protective vehicles, increased seatbelt and helmet use, and anti-impaired driving campaigns, have reached their practical limits and new safety strategies will be required to achieve additional safety gains.

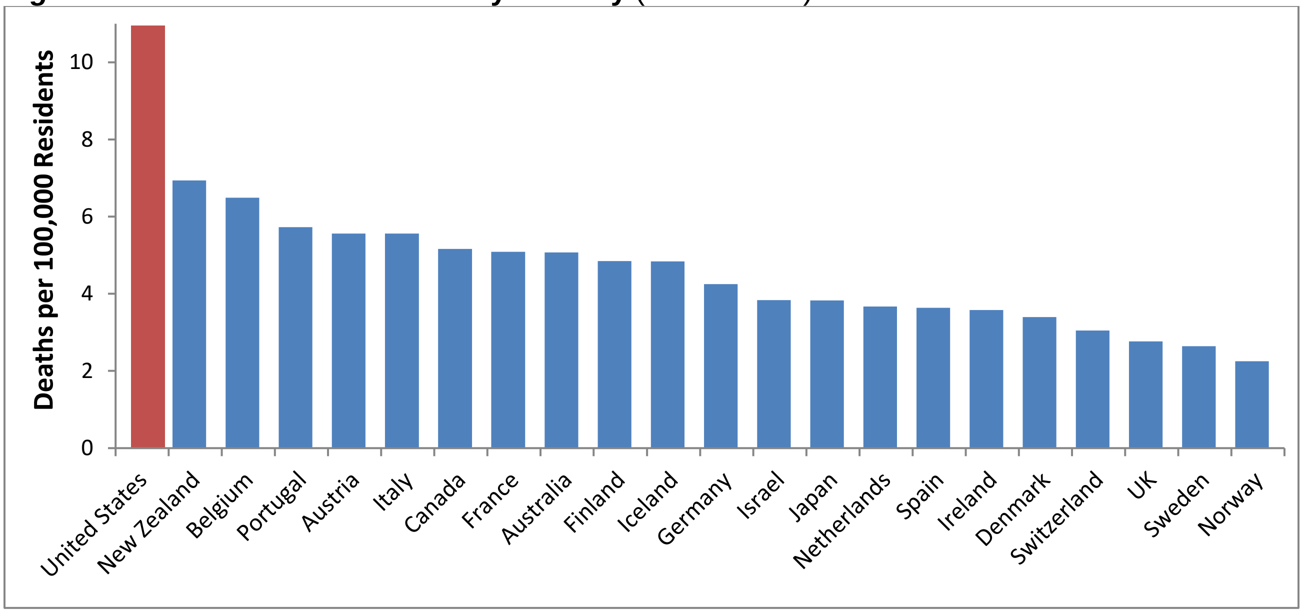
Figure 2 **Per Vehicle-Mile and Per Capita U.S. Traffic Fatality Rates** (FHWA 2015, FI-201)



Traffic fatality rated declined during most of the Twentieth Century, but increased after 2011.

International comparisons indicate that large safety gains are possible. The U.S. has the highest per capita traffic fatality rate among its peers Figure 4. Geographic factors do not explain this: Australia and Canada have lower population densities, and Sweden, Norway and Finland have more extreme weather, yet all have much lower traffic death rates and faster crash rates declines than the U.S. (ITF 2021).

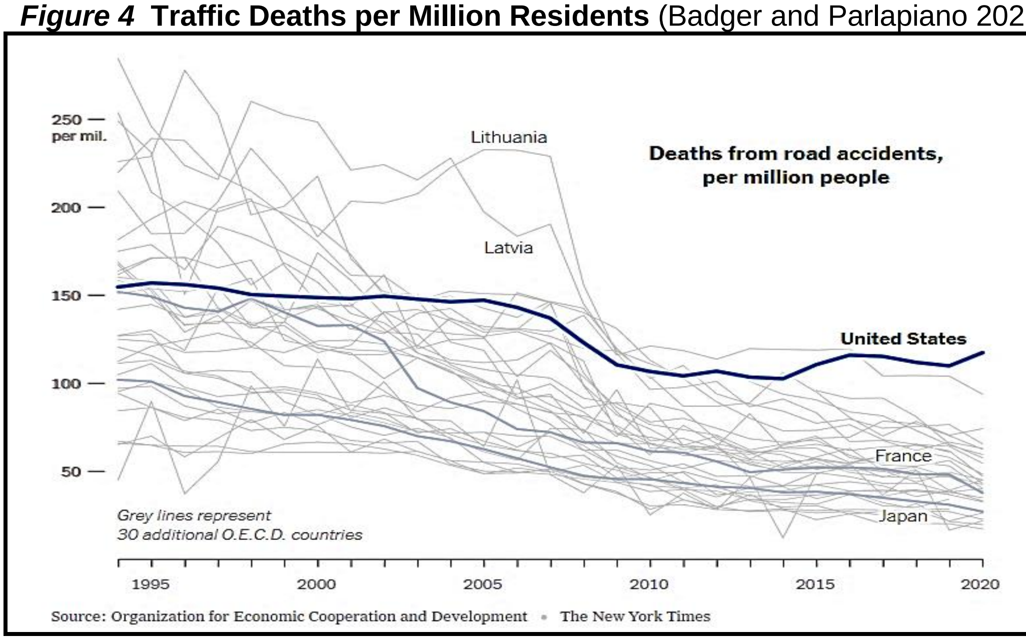
Figure 3 **Traffic Death Rates by Country** (OECD 2015)



The U.S. has, by far, the highest traffic fatality rate among peer countries.

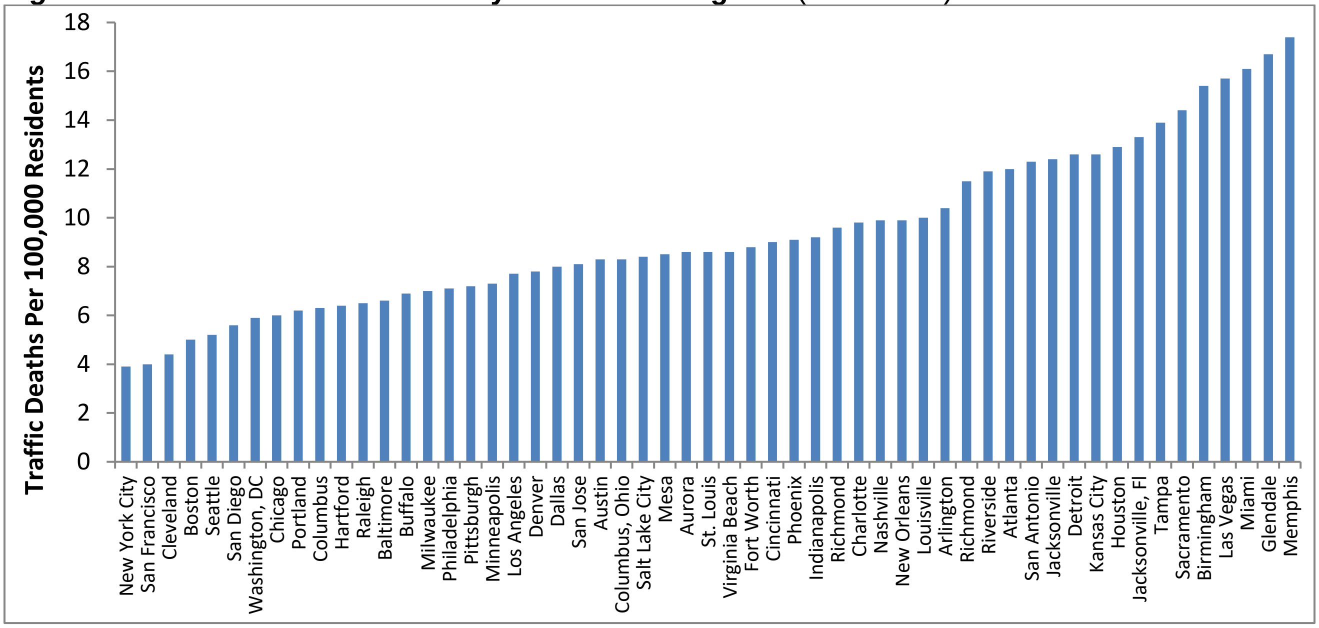
The disparity between the U.S. and peer countries is increasing, as illustrated below.

Figure 4 **Traffic Deaths per Million Residents** (Badger and Parlapiano 2022)



Traffic death rates declined much less in the U.S. than other OECD countries, and are now much higher than peers.

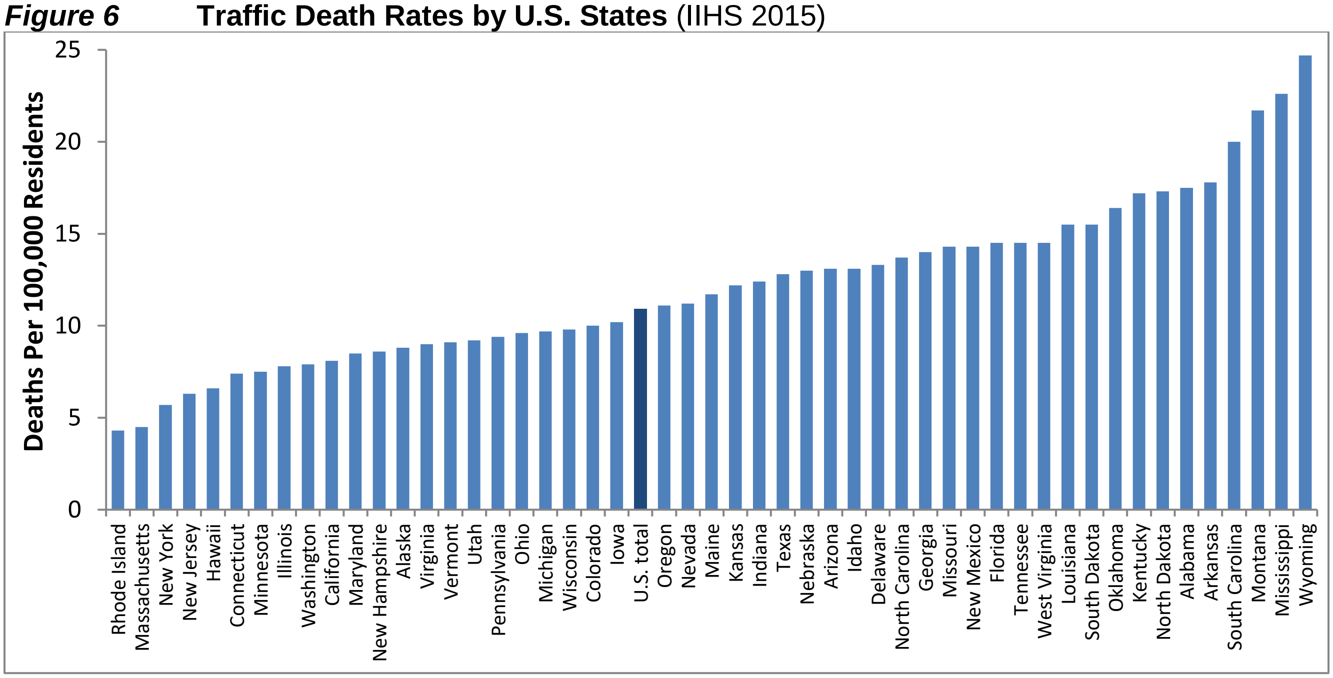
Figure 5 **Traffic Death Rates by U.S. Urban Regions** (CDC 2012)



Crash rates vary significantly between cities, reflecting differences in their transport and land use patterns.

There are similar variations at other geographic scales, as figures 4 and 4 illustrate. For example, Seattle, San Diego and Portland have less than half the crash rates of Atlanta, Houston and Sacramento, and Minnesota, Illinois and Washington have about half the traffic fatality rates of Oklahoma, Kentucky and South Carolina.

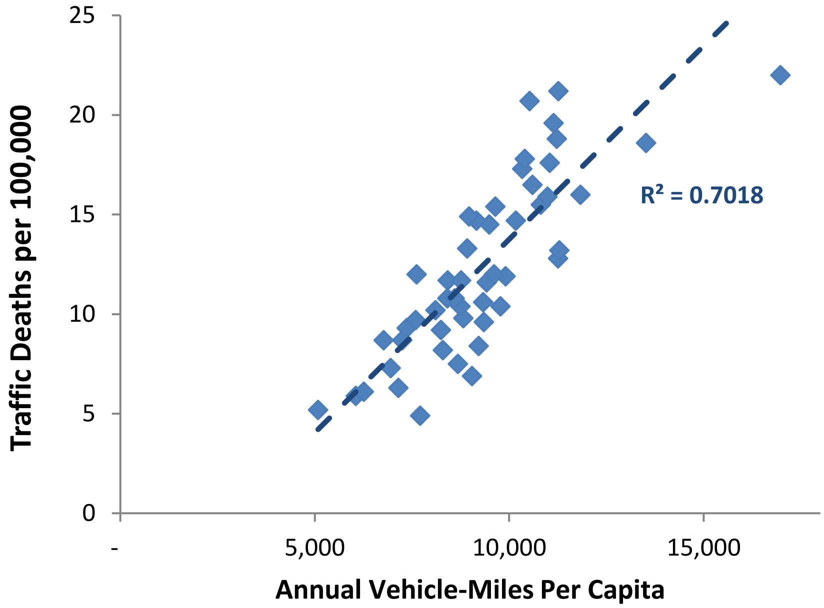
Figure 6 **Traffic Death Rates by U.S. States** (IIHS 2015)



Crash rates vary significantly between U.S. states, reflecting differences in their transport and land use patterns.

What explains these differences? Do drivers in high crash rate areas have more dangerous vehicles or driving conditions? Are their public officials, traffic engineers or drivers less concerned about safety than in lower crash rate areas? Probably not. A better explanation is that residents drive more annual miles at higher speeds than in lower crash rate areas, as illustrated below.

Figure 7 **Traffic Fatalities Versus Mileage for U.S. States** (IIHS 2020)



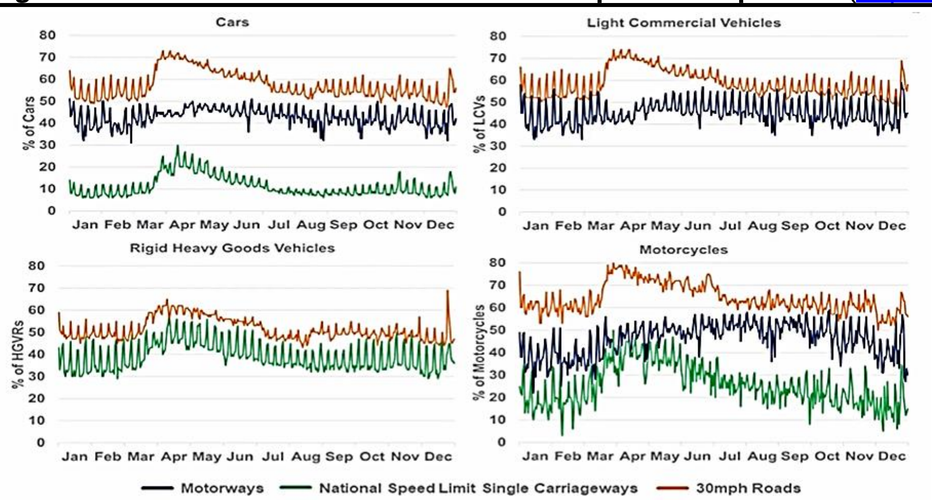
All else being equal, traffic fatality rates increase with annual vehicle-miles per capita. As a result, planning decisions that stimulate vehicle travel tend to increase crashes, and vehicle travel reduction policies tend to increase safety.

COVID-19 Impacts

Although urban living and public transit travel were initially considered to have high contagion risks, once COVID-19 became widespread, infection and death rates were found to be higher in automobile-dependent suburbs and rural areas than in walkable and transit-oriented neighborhoods (Litman 2020).

During 2000, the COVID-19 pandemic reduced U.S. vehicle travel by 13% (Sivak 2021), which significantly reduced total crashes and insurance claims, typically by 15-25% (Carrns 2021), but increased traffic deaths 7% (Shepardson 2021), apparently because reduced congestion increased higher-risk activities such as speeding and impaired driving (Job 2020; Kuntzma 2022; Stiles, et al. 2021). Similar patterns occurred in Britain (Figure 7). This indicates that the relationships between vehicle travel and crashes is complex and can be overwhelmed by other factors such as traffic speed and risky driving.

Figure 8 **UK Pandemic Period Traffic Speed Compliance** (https://bit.ly/3vyNtbp)



The percentage of vehicles exceeding speed limits increased during the 2020 COVID-19 pandemic. This helps explain the increase in crash rates during this period.

(Based on UK DfT Vehicle Speed Compliance Statistics. Slide by Richard Owen, Agilysis)

However, the U.S.'s increase in crash fatalities was an anomaly. In most countries traffic fatalities declined during 2020. The study, *Global Impact of COVID-19 Pandemic on Road Traffic Collisions* (Yasin, Grivna and Abu-Zidan 2021) found that, of 42 countries analyzed, in 2020 road death *declined* in 33 (25%+ in 5 countries, 15–24% in 13 countries, and 1-15% in 15 countries), and *increased* in 10 (Albania, Canada, Estonia, Finland, Ireland, Latvia, Luxembourg, Montenegro, Switzerland and USA) compared with previous years. Similarly, the International Transport Forum's *Road Safety Annual Report 2021: The Impact of Covid-19* (ITF 2021) found that of 34 countries with valid data, during 2020 traffic volumes declined on average -12.2% and road deaths declined 8.6% compared with previous years. Road deaths decreased on all types of roads including motorways (-19.9%), rural roads (-15%) and urban streets (-10%). The reductions in death were particularly large for young (under 17 years) and elderly (75+ years), with almost a quarter fewer fatalities. Fatality rates per billion vehicle-kilometres decreased slightly for the eleven countries that publish mobility data, with significant variations. For instance, crash rates declined 17% in Sweden but increases 12% in the Netherlands. This indicates that the relationships between vehicle travel and crashes is complex and can be overwhelmed by other factors such as traffic speed and risky driving.

Autonomous Vehicle Impacts

Many people hope that new technologies will greatly reduce traffic risks. Proponents claim that since human errors contribute to 90% of crashes, autonomous vehicles will reduce crashes by 90% (Keeney 2017; Kok, et al. 2017). However, more objective experts predict that these technologies will take longer to develop, cost more, and introduce more risks than advocates claim (Ackerman 2017; Litman 2022; Zipper 2021). The safety benefits of technologies were often overestimated because travellers tend to take more risks when they feel safer, called *offsetting behavior*, *risk compensation* or a rebound effect (Chirinko and Harper, 1993; Rudin-Brown and Jamson 2013). For example, *high mounted stop lamps* were predicted to prevent 35% of rear-ending vehicle accidents, but once they become common this declined to just 4% (NHTSA 1998). Optimistic safety predictions tend to overlook the new risks autonomous vehicle technologies introduce (Hsu 2017; Koopman and Wagner 2017):

- *Hardware and software failures.* Autonomous vehicles require complex electronic systems and software. Operating a vehicle in traffic is demanding, and small failures - a false sensor, distorted signal or software error - can have catastrophic results. Self-driving vehicles will certainly have errors that contribute to crashes; the question is how frequently compared with human drivers.
- *Malicious hacking.* Self-driving technologies can be manipulated for amusement or crime.
- *Increased risk-taking.* When road users feel safer they tend to take additional risks, what safety experts call *offsetting behavior* or *risk compensation*. For example, if they expect self-driving vehicles to be very safe, fewer passengers may wear seatbelts and other road users may be less cautious.
- *Platooning risks.* Many potential benefits, such as reduced congestion and pollution emissions, require *platooning* (vehicles operating close together at high speeds on dedicated lanes). This will introduce new risks such as human drivers joining platoons, and more multiple-vehicle crashes.
- *Increased total vehicle travel.* The additional convenience and comfort of autonomous vehicles could increase total vehicle travel, and therefore cause additional risk exposure.

As a result, autonomous vehicles will probably reduce crashes much less than 90%. Their net safety benefits will depend on how they are programmed and used, and public polices such as road pricing and regulations. For example, to maximize mobility they can be programmed to operate at higher speeds, take greater risks, and have dedicated platooning lanes, but to maximize safety they should be programed to drive slower and be more cautious in unexpected situations (causing delays as they wait for human instructions). Congestion pricing and high-occupant vehicle lanes can encourage sharing of autonomous vehicle trips which can reduce total vehicle travel and therefore crashes.

Some experts acknowledge that autonomous vehicles may provide relatively modest safety gains. One major study concluded that, “Early research suggests that AV technologies have *promise* in mitigating traffic crashes, but their safety benefits are not guaranteed” (TRB 2019). Groves and Kalra (2017) argue that autonomous vehicle deployment is justified even if they only reduce crash rates 10%, but acknowledge that safety impacts depend on how this technology affects total vehicle travel. For example, if autonomous vehicles reduce per-mile crash rates 10% but increase vehicle travel 12%, total crashes, including risks to other road users, will increase.

This suggests that even if autonomous vehicles become common and affordable, and reduce distance-based crash rates, the new safety paradigm will still be justified: it will be important to consider how public policies affect total motor vehicle travel and therefore crash exposure, and to recognize the safety benefits of vehicle travel reduction strategies, even if they apply to autonomous vehicles.

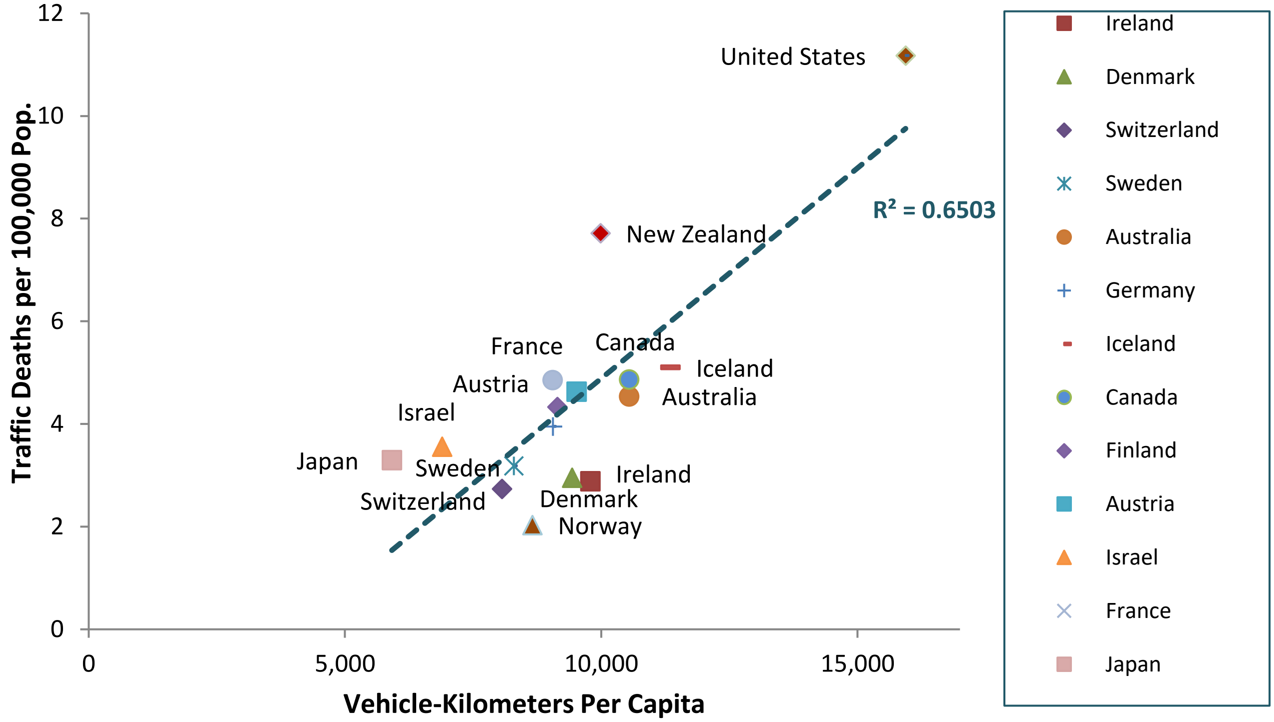
New Understanding of Traffic Risk

This section describes new research concerning how transport and land use factors affect crash risks. Also see Hamidi, Ewing and Grace (2016); ITF (2019); Litman and Fitzroy (2016); and Welle et al. (2018).

Total Vehicle Travel

Although many demographic, geographic and economic factors affect traffic death and injury rates, all else being equal, that is, for a given group or area, traffic casualties tend to increase with vehicle travel. For example, among higher-income countries for which annual vehicle travel is available, per capita crash rates tend to increase with per capita vehicle travel, as illustrated in Figure 8. The United States' per capita traffic fatality rate is higher than peer countries, as is its annual mileage. The 0.6503 R-square value indicates a strong statistical relationship between mileage and fatality rates.

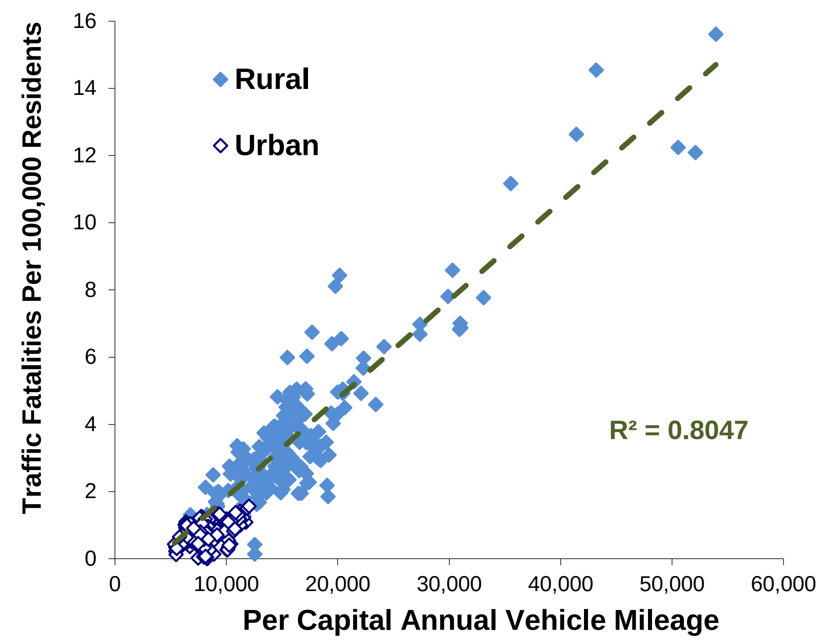
Figure 9 **Per Capita Traffic Deaths versus Vehicle-Travel, 2018** (BITRE 2018)



International data show that per capita traffic fatalities tend to increase with annual vehicle-kilometers.

This pattern occurs at other geographic scales. The figure below shows that per capita traffic deaths increase with per capita annual mileage among U.S. states, particularly in rural areas.

Figure 10 **Vehicle Mileage Versus Traffic Fatalities in U.S. States** (FHWA 1993-2002 data)

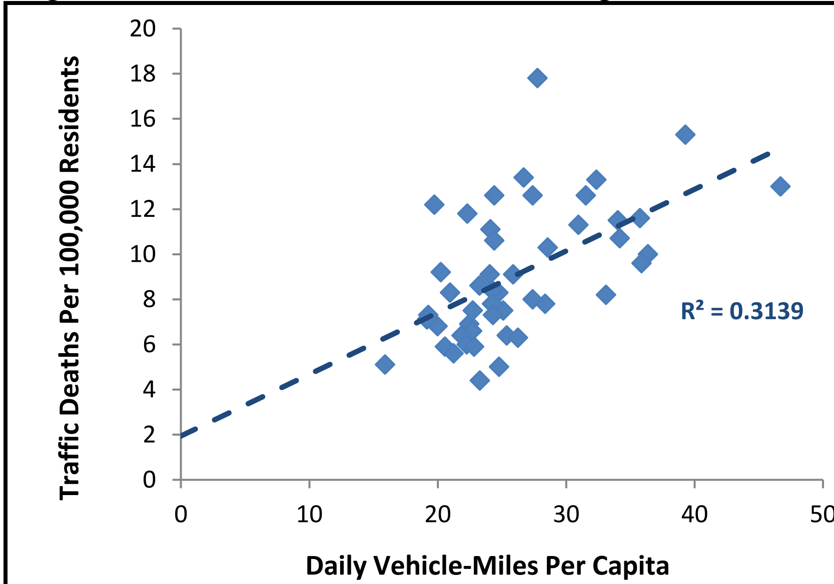


This figure shows various year's traffic fatality and annual mileage rates for urban and rural portions of U.S. states.

A state's per capita traffic death rate tends to increase with per capita vehicle travel, particularly in rural areas.

The figure below shows that per capita traffic death rates tend to increase with per capita annual vehicle-miles among U.S. urban regions. Other studies find similar patterns within urban regions: traffic casualty rates are much lower in compact, multi-modal neighborhoods than in sprawled, automobile-dependent areas (Ewing and Dumbaugh 2009; Ewing and Hamidi 2014; Marshall, Ferenchak and Janson 2024; Welle, et al. 2015 and 2018).

Figure 11 **Traffic Deaths Versus Mileage for U.S. Urban Regions** (FHWA and CDC data)



Per capita traffic fatality rates tend to increase with per capita vehicle-miles in U.S. Metropolitan regions.

A major epidemiological study evaluated factors that affect per capita crash casualty rates in a sample of 1,632 global cities with a total of 2.2 billion residents, equivalent to approximately 31% of the world's population (Thompson, et al. 2020). The researchers categorized cities into nine types (high transit, motor city, intense city, large block, cul de sac, checkerboard, irregular, sparse and informal) based on various urban design factors. Their results indicate that the poorest performing city types had about twice the regional traffic casualty rates as the best performing cities. The best performing city types featured more rail transit combined with denser road networks and smaller city blocks which tend to reduce vehicle travel and traffic speeds.

These studies reflect simple correlations that may overlook confounding factors related to vehicle travel and risks. More sophisticated analyses that account for various demographic, geographic and economic factors show statistically-strong positive relationships between mileage and traffic deaths. For example, Ahangari, Atkinson-Palombo and Garrick (2017) used annual data from the U.S. between 1997 and 2013 to capture the effect of seven factors that influence traffic risks: exposure, travel behavior, socioeconomics, macroeconomics, safety policies, and mitigating factors such as health care. Their results indicate that *Vehicle Miles Traveled* and *Vehicles per Capita*, have the strongest impact on per capita traffic fatality rates. Similarly, using data that accounts for various geographic and demographic factors from 147 urbanized areas in the United States, Yeo, Park and Jang (2015) found that each 1% increase in per capita VMT is associated with a 0.549% increase in traffic deaths. Similarly, comprehensive analysis using 2010 U.S. data, Ewing, Hamidi and Grace (2016) found that, normalizing for other factors, each 1% increase in VMT is associated with 0.3% increase in per capita traffic deaths.

The study, *Residential Accessibility's Relationships with Crash Rates Per Capita*, (Merlin, et al. 2020) found that in Knoxville, TN, per capita crash rates are lower in accessible neighborhoods with less per-capita vehicle miles, but this is partly offset if those areas have heavy through-traffic which tends to increase total (including pedestrian and bicyclist) crash casualty rates.

A study by Ralph Buehler and John Pucher, "The Growing Gap in Pedestrian and Cyclist Fatality Rates Between the United States and the United Kingdom, Germany, Denmark, and the Netherlands, 1990–2018," (Buehler and Pucher 2021) found that U.S. pedestrian fatalities per km were 5-10 times higher, and bicyclist fatalities 4-7 times higher, than in peer countries. They found that the gap in fatality rates between the U.S. and the other countries continued to grow over the time period, especially between 2010 and 2018 when pedestrian and cyclist fatalities per km actually grew by 17% and 33% respectively, while fatality rates either fell or remained stable in the other countries. They concluded that low pedestrian and bicycle crash rates in European countries reflect:

- Better walking and cycling infrastructure.
- Fewer vehicle km travelled.
- Lower urban speed limits.
- Better enforcement of laws against speeding, drink driving and smartphone use while driving.
- Smaller and less powerful personal motor vehicles.

A major New Zealand study (Deloitte 2019) concluded that reductions in the country's crash rates from 1990 to 2012 resulted from improvements in vehicles (45%), better driver behavior (36%) and better roads (19%), but these gains were offset by increased vehicle-kilometres; it found that a 1% increase in VKTs is associated with a 2.5% increase in crashes.

A major study by the U.S. National Academy of Sciences, *Identification of Factors Contributing to the Decline of Traffic Fatalities in the United States from 2008 to 2012* (Blower, et al. 2020), investigated factors that affect crash risks and contributed to a 25% decline in traffic deaths during this time period. The analysis indicates that total vehicle travel stayed relatively steady, but crash rates per vehicle-mile declined significantly during economic recessions. The evidence suggests that recessions tend to reduce driving by high-risk groups, particularly younger drivers. The study found that people under 26 years of age accounted for almost 48% of the decline in fatalities. Other higher risk driver groups may also contribute to the decline but are more difficult to identify in crash statistics. Detailed statistical analysis found that the three most significant contributors to the traffic fatality decline were the substantial increase in teen and young adult unemployment, reductions in median household income, and the reduction GDP per capita. Declines in rural vehicle travel and beer consumption, plus stricter DUI laws also contributed. State highway spending and changes in safety belt use rates and fuel prices were not significant contributors because they changed little over the period.

A detailed study of 144 mid-size U.S. urban regions by Frederick, Riggs and Gilderbloom (2017) found powerful statistical evidence that residents of more auto-dependency American cities can have harmful health effects, including higher traffic casualty rates than in cities where a greater portion of trips are by walking, bicycling and public transit. Adults living in modally diverse cities are more likely to live longer and better, and their children begin life in a better physical condition.

Since about two-thirds of casualty crashes involve multiple vehicles, and crash rates increase with traffic density (vehicles per lane-mile), changes in total vehicle travel can provide proportionately larger casualty changes, particularly in higher traffic density areas (Vickrey 1968). Edlin and Karaca-Mandic (2006) found that each 1% increase in total vehicle travel increases total crash costs by substantially more than 1% in virtually all U.S. states, and by 3.3- 5.4% in dense states such as California. Described differently, vehicle travel reductions can provide *external* safety benefits by reducing risk to other road users, so people become safer if their neighbors drive less.

Vision Zero is a policy goal to eliminate traffic deaths and serious injuries. It takes a public health approach to collisions, which assumes that they are a preventable health threat. It places responsibility for road safety on transport planning, system designers, described as "Embracing system accountability instead of touting individual responsibility" (Job 2020). Vision Zero plans generally include a combination of targetted safety programs, traffic speed reduction and vehicle travel reduction strategies (Kim 2022; Kim, Muennig and Rosen 2017).

Quality of Transport Options

The quality of non-auto mobility options significantly affects crash rates (Stimpson, et al. 2014).

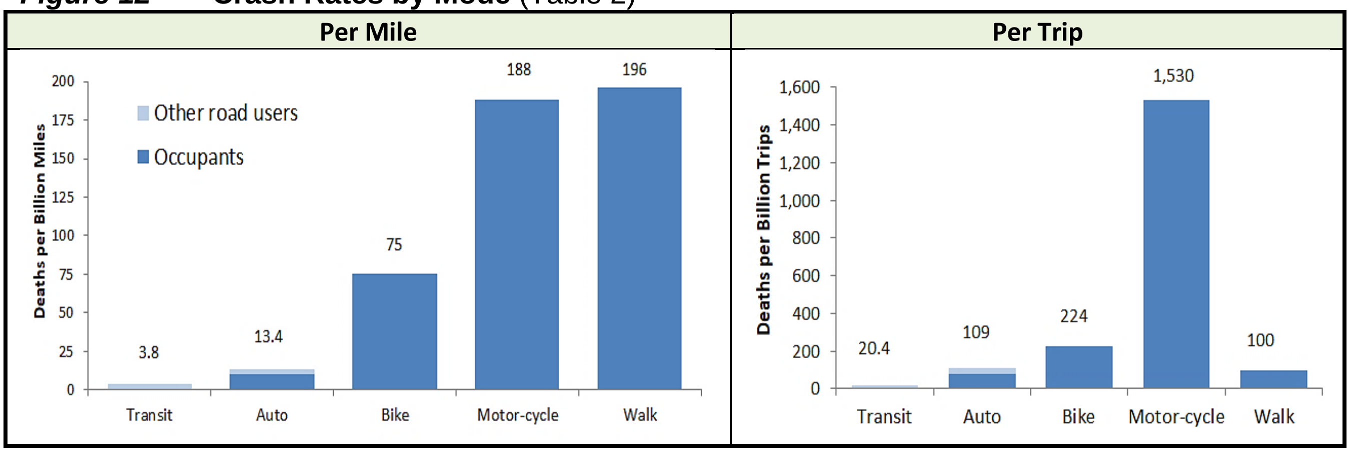
Table 2 **2009 Crash Rates by Mode** (NHTS and NHTSA data)

	Totals	Transit	Auto	Bike	Motorcycle	Walk
Occupant fatalities[1]	35,978	48	26,408	628	4,286	4,109
Other road user fatalities[1, 2]		178	9,023	NA	NA	NA
Personal travel mode share[3]		1.9%	83%	1.0%	1.0%	10.4%
Personal trips (billions)[3]	392	11	325	2.8	2.8	41
Average miles per trip[3, 4]		5.5	10	3	10	0.5
Total miles (billions)[5]	2,976	60	2,645	8.4	22.8	21
Occupant deaths per billion miles	*12.0*	*0.8*	*10.0*	*75*	*188*	*196*
Other deaths per billion miles	*0.1*	*3.0*	*3.4*	*0*	*0*	*0*
Total deaths per billion miles	*12.1*	*3.8*	*13.4*	*75*	*188*	*196*
Occupant deaths per billion trips	*92*	*4.4*	*81*	*224*	*1,530*	*100*
Other deaths per billion trips	*NA*	*16*	*28*	*NA*	*NA*	*NA*
Total deaths per billion trips	*92*	*20.4*	*109*	*224*	*1,530*	*100*

This table calculates internal (occupant) and external (other road user) death rates for various modes.

Table 2 and Figure 12 show per mile and per trip crash rates by mode. More than three-quarters of transit fatalities involve other road users, but even considering these, transit travel had the lowest total death rate. About a quarter of automobile deaths involve other road users. Bike, motor-cycle and walk have relatively high death rates per mile but impose little risk on others, and since walk and bike trips tend to be shorter than motorized trips, their per trip crash rates are similar to auto travel (ABW 2016).

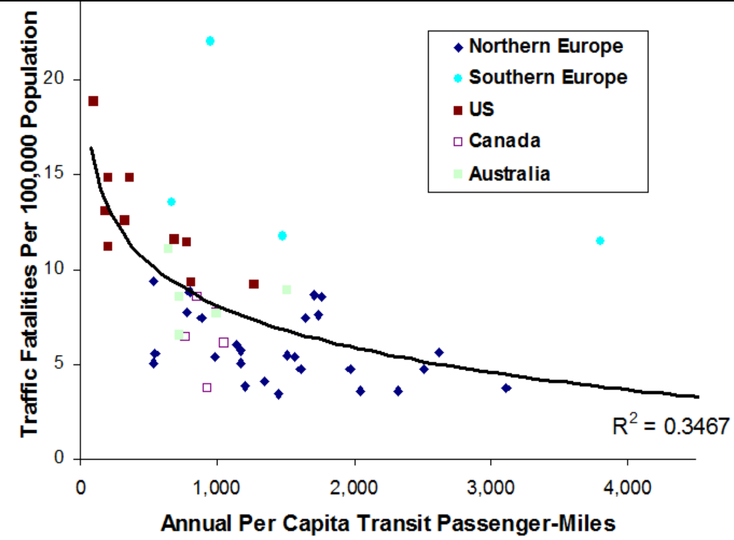
Figure 12 **Crash Rates by Mode** (Table 2)



Public transit has the lowest total (occupant and external) casualty rate. Auto (cars and light trucks) have moderate crash rates, about a quarter of which is external. Bike and walk have relatively high per mile crash rates, but their trips are short and impose little external risk, so their total per trip death rates are not much higher than driving.

[1] www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_02_01.html_mfd.
[2] www.apta.com/resources/statistics/Documents/FactBook/2016-APTA-Fact-Book.pdf.
[3] http://nhts.ornl.gov/2009/pub/stt.pdf. Excludes commercial vehicle travel.
[4] www.apta.com/resources/statistics/Documents/FactBook/2016-APTA-Fact-Book.pdf.
[5] www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_35.html

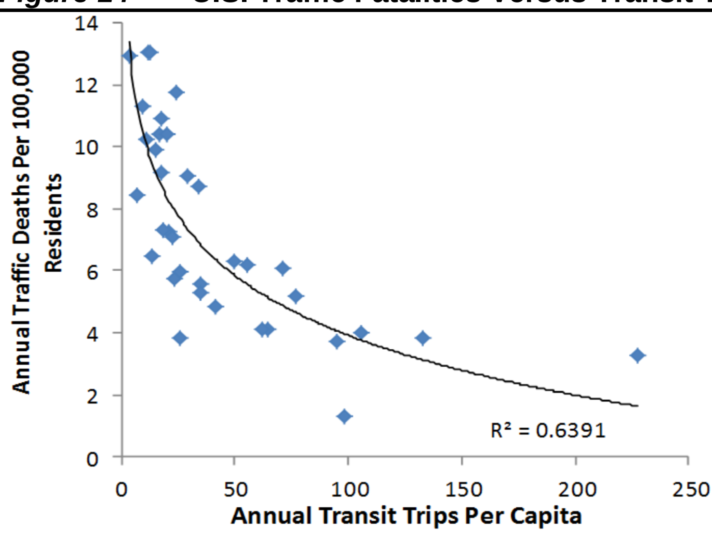
Figure 13 **Traffic Fatalities Vs. Transit Travel** (Kenworthy and Laube 2000)



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

Figure 14 and 15 illustrate the relationship between per capita transit travel and death rates. U.S. urban regions where residents average more than 50 annual transit trips have about half the fatality rates as regions where residents take fewer than 20 annual trips. This represents a small increase in transit mode share, from about 1.5% to 4%, which alone cannot explain the large safety gains. This suggests that many factors that encourage transit travel, such as compact development, walkability and reduced parking supply, also increase traffic safety.

Figure 14 **U.S. Traffic Fatalities Versus Transit Trips** (FTA 2012; NHTSA 2012)

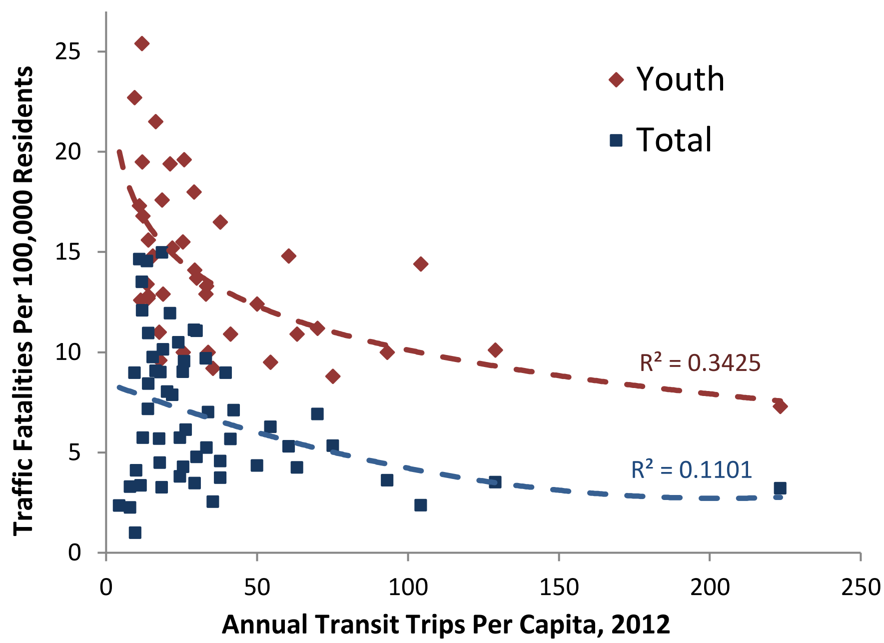


This graph illustrates the relationship between per capita transit ridership and total (pedestrian, bicyclist, automobile occupant and transit passenger) traffic fatalities for 35 large North American cities.

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

The statistical relationship between transit ridership and traffic safety is particularly strong for youths, age 15-25, as illustrated below, which suggests that many young people want to reduce their driving and associated risk, but can only do so if they have adequate alternatives.

Figure 15 **Youth and Total Traffic Fatality Rates Compared to Transit Travel** (CDC 2012)

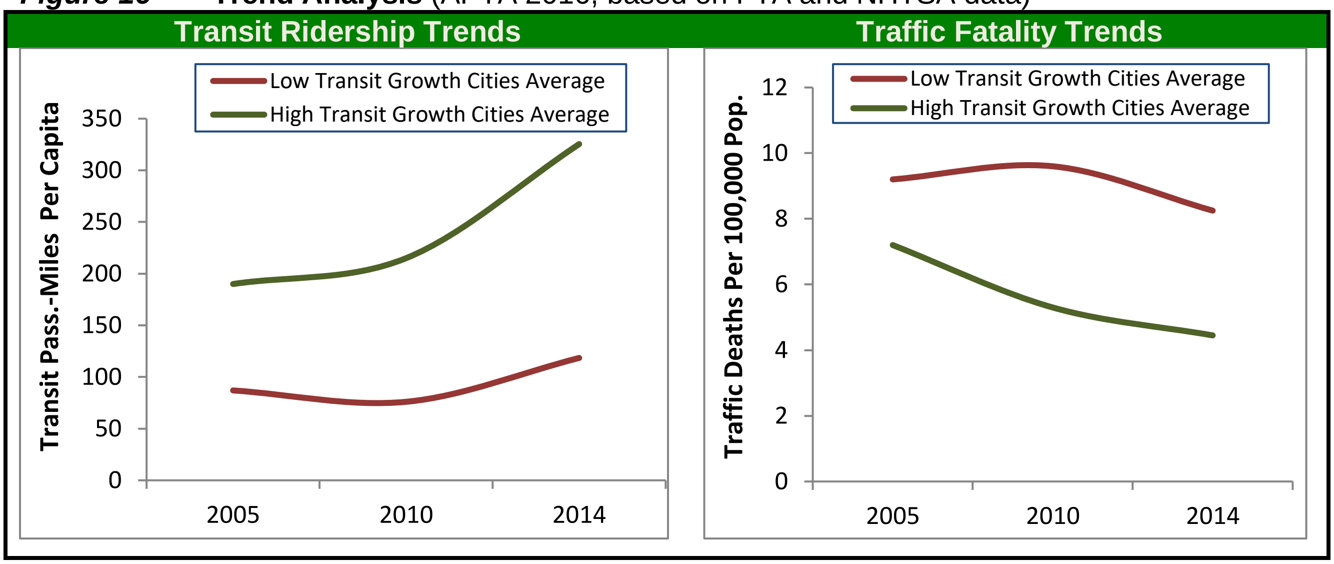


Youths (15-25 years old) have about twice the traffic fatality rates as the total population average, and both youth and total fatality rates tend to decline with increased transit ridership.

This statistical relationship is particularly strong for youths. This suggests that many young people are willing to reduce their driving and associated risk, but can only do so if they have adequate alternatives

Many studies show that transit improvements tend to increase transit safety (Duduta, Adriazola-Steil and Hidalgo 2013; Litman 2016; Truong and Currie 2019) The figures below compares transit ridership and total traffic fatality rates between four high-transit-growth cities (Denver, Los Angeles, Portland and Seattle, green line) and four low-transit-growth cities (Cleveland, Dallas, Houston and Milwaukee, red line). Cities with more transit growth had much larger crash declines (38% versus 10%), indicating that increasing transit ridership increases safety for all travellers.

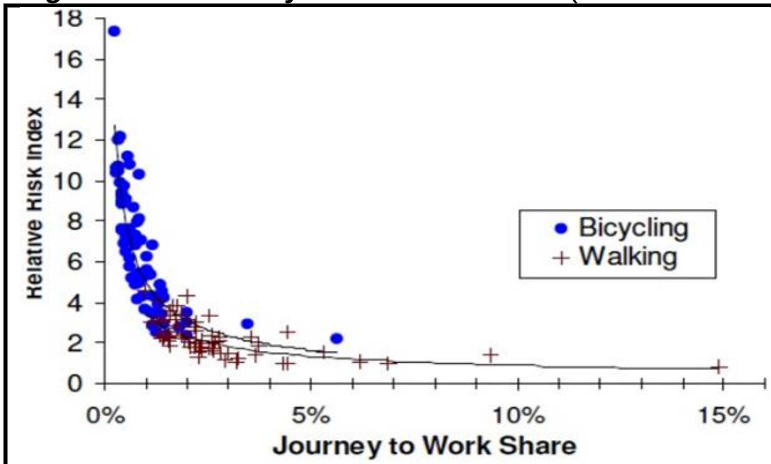
Figure 16 **Trend Analysis** (APTA 2016, based on FTA and NHTSA data)



High-transit-growth cities experienced far greater safety gains than low-transit-growth cities or national trends. This suggests that pro-transit policies can significantly increase safety for all travellers.

Because active modes (walking and bicycling) have high per-mile or -kilometer casualty rates, some researchers to conclude that “a shift from passenger vehicle travel (lower risk) to nonmotorized travel (higher risk) could result in an overall increase in the numbers of people killed in traffic” (Beck, Dellinger and O'Neil 2007). However, numerous studies find that both active mode and total (all mode) crash casualties tend to decline as active travel increase in an area, an effect called *safety in numbers* (ABW 2016; Castro, Kahlmeier and Gotschi 2018; ECF 2012; ITF 2019; NACTO 2016), illustrates below.

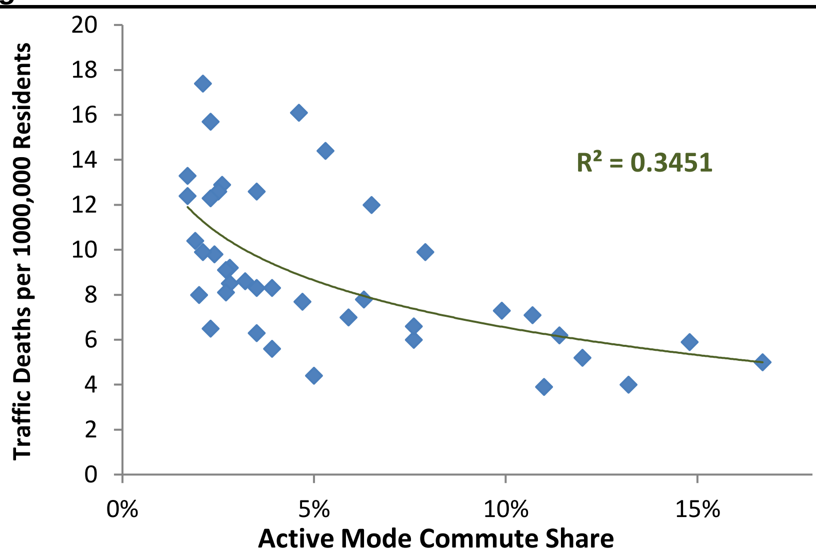
Figure 17 **Safety in Numbers Effect** (Jacobson 2003)



Data from 68 California cities indicates that as walking and cycling commute mode share increases, pedestrian and bicycling casualty rates tend to decline significantly: a few percentage point increase in active mode share is associated with proportionately larger reductions in injury rates.

US urban regions with active mode shares over 10% average about half the per capita traffic fatality rates as those with active mode shares under 5% , as illustrated below. Comprehensive analysis by Marshall, Ferenchak and Janson (2018) and Marshall and Ferenchak (2024) found that total traffic fatality rates in U.S. cities decline with increased bicycling mode shares. Murphy, Levinson and Owen (2017) found that in 448 Minneapolis city intersections, individual pedestrians’ motor vehicle crash risk declines as pedestrian traffic increases. Tasic and Porter (2018) find that, all else being equal, expanding sidewalks in an area tends to reduce non-motorized crash rates.

Figure 18 **Active Commute Mode Share and Traffic Deaths** (Census and CDC Data)



Total per capita traffic death rates tend to decline as active (walking and cycling) commute mode shares increase in U.S. urban regions.

This and other research indicate that more active travel tends to increase overall traffic safety.

Various factors help explain the large total crash reductions associated with more active and public transport (Marshall and Ferenchak 2019):

- *Safer travel conditions.* Both active safety and travel tend to increase with improved sidewalks, crosswalks, cycling facilities, streetscaping, traffic speed control and education programs.
- *Complementary factors.* Many factors that encourage walking and cycling, such as connected streets, higher parking and fuel prices, and compact development, also tend to increase traffic safety.
- *Reduced total travel.* Residents of more walkable and bikeable communities tend to drive less, reducing risk exposure. Shorter active mode trips often substitute for a longer automobile trip, for example, walking or biking to local shops rather than driving to regional shopping centers. Improving walking and cycling conditions reduces chauffeuring trips. Since most public transit trips involve walking and cycling links, improving their conditions can increase transit travel.
- *Reduced risk to other road users.* Pedestrians and bicyclists impose less risk on other road users.
- *New users may be more cautious than current users.* Walkers and cyclists who observe traffic rules and use protective gear (such as helmets and lights) can have lower than average casualty rates.
- *Increased driver caution.* As walking and bicycling increases in an area, drivers are likely to become more aware and cautious.
- *Less high-risk driving.* Improving non-auto modes allows young, old, impaired and distracted travellers to reduce driving, increasing the effectiveness of safety programs such as graduated licenses, senior driver testing and anti-impaired and distracted driving campaigns. For example, ride-hailing and public transit availability can help reduce post-drinking driving (Greenwood and Wattal 2015; Jackson and Owens 2011).
- *Stronger traffic enforcement*. In automobile dependent communities, courts are less likely to restrict licensure and confiscate vehicles of high-risk drivers (Wilson 2022).

Relatively modest investments can increase active mode safety and travel. For example, the U.S. Federal Highway Administration's Nonmotorized Transportation Pilot Program, which invested about $100 per capita in pedestrian and cycling improvements in four typical U.S. communities, caused walking trips to increase 23% and cycling trips to increase 48%, mostly for utilitarian purposes (FHWA 2014). Despite this increase in exposure, pedestrian fatalities declined 20% and bicycle fatalities 29%, causing per-mile fatality rates to decline 36% for pedestrians and 52% for bicyclists.

Analysis by Frank, et al. (2011) indicates that increasing an area's sidewalk coverage ratio from 0.57 (sidewalks on both sides of approximately 30% of streets) to 1.4 (sidewalks on both sides of 70% of streets) will reduce vehicle travel 3.4% and carbon emissions 4.9%. Guo and Gandavarapu (2010) found that completing a typical U.S. community's sidewalk network increases average per capita non-motorized travel 16% (from 0.6 to 0.7 miles per day) and reduce automobile travel 5% (from 22.0 to 20.9 vehicle-miles), representing about 12 miles of reduced driving for each mile of increased non-motorized travel. Similarly, Wedderburn (2013) found that in New Zealand cities, each additional daily transit trip by driving age (18+ years) residents is associated with increases of 0.95 walking trips and 1.21 walking kilometers, and two fewer daily car trips. Similarly, U.S. cities that expanded their bicycle lane networks tend to experience increased cycling activity and reduce crash rates (NACTO 2016).

Transportation Pricing

Recent studies using various analysis methods and data sets indicate that more efficient transportation pricing, such as road tolls and fuel price increases, reduces traffic casualty rates (Litman 2014). A comprehensive study of 14 industrialized countries found that a 10% gasoline price decline caused road fatalities to increase 2.19% (Ahangari, et al. 2014). Burke and Nishitateno (2015) found that a 10% fuel price increase typically reduces traffic deaths by 3-6%, and estimate that removing global fuel subsidies would reduce approximately 35,000 annual road deaths worldwide.

U.S. studies find similar results. Leigh and Geraghty (2008) estimate that a sustained 20% gasoline price increase would reduce approximately 2,000 annual U.S. traffic deaths plus 600 air pollution deaths. Grabowski and Morrisey (2004 and 2006) estimate that each 10% fuel price increase reduces total traffic deaths 2.3%, with larger decline for drivers aged 15-21. Morrisey and Grabowski (2011) find that a 10% U.S. fuel price increase reduces fatalities by 3.2–6.2% with the largest percentage reductions among 15- to 17-year-old drivers, and a 10% beer tax increase reduces motor vehicle fatalities by 17-24 year old drivers by approximately 1.3%. Studies by Chi, et al. (2010a, 2013 and 2015) indicate that U.S. fuel price increases reduce both per capita and per-mile crash rate, so a 1% reduction in total VMT reduces total crashes more than a 1%, with particularly large reductions in youth and drunken driving crashes.

Green, Heywood and Navarro (2015 and 2020) found that after London's congestion charge was implemented central area weekday traffic accident rates decline significantly. Within the 8-square-mile charging zone, vehicle travel declined 14% and traffic accidents by a third, traffic accident rates declined 22% (from 4.51 to 3.51 per million vehicle-miles), and traffic casualty (injury or death) rates declined 25%, indicating that the higher travel speeds enabled by reduced congestion do not increase crash severity. Crash rates also declined 16% in areas up to four kilometers outside the charging zone, indicating that congestion pricing reduces rather than just shifting traffic and crash locations.

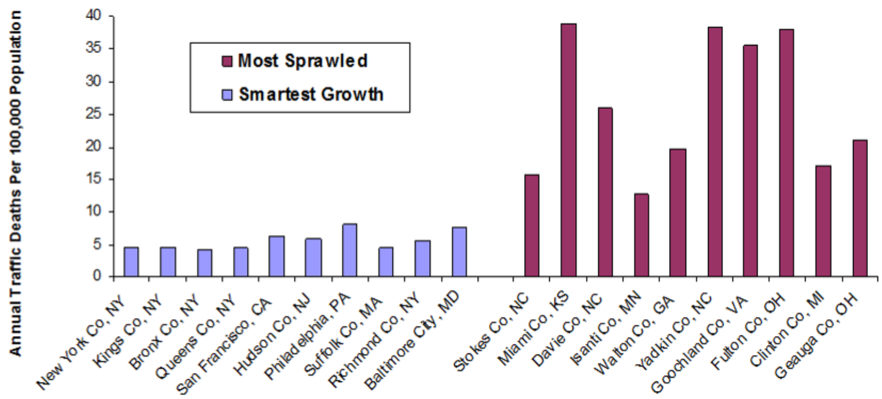
Analyzing three million vehicle-years of insurance claim data, Ferreira and Minike (2010) found that annual crash rates and claim costs tend to increase with annual vehicle travel, and so recommend distance-based pricing. Since per-mile premiums incorporate other risk factors, higher risk motorists have more incentive to reduce their mileage and risks. For example, a low-risk driver who currently pays $360 annual premiums would pay 3¢ per mile and so would reduce mileage about 5%, but a higher-risk driver who currently pays $1,800 annual premiums would pay 15¢ per vehicle-mile and so would be expected to reduce mileage more than 20%. This should provide proportionately large safety benefits (i.e., a 10% reduction in total vehicle travel reduces crashes and claim costs more than 10%).

Some vehicle pricing encourages higher risk driving. Most vehicle costs – depreciation, financing, insurance, registration fees and residential parking – are fixed, motorists pay the same regardless of their annual mileage. This gives vehicle owners an incentive to maximize their driving in order to "get their money's worth" from their large fixed investments. For example, a typical motorist who pays $10 a day in fixed costs and 20¢ per mile in variable costs has no financial incentive to use public transit rather than drive for most trips; the transit fares will equal their marginal vehicle costs and they would feel that their fixed costs are wasted. This is particularly true of higher risk drivers who pay high insurance premiums, often more than $2,000 annually, for unlimited mileage coverage. Similarly, most parking is unpriced – it is financed indirectly through taxes, rents and higher prices for retail goods – which encourages driving. Most jurisdictions impose high minimum parking requirements on restaurants, bars and pubs, which encourages their patrons to arrive and depart by automobile.

Land Use Development Factors

Various studies using a variety of methods and data sets indicate that traffic casualty rates decline with development density (Ahangari, Atkinson-Palombo and Garrick 2017; Ewing, Hamidi and Grace 2016). The following figure illustrates results from one study.

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



Of 280 U.S. counties analyzed, the ten with the lowest sprawl rating have about a quarter the per capita annual traffic fatality rates of the most sprawled counties.

Ewing and Hamidi (2014) found that a 10% increase in their Smart Growth index reduces per capita crash fatality rates 13.8%. Dumbaugh and Rae (2009) analyzed crashes in San Antonio, Texas neighborhoods. Accounting for 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 freeway-mile in 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.
- Each additional arterial-oriented retail or commercial parcel increased crashes 1.3%, and each additional big box store increased crashes 6.6%, while pedestrian-scaled commercial uses were associated with a 2.2% reduction in crashes.
- The number of both young and older drivers were associated with increased total crashes.

Similarly, Garrick and Marshall (2011) found that in California, more compact, connected and multi-modal urban areas have about a third of the traffic fatality rates as those that are more sprawled, automobile dependent. These studies indicate that sprawl-inducing practices such as separated land uses, disconnected road networks, and higher roadway design speeds tend to increase crash casualty rates by increasing vehicle mileage and speeds. Several factors help explain why Smart Growth provides large safety benefits: it reduces total vehicle travel and traffic speeds, improves emergency response, and by improving travel options helps reduce higher-risk driving, by youths, seniors and drinkers. As a result, Smart Growth complements traffic safety strategies such as graduated driver's licenses and anti-drunk-driving campaigns.

Ewing, Hamidi and Grace (2016) found that at the U.S. county level, accounting for various geographic and demographic factors (land use density and mix, block size, roadway connectivity, Walkscore, household size, employment and income, race fuel price and climate factors) dispersed, sprawl land use development is associated with *lower* per capita rates of minor "fender bender" crashes, but significantly *higher* rate of fatal crashes, due to the combination of more total motor vehicle travel and higher traffic speeds in dispersed, automobile-oriented areas. Similarly, accounting for demographic and geographic factors (income, fuel prices and compactness) in 147 U.S. urban regions, Yeo, Park and Jang (2015) found that per capita traffic fatality rates increase with sprawl, apparently due to a combination of increased vehicle travel, higher traffic speeds and slower emergency response. Similarly, Ahangari, Atkinson-Palombo and Garrick (2017) found that traffic death rates decline with urban densities.

Najaf, et al. (2018) find that an urban area's per capita crash rates decline with more job-housing balance, more polycentric design, increased population density and less low-density sprawl, improving transportation network connectivity, more public transit facilities, and grade-separated highways. They conclude that these safety gains result primarily from reductions in per capita vehicle travel and traffic speeds. They estimate that, all else being equal, a 10% increase in urban density or the spatial distribution of employment reduces fatal crash rates by >15%, a 10% increase in network connectivity increases traffic safety 4.13%, and a 10% increase in public transit supply reduces fatalities 8.28%.

Traffic Speeds and Congestion

Extensive research indicates that that higher traffic speeds increase crash frequency and severity, and speed reductions tend to reduce risk, particularly for vulnerable road users (ITF 2018; NACTO 2020). Crash rates tend to be lowest on moderately congested roads (V/C=0.6) and increase with more or less congestion (Marchesini and Weijermars 2010). Crash casualty rates often increase when congestion is reduced (Potts, et al. 2014). For example, the TomTom Traffic Index's five most congested U.S. cities (Los Angeles, San Francisco, Honolulu, Seattle and San Jose) average 5.6 traffic deaths per 100,000 residents, about half the 10.2 fatality rate of the five least congested cities (Richmond, Birmingham, Cleveland, Indianapolis and Kansas City). Since per capita traffic deaths tend to increase with per capita vehicle travel, roadway expansions that induce additional vehicle travel tend to increase traffic casualties (Luoma and Sivak 2012). One study estimated that the increased crash costs that result from reduced congestion offset 5-10% of congestion reduction benefits (Wallis and Lupton 2013).

Transportation Demand Management Programs

Transportation Demand Management (TDM) programs include Commute Trip Reduction (CTR), freight transport management, parking management and mobility management marketing (Peterson 2017; VTPI 2016). Their impacts vary depending on conditions. For example, commute trip reduction programs typically reduce affected vehicle travel 5-15% if they only provide information and encouragement, and 10-30% if they include financial incentives such as parking pricing or cash out (Kuzmyak, Evans, and Pratt 2010). Voluntary Travel Behavior Change (VTBC) programs typically increase use of non-auto modes by 5-10%, and provide equal or larger motor vehicle travel reductions (CARB 2013).

Education and Promotion Campaigns

Many governments sponsor traffic safety campaigns that rely primarily on education and promotion. They tend to be uncontroversial, since they are relatively inexpensive and do not require behavior change, but their effectiveness tends to be modest. The National Highway Traffic Safety Administration's *Countermeasures That Work* report gives education campaigns a minimum one-star rating indicating "limited or no high-quality evaluation evidence" of their effectiveness.

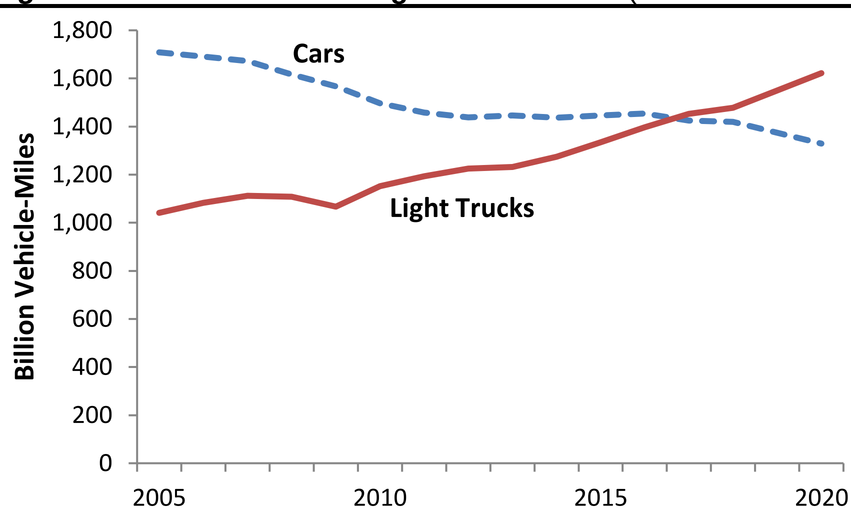
> "Thoughtfully designed and implemented, education programs can and do induce safer travel behaviors, especially if they target a specific audience with new and actionable information. But all too often, education campaigns reiterate messages people already know, like the dangers of speeding or texting while driving, or emphasize humor or fear, which generally fails to shift behavior. Worse, they put the ultimate onus for safety on the individual, sapping resources that could go toward more systemic solutions. (Zipper 2022).

Vehicle Design

Traffic safety analysis often focuses on the risks travellers bear while ignoring the risks they impose. For example, the Insurance Institute for Highway Safety (IIHS) and the National Highway Traffic Safety Administration (NHTSA) rate vehicle occupant protection and compare fatality rates between vehicle models (Tucker 2023. This implies that safety increases with vehicle size and weight. The IIHS states, "Smaller, lighter vehicles generally offer less protection than larger, heavier ones. There is less structure to absorb crash energy. People in lighter vehicles also experience higher crash forces when struck by heavier vehicles. If safety is a major consideration, pass up very small, light vehicles." (IIHS 2023).

Such analysis encourages motorists to purchase larger vehicle to protect themselves, ignoring the additional risk they impose on others, leading to an arms race that increases total traffic risk. If larger, heavier vehicles actually increased overall safety total U.S. traffic deaths would have declined as light trucks and SUVs became more common between 2008 and 2020, and would be lower in rural areas where vehicles tend to be larger, but that does not occur. This indicates that the increased safety larger vehicles provide to occupants is offset by the increased risk they impose on others (Davis 2021).

Figure 20 **Cars Versus Light Truck Travel** (Davis and Boundy 2022, Tables 4.1, 4.2)



If overall safety increased with vehicle size total crashes should have declined in the U.S. between 2005 and 2020 as light trucks became more common in the vehicle fleet, but total traffic deaths increased during much of this period, indicating that safety gains to those vehicle occupants were more than offset by increased risk to others.

Toward More Comprehensive Impact Analysis

The old planning paradigm is reductionist, meaning that individual problems are assigned to agencies with narrowly-defined responsibilities. For example, transportation agencies were responsible for reducing traffic congestion, public health agencies for achieving health goals, and environmental agencies on reducing pollution, with little consideration of other goals. This type of planning can result in one agency implementing solutions to the problems within its responsibility that exacerbate other problems, and it tends to overlook policies that provide smaller but diverse benefits. The new paradigm supports more comprehensive analysis which considers multiple goals in order to identify win-win solutions, policies and programs that help achieve multiple goals.

Table 3 shows how this concept applies to traffic safety. The left column identifies various planning goals. Policies that encourage safer vehicles, roads and driving may reduce crashes but achieve few other goals and contradict some. For example, larger vehicles with features such as air bags and antilock brakes increase occupant safety but increase user costs, fuel consumption and pollution emissions. Safer roads with grade separation, wider lanes and more clear-space increase roadway costs, and by inducing more vehicle travel increase traffic external costs. Restrictions on young and senior drivers increase their costs and reduce their mobility options. In contrast, TDM and Smart Growth policies, which reduce total vehicle travel and create more compact communities, increase safety and help achieve most other goals, and so can be considered win-win solutions.

Table 3 **Comparing Strategies**

Planning Goals	Safer Vehicles	Safer Roads	Safer Driving	TDM and Smart Growth
Congestion reduction				✓
Roadway cost savings		×		✓
Parking cost savings				✓
Consumer savings and affordability	×		×	✓
Traffic safety	✓	✓	✓	✓
Improved mobility options for non-drivers			×	✓
Energy conservation	×	×		✓
Pollution reduction	×	×		✓
Physical fitness and health (exercise)				✓
Land use objectives (reduced sprawl)		×		✓

(✓ = achieves goal. × = contradicts goal) Safer vehicles, roads and driving may reduce crashes achieve few other goals, and sometimes contradict them. Transportation demand management (TDM) and smart growth increase safety in addition to helping to achieve other planning goals, and so can be considered win-win solutions.

Many common planning practices can increase total vehicle travel and crash risk (DeRobertis, et al. 2014; Dumbaugh and Rae 2009). For example, roadway expansions, parking minimums in zoning codes, and low-density development tend to induce more vehicle travel (CARB 2014). Some planning practices intended to increase traffic safety many increase total crash risks. For example, since grade-separated highways have low per-mile traffic fatality rates, transportation agencies often justify road widening, straightening, grade separation, hierarchical street systems that force traffic onto higher-speed arterials, and expanded clear zones for safety sake, but such treatments cause motorists to drive farther and faster, which tends to increase total crash casualties (Ewing, et al. 2023; Garrick and Marshall 2011). More dispersed development, wider roads, and higher traffic speeds also discourage walking and bicycling, which further increases vehicle travel and reduces the *safety in numbers* effect.

Because they feel safer, wider and straighter roads encourage drivers to take additional incremental risks, such as driving slightly faster or being distracted, a phenomena called *risk compensation*. The additional vehicle travel caused by increased travel speeds is called *induced travel* (Milam, et al. 2017). As a result of these factors, roadway expansions often provide smaller safety benefits than predicted.

Marshall (2018) investigates factors that cause the US to have about twice the traffic fatality rate as Australia. These include Australia's more urban population, multimodal infrastructure, more public transit ridership and higher driving costs that reduce total vehicle travel and therefore crash exposure; stronger greater reliance on roundabouts, narrower streets and other self-enforcing roadway design practices; plus more enforcement of seat belt usage, impaired driving, speeding regulations and driving restrictions. Australia enacted their version of Vision Zero – called the Safe System Approach – more than a decade before similar policies began cropping up in US cities.

This is not to ignore the benefits provided by higher speed roads, separated land uses, subsidized parking and hierarchical road networks, but it is important to account for the additional crashes they cause in their evaluation. This is particularly important when comparing modal alternatives, such as whether to address traffic congestion by expanding roadways or instead by improving alternative modes and implementing TDM strategies; the former is likely to increase total vehicle travel and therefore crashes while the latter are likely to reduce total vehicle travel and crashes. These impacts should be considered when determining the best overall congestion reduction strategies.

New Paradigm Safety Strategies

This section evaluates the safety impacts of various transportation demand management strategies. For more information see Sustainable & Safe *(Welle, et al. 2018), and* Road Safety in Cities *(ITF 2022).*

Sustainable Traffic Safety Planning

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

Establish a Safe Systems Approach (SuM4All 2023)

A Safe System approach recognizes that road transport is a complex system. Safety requires that all transport system stakeholders—the ones who plan, design, and maintain roads, manufacture vehicles, and administer safety programs—must share responsibility for traffic safety. It should take a proactive and integrated approach rather than reacting after hazards occur. It requires the following policies.

- Establish safety as the primary goal of transportation system planning, designing, and engineering.
- Articulate a clear, evidence-based vision toward the Safe System approach, with bold achievable targets and intermediate implementation milestones.
- Reform legislations, standards, and regulations to ensure accountability among all stakeholders involved in safe road infrastructures, safe vehicles, and safe road use. Allocate road safety funds.
- Build a dedicated, open-access national data repository for road safety, covering all facets from crash data, victim details, vehicle, infrastructure, and speed data to ensure evidence-based strategies.
- Flip the traditional hierarchy to prioritize active and sustainable modes of transport while making the system safer for all users.
- Reorient spatial development and urban mobility plans toward integrated transport and land use systems along with demand management measures to reduce vehicle kilometers traveled.
- Adopt citywide speed limits and low speed zones in places with high demand for walking, cycling and other activities and implement these through traffic calming and enforcement.
- Set safe speeds and speed management measures, supported by effective enforcement, along road stretches and at intersections to provide safe walking and cycling facilities.
- raise awareness include linking climate action and public health with road safety, adopting a children-first approach, highlighting the economic and social costs of road crashes and fatalities, involving active road users, and emphasizing gender safety, security, and universal accessibility.
- Build broad-based consensus and buy-in from communities impacted by transport and road safety plans through information, public participation, and engagement during different stages of a project.

Traffic Speed Reductions

According to extensive research by the International Transport Forum, crash frequency and severity increase disproportionally with traffic speeds (ITF 2018). A 1% increase in average traffic speed results in approximately a 2% increase in injury crash frequency, a 3% increase in severe crash frequency, and a 4% increase in fatal crash frequency. Conversely, mean speed reductions are associated with reduced traffic casualties. It recommends that to optimize safety, speed limits should be no more than 30 km/h in built up areas where vulnerable road users mix with motor vehicle traffic; 50 km/h in areas with intersections; and 70 km/h on rural roads without median barriers to prevent head-on collisions.

Conventional roadway planning tends to prioritize speed. Road performance is often evaluated based on traffic speeds and delay, using indicators such as roadway Level of Service (LOS) and the Travel Time Index (TTI) which favors speed-increasing roadway projects. The *Manual on Uniform Traffic Control Devices* applies the "85th Percentile Rule," which bases speed limits on the speed at which 85% of vehicles travel in free-flowing conditions, so reflect driver preferences, not safety (Bronin and Shill 2021). These practices result in roadways designed to maximize traffic speeds with wider lanes, minimum cross-street and wide clear zones. These design features tend to increase total crashes and crash severity (Dumbaugh and Rae 2009), particularly in urban areas (CALTRANS 2014; Larson 2018).

Table 4 **Forgiving Roadway Design Versus Slower Design Speeds** (Larson 2018)

Forgiving Roadway Design	Slower Design Speeds
Suitable for undeveloped rural areas	*Suitable for more developed urban areas and towns*
Increased safety at high speeds	Fosters the safety of low speeds
Wide travel lanes	Narrow travel lanes
Broad smooth curves	Short, tight curves
Clear zone free of fixed objects	Shoulders are used for parking, bike lanes and loading zones
Feels comfortable to drive fast	Feels dangerous to drive fast

Conventional traffic safety programs often favor "forgiving" road design. This may reduce crash severity in rural areas, but by increasing traffic speeds tends to increase crash severity, particularly for vulnerable modes.

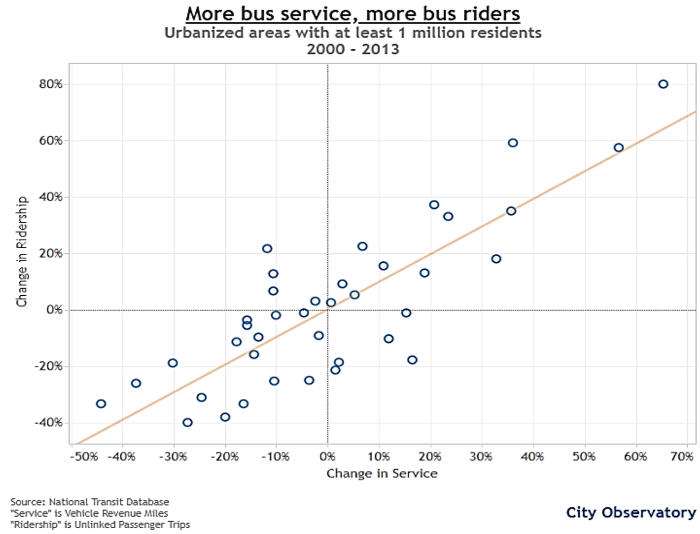
The elasticity of vehicle travel with respect to travel time is –0.2 to –0.5 in the short run and –0.7 to –1.0 over the long run, meaning that a 10% reduction in average traffic speeds reduces affected vehicle travel by 2-5% during the first few years, and up to 7-10% over the long run (Schiffer, Steinvorth and Milam 2005). As a result, higher traffic speeds tend to induce additional vehicle travel, and speed reductions reduce total vehicle travel and crash exposure. Narrower roads with fewer traffic lanes are associated with significantly lower crash risk to pedestrians (AARP and CNU 2021; Ewing, et al. 2023).

Traffic speeds can be reduced by redesigning roadways for lower speeds, with narrower traffic lanes, more traffic circles and crosswalks, and other traffic calming features, often called *road diets* or *streetscaping*. It can also involve reducing speed limits and increasing enforcement. Because current roadway design practices tend to favor higher traffic speeds, reforms are often required to increase the value of crash costs relative to travel time costs in project evaluation, and to change planning practices such as the 85th percentile rule which favors higher speed limits (Bronin and Shill 2021).

Transit Service Improvements

Public transit service improvements include more routes, increased service speed and frequency, nicer vehicles and waiting areas, improved user information and more convenient payment systems. Such improvements tend to increase ridership and reduce automobile travel. High quality transit (urban rail and bus rapid transit) often leverages additional vehicle travel reductions by allowing some households to reduce their vehicle ownership, and by supporting more compact development, so each 1% increase in ridership reduces automobile travel by more than 1% (ICF 2010).

Figure 21 **Ridership Versus Service Hours** (Hertz 2015)



As transit service increases in a city, so does ridership. This tends to reduce automobile travel and traffic crash rates.

As public transit travel increases in a community total (pedestrians, cyclists, motorists and transit passengers) per capita traffic casualty rates tend to decline (Scheiner and Holz-Rau 2011). Various studies using diverse analysis methods and data sets indicate that relatively small ridership gains are associated with proportionately larger reductions in per capita crash rates (Duduta, Adriazola-Steil and Hidalgo 2013; Small 2018). Much of these ridership gains resulted from relatively fast and inexpensive service improvements such as better routing, increased service, reduced fares and better rider information (Peterson 2017; Walker 2015). This suggests that transit service improvements can provide cost-effective safety gains in addition to other community benefits.

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

HOV and Bus Priority

High Occupancy Vehicle (HOV) lanes, bus lanes, and bus priority traffic control systems improve transit performance (speed, reliability and operating cost efficiency) and encourage ridesharing (car- and vanpooling). HOV lanes can reduce vehicle trips on a particular roadway by 4-30% (Turnbull, Levinson and Pratt 2006). Ridesharing programs typically attract 5-15% of commute trips if they offer only information and encouragement, and 10-30% if they also offer incentives such as HOV Priority and efficient parking pricing (Evans and Pratt 2005). In addition to their direct impacts these strategies can also leverage additional vehicle travel reductions, for example, if some commuters who shift from driving to public transit or vanpooling subsequently reduce their vehicle ownership.

Active Transport (Walking and Cycling) Improvements

Improving sidewalks, crosswalks, bike lanes, pathways, plus traffic calming and cycling education, can directly increase walking and cycling safety, and by reducing vehicle travel, increase overall traffic safety. As previously described, in typical North American communities, completing sidewalk and bike facility networks is predicted to reduce total personal vehicle travel about 5%, which should provide at least proportional crash reductions, and more if these improvements reduce traffic speeds or are particularly effective at reducing higher risk driving, for example, allowing drinkers to walk rather than drive home, and young men to reduce driving. This is supported by previously described evidence indicating that relatively modest increases in active mode shares are associated with large reductions in a community's per capita crash rates. This suggests that comprehensive active transport improvements can reduce resident's total crash casualty rates 5-10%. Most improvements can be implemented in a few years.

Expanded Carsharing Services

Carsharing refers to vehicle rental services designed to substitute for personal vehicle ownership. They are located in residential neighborhoods, priced by the hour, and marketed to local residents. Although carsharing may increase vehicle travel by households that lack motor vehicles, they can significantly reduce household vehicle ownership, which reduces vehicle travel (ITF 2015). Carsharing members typically own 40% fewer vehicles and drive 33% fewer annual miles than average (Clewlow 2015). If 10-30% of households live in areas suitable for carsharing (typically 10 residents or more per acre), and 10-30% of area households would use carsharing if available, and carsharing reduces participating household's vehicle travel 33%, the total vehicle travel reduction and potential safety gain is 0.3-3%, with larger impacts in denser neighborhoods.

Raise Fuel Taxes to Fully Finance Roadway Costs or as a Carbon Tax

A basic economic principle is that markets are most efficient and equitable if prices (what users pay for a good) reflect marginal costs (the full incremental costs of that good). This suggests that, as much as possible, motorists should pay for roads, and compensate society for external costs they impose on other people, sometimes called the *polluter pays principle*.

Road user fees (road tolls, special fuel taxes and vehicle registration fees) are often insufficient to fully finance roadway costs (SUTP 2014). For example, in 2015 U.S. government agencies spent $235 billion on roadways, of which $113 (48%) was from user fees and $122 billion from general taxes (FHWA, 2017, Table HF-10). Fuel taxes would need to increase 50¢ per gallon or more to fully finance roadways. A 50¢ per gallon fuel tax can also be justified as a $55 per tonne carbon tax. With current $2.50 per gallon fuel prices, a 50¢ per gallon tax represents a 20% increase. Previously described research indicates that each 10% fuel price increase typically reduces traffic deaths 2-6% (Ahangari, et al. 2014; Burke and Nishitateno 2015), suggesting that a 50¢ per gallon tax should reduce fatalities by 4-12%.

Efficient Parking Pricing

Motorists currently park without a fee at most destinations, due to unpriced on-street parking and off-street parking required in zoning codes. As a result, most parking costs are borne indirectly through general taxes, building rents, and higher costs for retail goods. Considering land, construction and operating costs, a typical urban parking space has an annualized cost of $500 to $3,000 (Litman 2009).

There are many possible ways to efficiently price parking. Municipal governments can expand where parking is metered; businesses can charge for off-street parking; employee parking can be priced or "cashed out" (non-drivers receive the cash equivalent of parking subsidies offered to motorists); residential parking can be unbundled (rented separately from building space); and existing parking fees can be adjusted to be more efficient, for example, with rates that reflect costs and demand (VTPI 2016). Charging users directly for parking typically reduces affected vehicle ownership and use by 10-30% (CARB 2014), which should provide comparable crash reductions. More efficient parking pricing can be implemented relatively quickly, and with new technologies, transactions costs can be minimized.

Congestion Pricing (Road Tolls that Increase Under Congested Conditions)

Congestion pricing consists of road tolls that increase under congested conditions. Research by Green, Heywood and Navarro (2015) indicates that London's congestion pricing program reduced peak-period vehicle travel by 10% and crashes by 30% in the priced area, and reduced crashes in nearby areas by 16%. Since less than a third of total vehicle travel occurs under urban-peak conditions, which suggests that congestion pricing can reduce total crash rates 5-15%, depending on how broadly it is applied.

Distance-Based Vehicle Insurance and Registration Fees

Distance-Based (also called Pay-As-You-Drive, Usage-based, Mileage-Based and Per-Mile Premiums) means that vehicle insurance premiums and registration fees are based directly on how much it is driven. Vehicle purchase taxes also be converted into distance-based fees, so a $1,000 tax becomes 1¢ per vehicle-mile. This price structure gives motorists a new opportunity to save money if they reduce their vehicle travel (Ferreira and Minike 2010; Greenberg and Evans 2017; VTPI 2016).

An average motorist who currently pays $1,200 annual insurance premiums and registration fees would pay about 10¢ per mile, approximately equivalent to a 60% fuel price increase, but this is not a new fee, simply a different way of paying existing fees. This should reduce affected vehicles' average annual mileage 10-15%. Since all existing rating factors are included in the rate structure, higher risk motorists would pay more per mile under distance-based pricing, and so should reduce their mileage more than average. For example, a lower-risk motorist who currently pays $500 annually would pay about 4¢ per mile, and so would reduce mileage 5%, but a higher-risk motorist who pays $2,400 for insurance would pay about 20¢ per mile, resulting in particularly large reductions in higher-risk driving. As a result, distance-based insurance pricing should reduce crash rates even more than mileage. This suggests that distance-based insurance and registration fees can reduce affected vehicles' crash casualties 10-20%.

There are many possible ways to implement distance-based pricing. Some systems use electronic devices to track when, where and how people drive, but this imposes significant costs and raises privacy concerns. Basic distance-based pricing only requires an annual odometer reading. If offered as a consumer option, probably 5-15% of motorists would choose electronic pricing and 30-50% (those with vehicles driven less than about 10,000 annual miles) would choose basic distance-based pricing. Incentives or mandates could result in most or all motorists having distance-based pricing. If universally applied total crashes should decline at least 15%.

Commute Trip Reduction Programs

Commute trip reduction programs encourage commuters to use resource-efficient modes. They can include various services and incentives such as ridematching services, bicycle lockers, guaranteed ride home programs, flextime and telecommute options, transit encouragement, and financial incentives for using efficient modes. Programs that include information and encouragement typically reduce automobile trips by 5-15%, and those that include significant financial incentives typically reduce automobile trips 15-30%. Commute trip reductions programs can leverage additional vehicle travel reductions, for example, if incentives to use non-auto commute modes convince households to reduce their car ownership or locate in a more multi-modal community. About 20% of personal vehicle travel is for commuting, and perhaps half of commuters are suited to such programs, so perhaps 10% of total travel could be reduced 5-30%, or 0.5-3%. Safety gains are probably about proportional to vehicle travel reductions. Washington State's Commute Trip reduction law is one of many factors that contributed to significant vehicle travel reductions and traffic safety gains in the Puget Sound region (Peterson 2017).

Mobility Management Marketing

Mobility management marketing (also called *Voluntary Travel Behavior Change Programs*) uses mass and personalized marketing strategies to encourage households to try resource-efficient travel options, usually implemented by government agencies or non-profit organizations as part of a comprehensive TDM program. They have proven successful in many conditions including urban and suburban areas, and influence various types of trips. They typically reduce affected households' vehicle travel by 5-10% (CARB 2013). Crash reductions are likely to be about proportionate. Assuming that 60% of households are candidates for such programs, they can reduce affected households' crashes 5-10% and total crashes 3-6%. Such programs can be implemented in a few months.

More Connected and Complete Streets

Street connectivity refers to street network density, such as intersections per square mile. Increased connectivity tends to reduce vehicle travel by reducing travel distances between destinations and by supporting alternative modes, particularly where paths provide walking and bicycling shortcuts (Handy, et al. 2014). Ewing and Cervero (2010) find that intersection density and street connectivity are the second greatest land use factor affecting vehicle travel, so a 10% density increase reduces vehicle travel 1.2%. Holding other factors constant, increasing from 31.3 to 125 intersections per square kilometer is associated with a 41% decrease in vehicle travel (Marshall and Garrick 2012).

Complete streets are designed to accommodate diverse users and uses, including walking, bicycling, transit, automobile travel, plus nearby businesses and residents (SGA 2020). This tends to increase traffic safety, and by improving active and public transportation, reduce total vehicle travel and crashes. Compared with sprawled, automobile-oriented development, high street connectivity and complete streets designs can reduce local crash casualty rates 10-30% (Ewing and Cervero 2010; Marshall, Ferenchak and Janson 2018). Similarly, Mohan, Bangdiwala and Villaveces (2017) found that traffic death rates decline with more roadway junctions and fewer kilometers of arterial grade roadways.

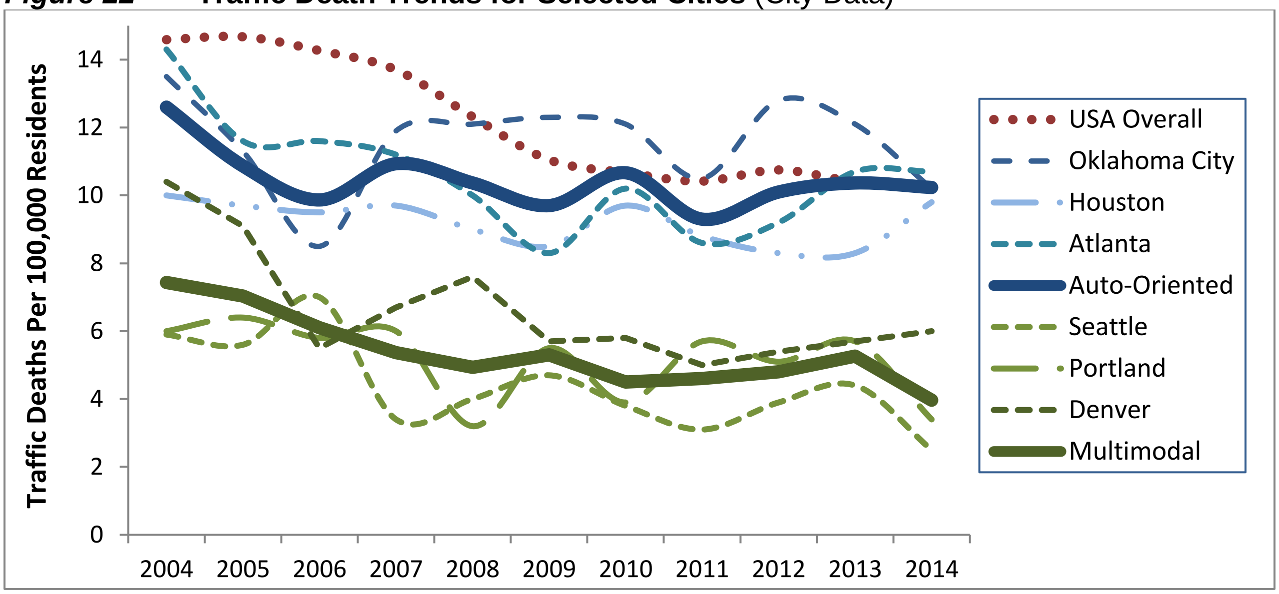
More Comprehensive and Multi-modal Planning

Many common planning practices tend to favor automobile travel over other modes. For example, conventional transportation planning evaluates transportation system performance based primarily on roadway Level-of-Service (LOS) indicators, which reflect motor vehicle traffic speeds and delay; there are generally no indicators for other modes or other accessibility factors such as development density and mix (DeRobertis, et al. 2014). More comprehensive and multi-modal planning gives more consideration to non-auto modes and accounts for other planning goals besides vehicle travel speed (NYCDOT 2012).

Current transportation funding practices also tend to favor road and parking over investments in other modes. For example, dedicated state highway funds encourage local and regional governments to define their transportation problems in terms of inadequate roadway capacity rather inadequate mobility options or roadway underpricing (in fact, federal policies prohibit congestion pricing on most U.S. highways), and minimum parking requirements in zoning codes subsidize automobile ownership and use, discourage efficient pricing and stimulate sprawled development.

More comprehensive and multi-modal planning provides a foundation for new paradigm safety strategies, including more support for non-automobile modes, Smart Growth policies and TDM programs. Although impacts are difficult to predict precisely, their safety benefits are potentially large, as indicated by the much larger crash rate reductions in U.S. cities that emphasize multi-modal planning (Denver, Portland and Seattle) compared with those that apply conventional, auto-oriented planning (Atlanta, Houston and Oklahoma City), illustrated in Figure 20.

Figure 22 **Traffic Death Trends for Selected Cities** (City Data)



Cities that emphasized multi-modal planning (Denver, Portland and Seattle) experienced much larger traffic death rate reductions (47%) than cities (Atlanta, Houston and Oklahoma City) with conventional planning (19%).

Reduced Parking Requirements

Most jurisdictions currently require that numerous parking spaces be included with any development. This makes automobile travel convenient and inexpensive, and development more dispersed, often to the detriment of other travel modes. Parking requirements discourage infill development, creating sprawled communities, and large parking lots crate unpleasant walking environments. In typical North American communities these requirements result in the provision of 2-6 parking spaces per motor vehicle, representing a $1,000-$6,000 annual economic subsidy per motorist (Chester, et al. 2015; Scharnhorst 2018). This is economically inefficient and unfair, and by increasing automobile travel and discouraging use of other modes, tends to increase traffic crash rates.

Reducing parking requirements does not eliminate parking, it simply allows developers to determine the number of parking spaces to provide based on market demands, which often results in unbundled parking (renting parking spaces separately from building space). As previously mentioned, charging motorists directly for parking typically reduces vehicle ownership and use by 10-30%, and more if implemented in conjunction with other transportation demand management strategies.

Although these impacts are indirect and there is little research specifically investigating how parking policies affect crash rates, reducing parking requirements can probably provide large traffic safety benefits by reducing vehicle ownership and use, increasing parking prices and allowing more compact development. This suggests that local crash casualty rates decline 5-15% if reduced parking allows a community to become compact and multi-modal. These impacts take years to occur.

Urban Rail and Bus Rapid Transit

As previously described, traffic crash rates tend to decline as public transit ridership increases in a community (figures 13 and 14). Residents of cities with more than 50 annual transit trips per capita have about half the average traffic fatality rate as regions with less than 20 annual trips per capita, indicating that relatively modest increases in transit travel are associated with large traffic safety gains. Urban rail and Bus Rapid Transit (BRT) tend to increase transit ridership by providing high quality service, including relatively high speed, frequency, rider comfort and station access, and by providing a catalyst for Transit Oriented Development. Some studies suggest that high quality public transit reduces drunk driving by giving drinkers an affordable and safety alternative to driving home after drinking (Broyles 2014).

A single rail or BRT line is generally insufficient to significantly affect regional travel or crash rates; to be effective they generally require an integrated network with supportive policies including improved walking, cycling and local bus services; reduced parking requirements; policies that encourage compact development around transit stations; and commute trip reduction programs. Where those policies are effectively applied it is possible to reduce per capita traffic fatality rates 30-60% within affected neighborhoods, and 10-30% region-wide.

Smart Growth and Transit Oriented Development

Smart Growth refers to policies and planning practices that encourage more compact, multi-modal urban development. Transit Oriented Development (TOD) refers to these policies applied specifically around transit stations. Various studies using a variety of analysis methods and data sets indicate that these development practices tend to increase traffic safety (ITF 2019; Welle, et al. 2015).

Recent research by the International Transport Forum found that denser cities tend to have lower traffic death rates (ITF 2019). The study suggests that this reflects:

- A higher proportion of public transport travel, which has very low risk.
- A higher proportion of foot or bicycle trips, which impose less risk on other modes.
- Less per capita vehicle travel and lower motor vehicle traffic speeds.

Hamidi, et al. (2015) found that more compact communities had significantly higher transit ridership, slightly higher *total* crash rates, but much lower *fatal* crash rates than sprawled communities: each 10% increase in their compact community index is associated with a 0.4% increase in total crashes, and a 13.8% reduction in traffic fatalities. Analyzing San Antonio, Texas neighborhood crash rates, Dumbaugh and Rae (2009) found that crashes are negatively associated with *population density* (each additional person per net residential acre reduces crash incidence 0.05%); automobile oriented services (each additional arterial-oriented commercial parcel increased total crashes 1.3%, each additional big box store increased total crashes 6.6%, and pedestrian-scaled commercial or retail uses were associated with a 2.2% reduction in crashes); and higher-speed roadways (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).

The most compact and multi-modal U.S. communities, often called Transit Oriented Developments, generally experience 2-3 deaths per 100,000 residents, an order of magnitude lower than the 20-40 deaths per 100,000 residents than in the most sprawled, automobile-dependent communities (for evidence see figures 4 and 5, which indicate the crash rates ranges among states and urban regional, and even larger variations at the neighborhood level). This suggests that policies which shift a community from extreme sprawl to the most compact and multi-modal can reduce traffic crash rates by as much as 90%, but in most situations their impacts will be smaller, and they take many years or decades to achieve large safety gains. Crash rate reductions of 10-30% are probably realistic for aggressive Smart Growth and Transit Oriented Development programs that cause a majority of community's residents to live in more compact and multi-modal neighborhoods.

The table below summarizes the new paradigm safety strategies.

Table 5 New Paradigm Safety Strategies

Strategy	Travel Impacts	Crash Rate Reductions
Shorter Term (less than three years)		
Reduce traffic speeds	A 10% speed reduction typically reduces vehicle travel 2-4%.	A 10% speed reduction reduces casualties 10-30%, with larger safety gains for active modes.
Transit service improvements (more routes, frequency, etc.).	Reduces vehicle travel, particularly if it stimulates transit-oriented development.	Each 1% transit ridership gain typically reduces traffic casualties 1% or more.
HOV and bus traffic priority	Reduces automobile travel and encourages transit and ridesharing.	Can reduce affected traveler's crash rates 10-30%, and total rates 1-5%.
Active mode improvements (better sidewalks, crosswalks, bikelane, etc.).	Increases walking and bicycling, and reduces motor vehicle travel.	Increases active mode safety, and can reduce total crash casualty rates 5-10%.
Expanded carsharing services	Reduces automobile ownership and use.	Can reduce crashes 0.3-3%.
Raise fuel taxes to fully finance roadway costs, or as a carbon tax.	Reduces total vehicle travel and traffic speeds.	A 50¢ per gallon tax typically reduces crash casualty rates 4-12%.
Efficient parking pricing (motorists pay directly for using parking spaces).	Typically reduces affected trips 10-30%, and may reduce vehicle ownership.	Each 10% increase efficiently priced parking reduces crash casualties 1-3%.
Congestion pricing (road tolls that increase under congested conditions)	Reduces automobile travel, particularly in large cities.	Reduces affected area crash casualty rates 15-30%, with smaller reductions nearby.
Distance-based vehicle insurance and registration fees.	Reduces vehicle travel, especially higher risk driving.	Reduces affected vehicles' crashes by 10-20%.
Commute trip reduction programs.	Reduces affected commute trips 5-30%.	Reduces affected commuters' crash casualty rates 5-30%, and total crashes 0.5-3%.
Mobility management marketing.	Encourages use of non-auto modes.	Can reduce affected households' crashes 5-10% and total crashes 3-6%.
Longer Term (more than three years)		
More comprehensive and multi-modal planning	Creates safer and more multi-modal transport systems.	Can lead to large vehicle travel and crash reductions.
More connected and complete streets.	Reduces traffic speeds, improves non-auto modes and reduces total vehicle travel.	Can reduce local crash casualty rates 10-30%.
Reduced parking requirements	Reduces crashes by reducing vehicle ownership and use.	Can reduce affected area's crash casualty rates 5-15%.
Urban rail and Bus Rapid Transit	Reduces vehicle ownership and use.	Can reduce crash rates 30-60% in affected areas and 10-30% region-wide
Smart Growth and Transit Oriented Development	Reduces traffic speeds, improves non-auto modes and reduces total vehicle travel.	Can reduce crash casualty rates 30-60% in affected areas and 10-30% region-wide

New paradigm safety strategies reduce total vehicle travel and traffic speeds.

Projected impacts depend on implementation scale. Many of these strategies significantly reduce vehicle travel and crash rates in a particular area or among a particular group, so their total impacts depend on how broadly they are implemented. For example, Commute Trip Reduction programs often reduce affected vehicle travel by 5-30%, so their total impacts depend on the portion of workers affected by such programs. Similarly, Smart Growth and Transit Oriented Development reduce residents' vehicle travel and crash casualty rates by 30-60% compared with conventional automobile-oriented neighborhoods, so their overall impacts depends on the portion of regional households located in such areas and therefore consumer demand for housing in compact, multi-modal neighborhoods.

Care is needed when predicting the total impacts of multiple strategies since their impacts are multiplicative not additive. For example, if transit improvements are predicted to reduce crashes by 15%, fuel price increases reduce crashes by 10%, and commute trip reduction programs are predicted to reduce crashes by 5%, the total reductions of implementing them together are calculated by multiplying their residual crash rates (85% x 90% x 95% = 73%), indicating a 27% crash reduction rather than the 30% reduction indicate by adding 15% + 10% + 5%.

Some strategies overlap. For example, increasing roadway connectivity and reducing parking requirements are both Smart Growth Strategies. While it would be true to say that reducing parking requirements can reduce crashes 5-15%, improved roadway connectivity can reduce local crashes 10-30%, and Smart Growth can reduce crashes by 10-30%, it would be double-counting to add these together to say that together they reduce crashes by 25-75%, since Smart Growth including reduced parking requirements and more connected roadways. On the other hand, many of these strategies have synergistic effects (total impacts are greater than the sum of their individual impacts), and so are most effective if implemented together. For example, public transit improvements are more effective if implemented with walkability improvements and parking pricing since together they give travellers both positive and negative incentives to shift modes.

These strategies complement existing traffic safety efforts. Many conventional traffic safety strategies attempt to reduce higher-risk driving, such as graduated licenses to reduce youth driving, special senior testing to identify high-risk drivers, and anti-impaired driving campaigns. To be effective and fair these strategies require suitable mobility options so youths, seniors and drinker have suitable alternatives to driving. Because travel demands are diverse, this requires diverse mobility options. For example, graduated licenses and senior driver testing will be more effective and less burdensome if implemented with more multi-modal planning that improves walking, bicycling, public transit and taxi/ride-hailing improvements, so youths and seniors can access services and activities without driving. Similarly, anti-impaired driving campaigns should be implemented with Smart Growth development policies that create more compact and mixed neighborhoods, so it is easier to visit a restaurant or pub by walking or public transit rather than driving.[6] As a result, multi-modal planning, Smart Growth and TDM programs support both old and new paradigm traffic safety strategies.

[6] Ironically, conventional zoning codes often apply very high minimum parking requirements to bars, pubs and restaurants, typically 6-12 spaces per 1,000 square feet (http://bit.ly/2Bsno0i), which contradicts efforts to discourage driving after drinking, and by increasing land requirements, often prevent the development of local drinking establishments accessible by walking. Allowing more neighborhood restaurants, bars and pubs can increase public safety and health.

New Paradigm Analysis Methods

This section describes how analysis methods to support the new traffic safety paradigm.

How impacts are analyzed can significantly affect planning outcomes. A solution that seems effective and beneficial evaluated one way may seem ineffective and harmful if evaluated using different metrics and perspectives. Table 5 compares old and new paradigm analyses frameworks. By using distance-based exposure units, focusing on internal impacts, and only considering safety, the current analysis framework ignores the additional crashes caused by increased vehicle travel, the risks the motorized travel imposes on pedestrians and cyclists, and additional benefits, besides safety, provided by vehicle travel reduction strategies. In these ways, it favors automobile-oriented solutions over multi-modal planning, Smart Growth and TDM programs.

Table 6 **Comparing Analysis Frameworks**

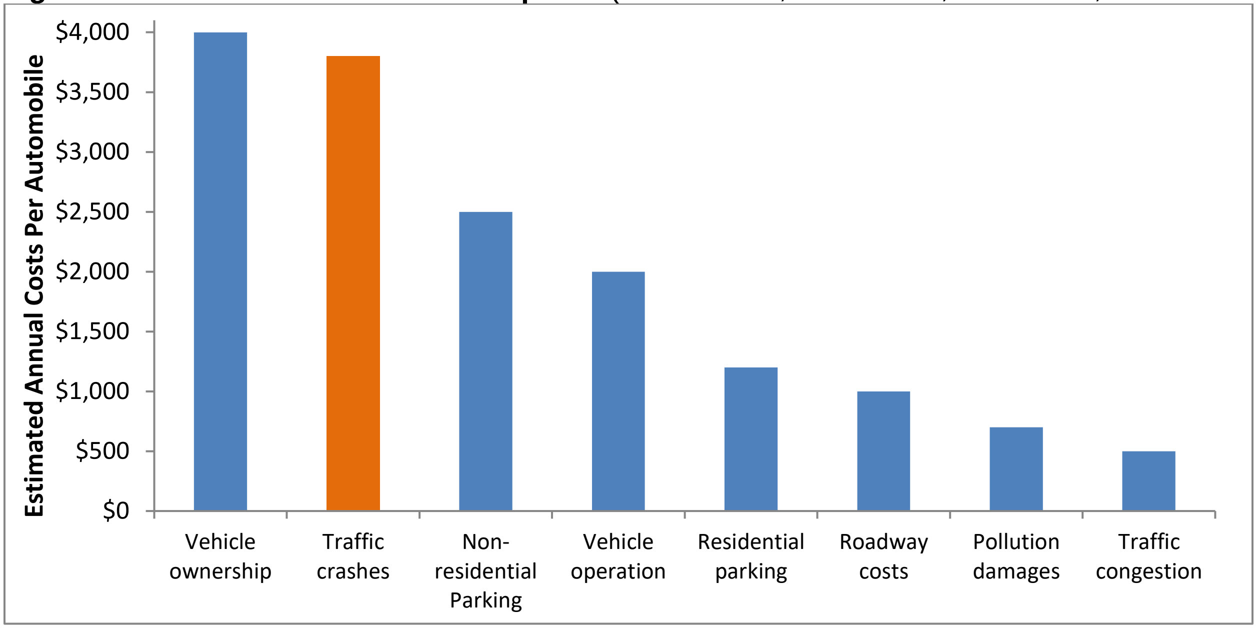
Factor	Old	New
Units of exposure	Distance-based units (e.g., casualties per 100 million vehicle-miles or billion vehicle-kilometers)	Per capita (e.g., casualties per 100,000 residents)
Perspective	Internal (user) impacts, such as casualties to vehicle occupants.	Internal and external impacts, such as casualties to vehicle occupants and other road users.
Scope of impacts	Traffic crash costs.	Traffic crash costs and other economic, social and environmental impacts.
Level of impacts	Direct impacts only.	Direct and indirect impacts, including short- and long-term effects on vehicle travel and risk exposure.

The new traffic safety paradigm is more comprehensive and integrated.

The old safety paradigm focuses on crash costs, the new paradigm considers all significant impacts. This is important because planning decisions often involve trade-offs between traffic risk and other impacts such as mobility, affordability and environmental quality. A traffic safety strategy is worth less if it conflicts with other planning goals, for example, if it increases costs to governments, consumer or businesses, or exacerbates pollution problems, but can be worth far more if it also helps achieve other planning objectives. New tools help decision-makers understand these trade-offs.

Various studies have estimated motor vehicle costs (DfT 2017; Kockelman, et al. 2013; Litman 2009). A major Federal Highway Administration study (Blincoe, et al. 2015) estimated that in 2010, U.S. traffic crashes costs, including property damage, medical care and lost productivity, plus values for pain and loss of life, totalled $836 billion, which averages about $3,800 annual per capita in current dollars. The figure below compares this with other vehicle costs including ownership (financing, depreciation, insurance, and registration fees, which average about $4,000 annually), non-residential parking (the 2-6 off-street parking spaces per vehicle provided at worksites, shops and other destinations) which average about $2,500 per vehicle, vehicle operation (about $2,000 for fuel and tire wear), residential parking (about $1,200 for a garage or carport), roadway and traffic service costs (which average about $1,000 per vehicle), traffic congestion (estimated to total $115 billion in 2010, or about $500 per vehicle), and motor vehicle air, noise and water pollution are estimated to average about $700 annually (some estimates are much higher). Figure 21 compares these costs.

Figure 23 **Automobile Costs Compared** (FHWA 2010; Kockelman, et al. 2013; Litman 2009)



Traffic crash damages are one of the largest costs of motor vehicle travel, less than vehicle ownership and non-residential parking, but smaller than all others. This suggests that a traffic safety program is not cost effective if it increases other costs, but can be far more beneficial overall if they reduce other costs or provide other benefits.

This is important because conventional traffic safety strategies, such as additional vehicle safety features (crash protection design, air bags, rear vision camera, etc.) and programs (sobriety checks, new driver testing, advertising campaigns, etc.) are costly and provide few benefits besides safety, while most new paradigm safety strategies provide large co-benefits. For example, multi-modal planning, pricing reforms, Smart Growth development policies and TDM programs tend to reduce congestion, infrastructure costs, consumer costs and pollution emissions, as well as improving mobility options for non-drivers, and public fitness and health.

These factors can significantly affect planning priorities. For example, when deciding whether to expand roadways or improve public transit to reduce congestion, conventional analysis usually ignores the additional risk to pedestrians and cyclists caused by wider roads and higher traffic speeds, additional crashes that result if roadway expansions induce additional vehicle travel and stimulates sprawled development; these impacts are invisible when projects are evaluated using distance-based vehicle crash rate data. The new paradigm recognizes the additional crash risks caused by induced vehicle travel and additional benefits provided by improved travel options, vehicle travel reductions, and more compact development.

Transportation professionals seldom acknowledge these issues or discuss how alternative analysis methods could provide different results. Transportation agencies often only report distance-based crash data with no discussion of alternative metrics or perspectives. Traffic safety analysis seldom discusses the additional crashes caused by policies that increase vehicle travel or traffic speeds, or the safety benefits of vehicle travel reduction strategies. By considering these impacts the new paradigm analysis framework provides more useful information to decision-makers.

Evaluating Current Traffic Safety Programs

This section evaluates whether various traffic safety programs and guides consider new paradigm solutions.

Table 6 **Review of Traffic Safety Programs**

Program	VMT Reduction Safety Strategies
Countermeasures That Work, NHTSA (https://bit.ly/48B43dx)	None
Desktop Reference for Crash Reduction Factors, ITE (www.ite.org)	None
Developing Safety Plans for Rural Road Owners, FHWA (http://bit.ly/2px3hIA)	None
Getting to Zero Alcohol-impaired Driving Fatalities, National Academy Press (*www.nap.edu/download/24951*)	Recommends improving public transit and ridehailing that serves alcohol drinkers
Global Status Report on Road Safety, World Health Organization (http://bit.ly/1GsQ3DJ)	Recommends walking, cycling and transit improvements.
Integrating Road Safety into Existing Systems and Policy, Global Transport Knowledge Practice (www.gtkp.com/themepage.php&themepgid=376).	Recommends integrated approaches, including multi-modal transport planning.
Highway Safety Manual, AASHTO , (http://bit.ly/2oF4Xix)	None
Highway Safety Program Guidelines, GHSA (www.ghsa.org)	None
Motor Vehicle PICCS, CDC (www.cdc.gov/motorvehiclesafety)	None
Roadway Safety Guide, Road Safety Foundation (www.roadwaysafety.org)	None
Safe Ride Programs, Mothers Against Drunk Driving (www.madd.org)	None
The Injury Research Foundation (www.tirf.ca)	None
Toward Zero Deaths (www.towardzerodeaths.org)	None
Canada's Road Safety Strategy (http://roadsafetystrategy.ca)	None
Toolbox for Road Safety (https://doi.org/10.1186/s40621-016-0098-z)	None
Traffic Safety Fundamentals Handbook, MDOT (https://bit.ly/48ESke3)	None
Transportation and Health Tool, USDOT and CDC (www.transportation.gov/transportation-health-tool)	Recommends multi-modal planning for safety and health.
Transportation Planner's Safety Desk Reference, USDOT (http://bit.ly/2oFbz0j)	Recommends VMT reduction strategies.
Vision, Strategies, Action: Guidelines (https://bit.ly/2ImGuum)	None
Vision Zero: Toolkit for Road Safety in the Modern Era (https://bit.ly/2VN2Blh)	None
Global Status Report on Road Safety, World Health Organization (http://tinyurl.com/pxfupc)	Recommends multimodal planning and traffic speed reductions for traffic safety.
Enhancing Policy and Action for Safe Mobility, Sustainable Mobility for All (https://bit.ly/3XxWwXL)	Recommends sustainable modes, compact development and vehicle travel reductions.
World Report on Road Traffic Injury Prevention, Global Road Safety Partnership (www.grsproadsafety.org)	Recommends demand management strategies.
Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System, (http://bit.ly/2nQZJmP)	Recommends some vehicle travel reduction strategies.

Of 24 major traffic safety programs reviewed, only eight mention multimodal planning or vehicle travel reduction strategies, and none provide detailed guidance on their evaluation or implementation.

Most traffic safety programs reflect the old paradigm (Sung, Mizenko and Coleman 2017). For example, the *2015 Traffic Safety Facts Report* (NHTSA 2017) shows casualties per 100 million vehicle-miles but not per capita, and the USDOT's safety performance indicators are all distance-based (USDOT 2017). Of nineteen major traffic safety programs considered in Table 6, only seven mention vehicle miles of travel (VMT) reduction strategies, and none provide guidance on evaluating or implementing them.

Most multi-modal recommendations provided by these programs are limited in scope. For example, a recent report by the U.S. National Academy of Sciences, *Getting to Zero Alcohol-impaired Driving Fatalities: A Comprehensive Approach to a Persistent Problem*, includes the following recommendation:

> Recommendation 4-4: Municipalities should support policies and programs that increase the availability, convenience, affordability, and safety of transportation alternatives for drinkers who might otherwise drive. This includes permitting transportation network company ridesharing, enhancing public transportation options (especially during nighttime and weekend hours), and boosting or incentivizing transportation alternatives in rural areas.

Although this recognizes the possibility that that improving travel options can reduce impaired driving, it implies that such programs target higher risk conditions. It ignores the effects that high quality public transit, and transit-oriented development has on per capita vehicle ownership which leverages reductions in high risk driving, and research showing large reductions in traffic fatality rates in transit-oriented communities. It also fails to evaluate the costs and co-benefits of anti-impaired-driving campaigns, which could justify more integrated solutions.

The Sustainable Mobility for All report, *Enhancing Policy and Action for Safe Mobility* (SuM4All 2023) proposes a safe systems approach to traffic safety, which recognizes the safety benefits of multimodal transportation and land use planning which reduces total vehicle travel and traffic speeds, and it supports transportation demand management strategies that reduce vehicle travel, although it provides little guidance for evaluating their safety benefits.

Many jurisdictions are starting to apply more multimodal planning, transportation demand management incentives, and Smart Growth policies, and some have established vehicle travel reduction targets (Litman 2021). These are justified for various reasons including reducing traffic congestion, public infrastructure savings, consumer savings, social equity, public health, emission reductions and habitat preservation; although they can also provide substantial traffic safety benefits these often receive little priority. New tools, such as California's *Vehicle Miles Traveled-Focused Transportation Impact Study Guide* (Caltrans 2020), can help policy makers and practitioners estimate the impacts that transportation and land use projects will have on total vehicle travel and therefore crashes. Traffic safety programs can incorporate this type of information into traffic safety planning.

Obstacles and Criticisms

This section describes various obstacles facing new paradigm traffic safety strategy implementation.

This new traffic safety paradigm faces various obstacles. Many stakeholders are unfamiliar with these concepts: transportation professionals seldom consider the additional crashes caused by planning decisions that stimulate vehicle traffic, or the potential safety benefits of vehicle travel reduction strategies. Multi-modal planning and TDM programs are generally intended to reduce congestion and emissions, safety benefits are often overlooked. Few guidance documents or modelling tools provide guidance for evaluating TDM and Smart Growth traffic safety impacts, or support their implementation.

Transportation professionals often emphasize that most crashes result from special risk factors, such as youth, senior, impaired or distracted driving, and so favor targeted safety strategies. From this perspective it seems inefficient and unfair to reduce total driving for safety sake, since that would punish all drivers for errors made by an irresponsible minority. However, even a perfect driver who never errors increases safety by reducing mileage and therefore their chance of being the victim of other drivers' mistakes, and most drivers make small errors that can contribute to a crash, such as driving a little faster than optimal for safety. Since most casualty crashes involve multiple vehicles, travel reductions tend to provide proportionately larger crash reductions, particularly in urban areas (Edlin and Karaca-Mandic 2006). As a result, mileage reductions by lower-risk drivers increase traffic safety.

It is also wrong to assume that vehicle travel reductions "punish" drivers: many TDM strategies improve travel options or provide positive incentives to use alternatives to driving, making travellers who reduce their driving better off overall. Critics may argue that these are ineffective safety strategies. It is true that many TDM strategies individually only affect a small portion of total travel so their safety benefits seem modest, but their impacts tend to be synergistic, so an integrated program can provide significant crash reductions and other benefits. Some strategies, such as new urban rail systems, may seem costly considering just their traffic safety impacts, but provide other important benefits including reduced traffic and parking congestion, infrastructure savings, user savings and affordability, improved mobility for non-drivers, improved public fitness and health, energy conservation and emission reductions. Considering all impacts new paradigm safety strategies are often very cost effective.

Critics could argue that these strategies' safety impacts are difficult to predict, but research described in this report can be used to model how policy and planning decisions affect travel activity and crash rates. Such models are no less accurate than those used to predict conventional safety strategy impacts; in fact, current models often exaggerate conventional strategies' net safety gains by ignoring induced travel and offsetting behavior effects (Rudin-Brown and Jamson 2013). More research is justified, but sufficient information is available to make reasonable predictions of new safety strategy impacts.

Conventional planning tends to overlook or undervalue policies and programs that provide traffic safety co-benefits. For example, detailed analysis by Oldham and Mills (2020) found that some public programs that are primarily intended to reduce crime or pollution emissions also increase traffic safety, but these impacts were overlooked or undervalued in the program evaluations, leading to their underinvestment. Similarly, public transit service improvements are generally intended to reduce traffic and parking congestion, and improve mobility for non-drivers, and Smart Growth development policies are generally intended to reduce the costs of providing public infrastructure and reduce environmental impacts, but these also provide significant traffic safety gains. Table 7 lists various multi-modal planning strategies that also tend to provide traffic safety co-benefits.

Table 7 **Multi-Modal Planning**

Improved Mobility Options	Mode Shift Incentives	More Accessible Land Use
Improved walking and cycling conditions	Efficient road and parking pricing	Compact and mixed development
High quality public transit services	Fuel price increases	More connected road networks
Ridesharing, ride-hailing and taxi services	HOV priority	Complete streets policies
Car- and bikesharing	Commute trip reduction programs	Reduced parking requirements

Various policies can create multi-modal communities where residents drive less and rely more on non-automobile modes, reducing traffic fatality rates. Their effects are synergistic and so should be evaluated together.

New paradigm safety strategies may seem outside traffic safety programs' scope, but this is an arbitrary distinction. Traffic safety programs now include road and vehicle design standards, law enforcement, business regulations, and social marketing; there is nothing inherently different about multi-modal planning, TDM and Smart Growth. These strategies are sometimes criticized as *social engineering*, with the implication that they force travelers to use undesirable mobility options, but such arguments that are generally false. In fact, multi-modal planning, TDM and Smart Growth tend to respond to consumer demands for non-auto modes, and remove existing market distortions, such as reducing parking minimize that subsidized automobile travel. Surveys indicate that many people would prefer to drive less and rely on alternative modes, provided they are convenient and affordable. For example, the National Association of Realtor's *National Community and Transportation Preference Survey* (NAR 2017), indicates that a growing majority of home buyers prefer living in a walkable urban neighborhood over a detached house that requires a longer commute and driving to shops, and most respondents like walking (80%), about half like bicycling, more than a third (38%) like public transit travel. More multi-modal planning responds to these demands, which increases safety among other benefits.

Another criticism is that new paradigm strategies are too slow, but as Table 4 indicates, many can be implemented in a few years. Experience indicates that communities can achieve significant safety gains within a few years by applying more multi-modal planning, TDM and Smart Growth policies. As Figure 18 showed, during a ten-year period, the cities with multi-modal planning and Smart Growth policies reduced their traffic fatality rates 2.5 times more than in cities with conventional planning and development policies (PBOT 2016; SDOT 2015), which suggests that new paradigm strategies can more than double the safety gains achieved by conventional safety programs alone.

Another obstacle is stakeholder (policy makers, practitioners, citizens, etc.) bias. Most stakeholders are themselves motorists, who tend to be proud of their skills (surveys indicate that most drivers consider themselves safer than average, called *illusory superiority*), and so are often offended by the idea that their driving is dangerous and should be reduced for safety sake. In addition, many stakeholders consider travel reduction a defeatist solution that denigrates conventional transportation planning and traffic safety programs. These responses misrepresent the issues. The new safety paradigm acknowledges that most drivers are responsible and cautious, and past traffic safety programs successfully reduced crash rates, but recognizes that new strategies can provide additional safety gains that will not otherwise occur, plus other important benefits, and so should be implemented.

Conclusions and Recommendations

After a half-century of decline traffic casualty rates have started to increase, indicating that conventional safety strategies are becoming less effective, so new approaches are needed to achieve ambitious safety goals. Recent research improves our understanding of factors that affect traffic risks and identifies new safety strategies. Numerous studies using various methods and data sets indicate that *exposure*, total vehicle travel, is a critical risk factor. Since most casualty crashes involve multiple vehicles, even a prefect driver who makes no errors increases safety by reducing mileage because this reduces their chance of being a victim of another driver's mistake. A paradigm shift is needed to apply this knowledge.

The old paradigm assumed that most crashes result from special risks, such as youth, senior, impaired and distracted driving, and so favors safety programs that target these risks. A new paradigm recognizes that all vehicle travel incurs risk, so policies that stimulate vehicle travel tend to increase crashes and vehicle travel reductions increase safety. This expands the scope of potential traffic safety strategies, as summarized below.

Table 8 **Scope of Safety Programs**

Conventional	New
Targetted	*General Reductions in Vehicle Travel and Speed*
• Targeted speed reductions. • Anti-impaired and distracted driving campaigns. • Special testing for youth and senior drivers. • Roadway design improvements. • Vehicle design improvements. • Vehicle occupant crash protection.	• Regional speed reductions. • More multi-modal transport planning (improved walking, bicycling, ridesharing and public transit). • Complete streets roadway design. • Efficient transport pricing (fuel tax increases, road tolls, parking fees, distance-based pricing). • Smart Growth development and complete streets policies. • TDM programs (commute and school travel management).

The New Paradigm expands traffic safety programs to include traffic reduction strategies that reduce exposure.

How risks are evaluated can significantly affects policy and planning decisions. The old paradigm relies on distance-based risk indicators which, ignores the additional crashes caused by policies which increase total vehicle travel and the safety provided by vehicle travel reductions. The new paradigm tends to measure crash rates per capita. Because vehicle travel reduction strategies provide co-benefits besides safety, the new paradigm supports comprehensive impact evaluation (CDC Foundation 2020).

The new paradigm faces various obstacles, including many stakeholders' preferences for targeted safety programs and aversion to vehicle travel reduction strategies. However, new paradigm strategies actually complement existing programs, which become more effective, equitable and acceptable if implemented with improved mobility options that help higher-risk travellers reduce their driving.

This is not to suggest that automobile travel should be eliminated for safety sake. However, surveys indicate that many people would prefer to drive less and rely more on alternatives, provided they are convenient, comfortable and affordable. In response, many communities are implementing more multi-modal planning, Smart Growth policies, and TDM programs. This research suggests that these strategies can significantly increase traffic safety.

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