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A New Traffic Safety Paradigm

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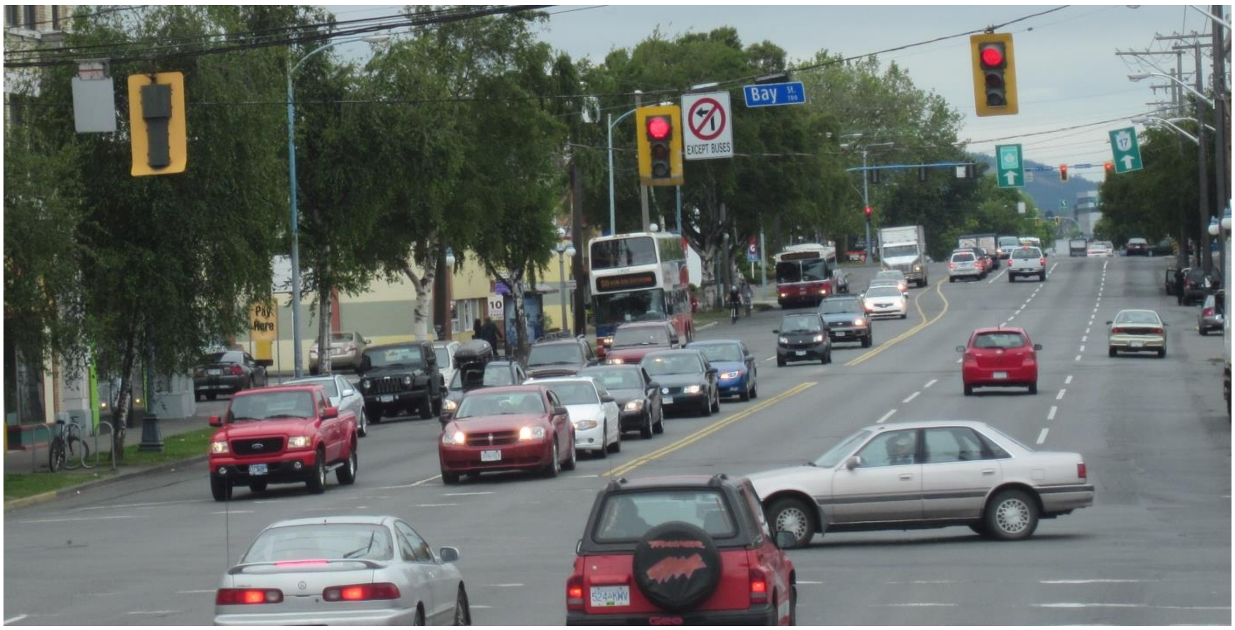

A new traffic safety paradigm recognizes ***exposure****, total vehicle travel, as a risk factor, and therefore the safety benefits of vehicle travel reduction strategies such as more multi-modal planning, more efficient transport pricing, Smart Growth development policies and Transportation Demand Management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

Abstract

Despite large investments in traffic safety programs and technologies, motor vehicle accidents continue to impose high social costs, and crash casualty rates have recently started to increase. New strategies are needed to achieve ambitious traffic safety targets such as Vision Zero. Recent research improves our understanding of factors that affect traffic risks and identifies new safety strategies. Applying this knowledge requires a paradigm shift. The old paradigm assumes that driving is generally very safe, and favors targeted safety programs that reduce special risks such as youth, senior, impaired and distracted driving. The new paradigm recognizes that all vehicle travel imposes risks, so in addition to targeted programs it also supports vehicle travel reduction strategies such as more multi-modal planning, efficient transport pricing, Smart Growth development policies and TDM programs. These strategies provide significant co-benefits, in addition to safety. This report examines our emerging understanding of traffic risks and new safety strategies.

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Introduction

Despite large investments in traffic safety, motor vehicle crashes impose huge social costs. According to a National Highway Traffic Safety Administration study, in 2010 United States motor vehicle crashes caused damages estimated to 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).

Information described in this report indicates that the long-term decline in traffic casualty rates is ending. Crash rates have recently increased, indicating that current traffic safety strategies have fulfilled their potential. To achieve ambitious safety goals such as *Road to Zero* (NSC 2017) we need additional traffic safety strategies. This will require a paradigm shift, a change in the way traffic risks are measured and potential safety strategies are evaluated (Hughes 2017; Litman 2013).

In a word, the new paradigm recognizes *exposure* – the amount that vehicles travel – as a risk factor. Total crashes are the product of distance-based crash rates (such as collisions per 100,000 vehicle-miles) times travel distance (such as per capita vehicle-miles); a change in either tends to cause proportional changes in total crashes. The old paradigm assumed that vehicle travel is generally very safe, and so ignored exposure as a risk factor. It argued that most crashes are caused by special risk factors, such as youth, senior, impaired and distracted driving, and so favored targeted safety strategies. The new paradigm recognizes that all vehicle travel imposes risks and so recognizes the additional crashes caused by planning decisions that increase vehicle travel, and the safety benefits of transportation demand management (TDM) strategies such as more multi-modal planning, efficient transport pricing, Smart Growth development policies, and TDM programs. Since most TDM strategies provide large co-benefits, besides safety, the new paradigm supports more comprehensive analysis that considers these impacts.

Table 1 compares the old and new traffic safety paradigms.

Table 1 Comparing the Old and New Traffic Safety Paradigms

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

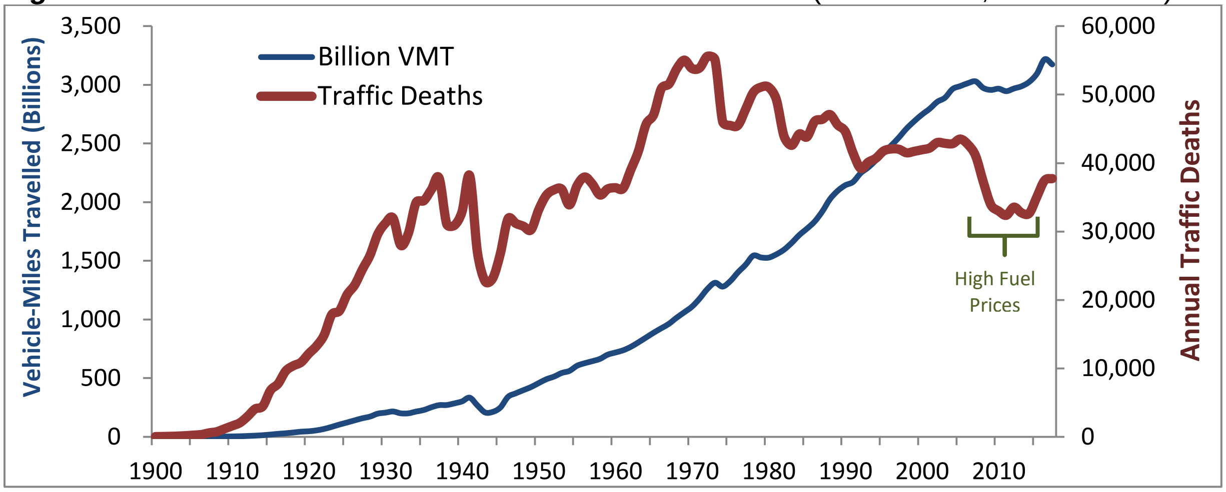
The old and new traffic safety paradigms differ in many ways.

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 new 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.

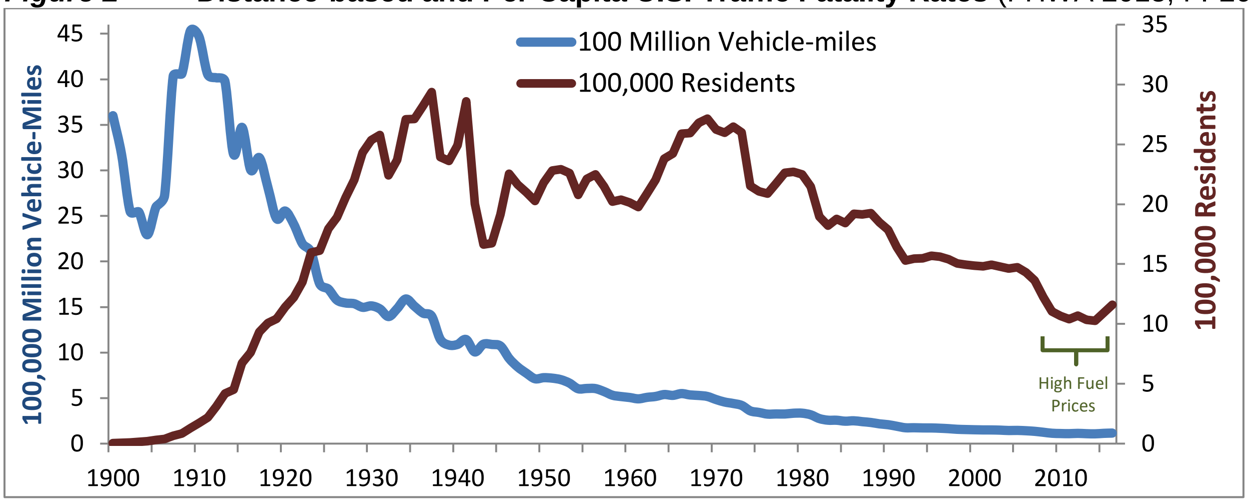
Figure 1 **Total Annual U.S. VMT and Traffic Fatalities** (FHWA 2015, Table FI-201)



Traffic death declined after 1973, but increased after 1993 and subsequently tracked total vehicle travel, and so recently increased when low fuel prices stimulated more vehicle travel.

Figure 1 shows annual U.S. vehicle travel and traffic deaths. Motor vehicle miles of travel (VMT) increased steadily during the Twentieth Century, but grew more slowly after 2006. Total deaths peaked in 1973, and then declined for three decades due to traffic safety strategies such as increased passenger protection and anti-drunk-driving campaigns, but this decline ended in 1993 and subsequently traffic deaths tracked annual vehicle travel. When VMT increased between 1994 and 2003, so did traffic deaths. When high fuel prices reduced VMT between 2004 and 2013, so did traffic deaths. When low fuel prices increased VMT after 2014, so did fatalities. Figure 2 shows distance-based and per capita traffic fatality rates. These declined during most of the Twentieth Century, but plateaued between 2010 and 2014 and recently increased.

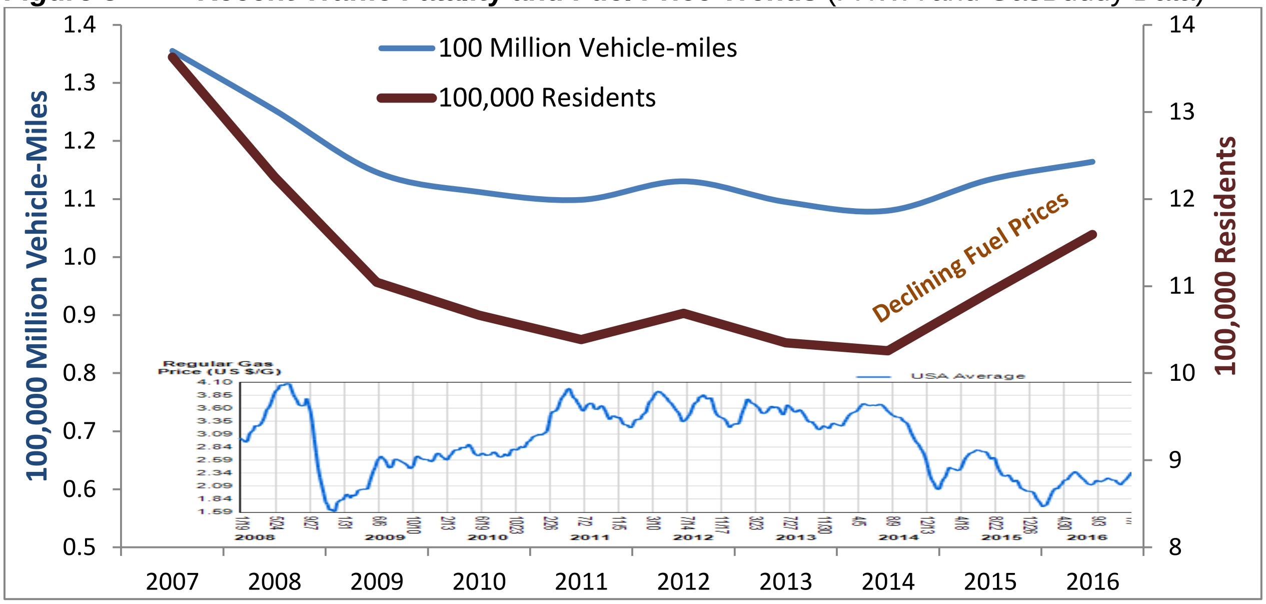
Figure 2 **Distance-based and Per Capita U.S. Traffic Fatality Rates** (FHWA 2015, FI-201)



Deaths per vehicle-mile declined significantly during the last century, but this decline stopped after 2010.

Figure 3 shows 2007 to 2016 U.S. fuel price trends and traffic fatality rates. When fuel prices were high, traffic fatality rates declined, but when fuel prices declined between 2014 and 2016, per capita vehicle travel and traffic death rates increased. This and other research described later in this report illustrate how factors that affect per capita vehicle travel, and therefore crash exposure, affect crash rates.

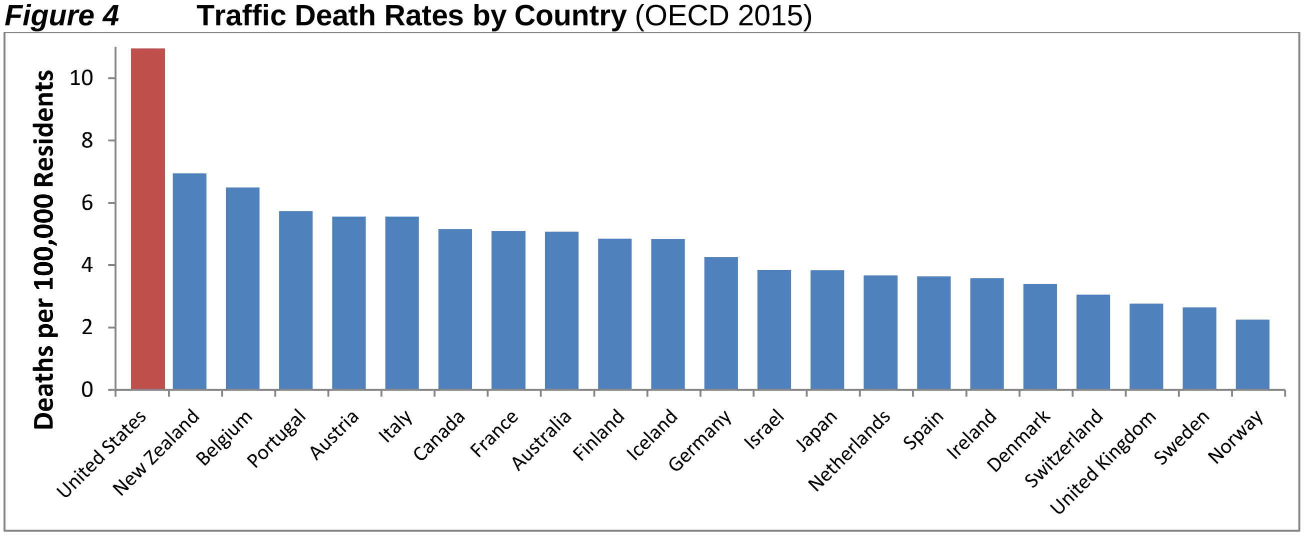
Figure 3 **Recent Traffic Fatality and Fuel Price Trends** (FHWA and GasBuddy Data)



Traffic fatality rates declined while fuel prices where high but increased after 2014 when prices went down.

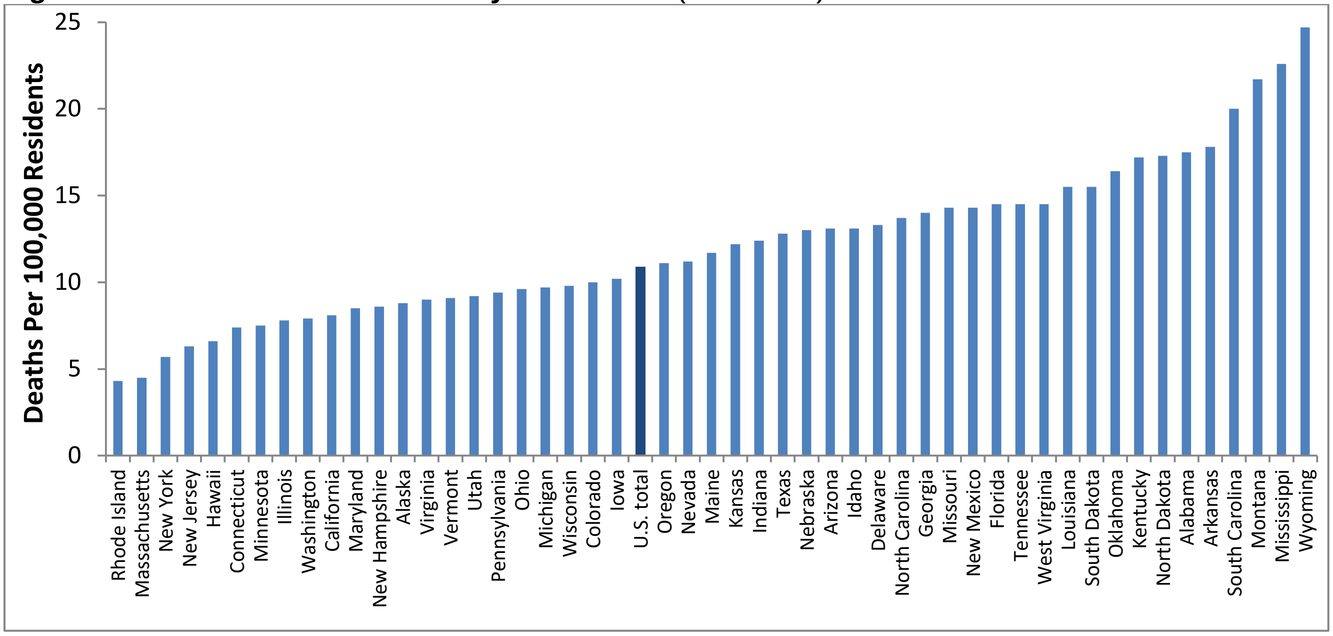
International comparisons indicate that large safety gains are possible. The U.S. has the highest per capita traffic fatality rate among its peers (Figure 4). Geographic factors do not explain this: Australia and Canada have lower population densities, and Sweden, Norway and Finland have more extreme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

Figure 4 **Traffic Death Rates by Country** (OECD 2015)



The U.S. has the highest traffic fatality rate among peer countries, nearly twice those of Australia and Canada, and three times those of European countries.

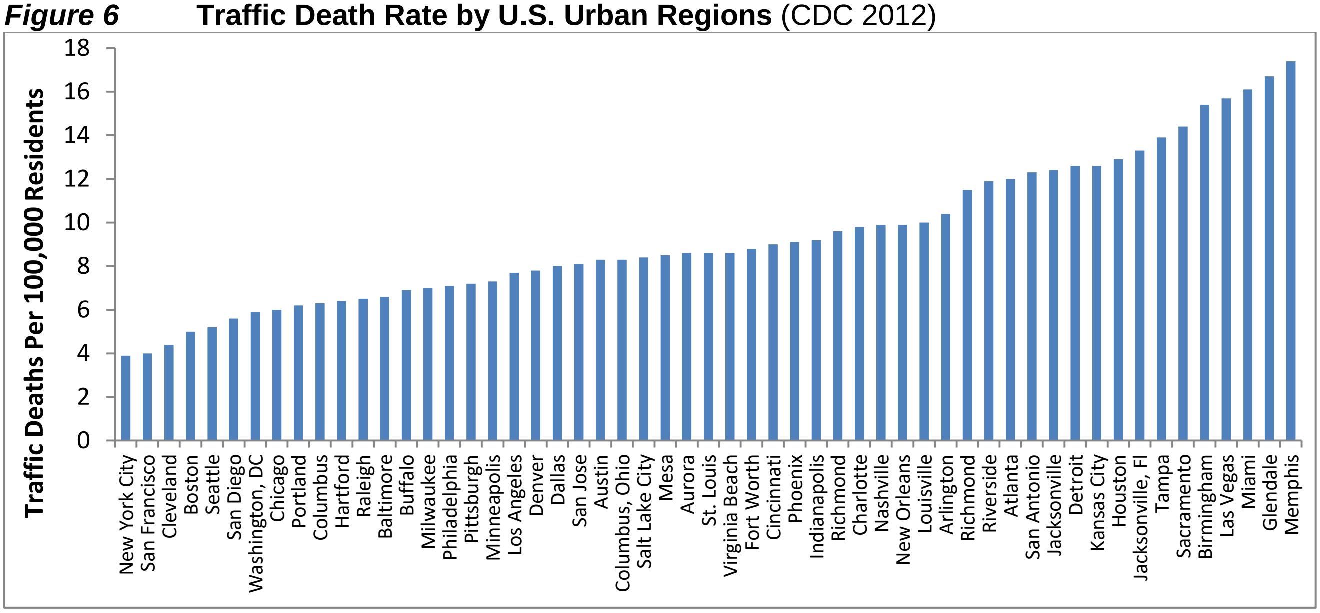
Figure 5 **Traffic Death Rates by U.S. States** (IIHS 2015)



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

There are also large crash rate variations between geographically similar states and regions, as illustrated in figures 5 and 6. For example, Minnesota, Illinois and Washington have about half the traffic fatality rates of Oklahoma, Kentucky and South Carolina, and Seattle, San Diego and Portland have less than half the rates of Atlanta, Houston and Sacramento, despite similar vehicles, roads and traffic safety programs. Evidence described in the next section of this report indicates that these variations largely reflect transport and land use policies that affect per capita vehicle travel.

Figure 6 **Traffic Death Rate by U.S. Urban Regions** (CDC 2012)



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

Many people hope that new technologies will soon eliminate traffic risks. Advocates claim that in a few years autonomous vehicles will be ubiquitous and inexpensive, and since human errors contribute to 90% of traffic crashes, they will eliminate 90% of crashes (Keeney 2017; Kok, et al. 2017). However, more objective experts predict that autonomous vehicles will take longer to develop, cost more, and introduce more risks than advocates claim (Ackerman 2017; Litman 2018; Shladover 2016). Optimistic safety predictions tend to overlook the additional risks these technologies can introduce (Hsu 2017; Koopman and Wagner 2017). These include:

- *Hardware and software failures.* Complex electronic systems can fail, as computer and Internet users often experience. 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 public policies that affect how they are programmed and used. For example, to maximize mobility they can be programmed to operate at higher speeds, take greater risks in unexpected situations, and have dedicated platooning lanes, but to maximize safety they should be programed to drive slower and be more cautious in unexpected situations (resulting in more frequent waits for human instructions), and public polices, such as efficient road pricing and high occupant vehicle (HOV) lanes, can reduce total vehicle travel and therefore risk exposure.

Some experts acknowledge that autonomous vehicles may provide relatively modest safety gains. For example, Groves and Kalra (2017) argue that autonomous vehicle deployment is justified even if they only reduce crash rates 10%, but acknowledge that total 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.

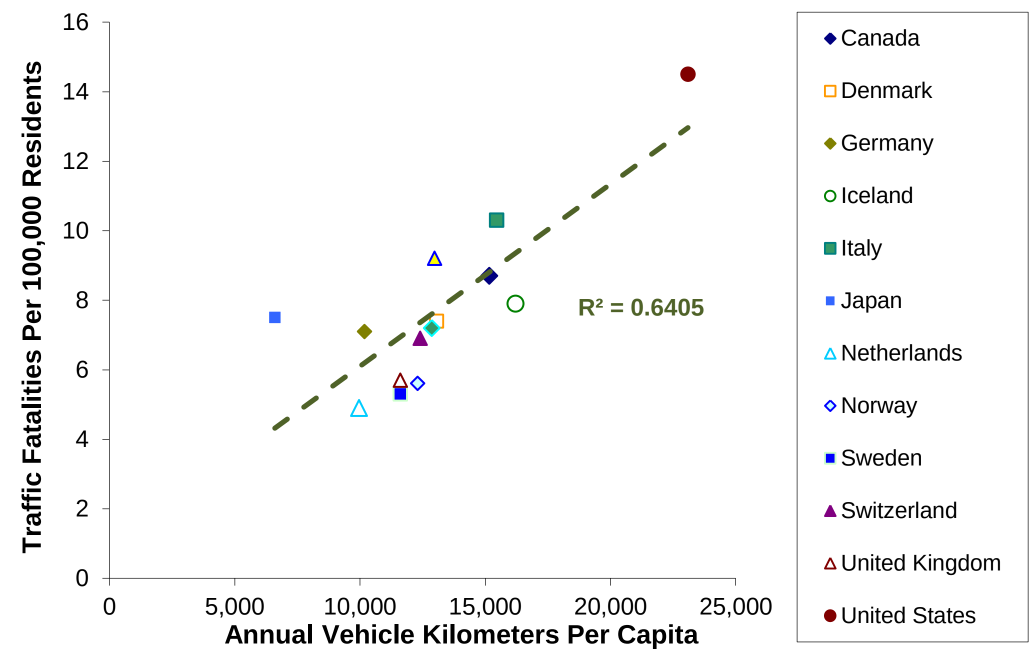
New Understanding of Traffic Risk

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

Total Vehicle Travel

Although many demographic, geographic and economic factors affect casualty 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, per capita crash rates tend to increase with per capita vehicle travel, as illustrated in Figure 7. As previously mentioned, the U.S. has the highest traffic death rate among peer countries, which can be explained by it having the highest per capita annual mileage.

Figure 7 **Vehicle Mileage and Traffic Fatality Rates in OECD Countries** (OECD Data)

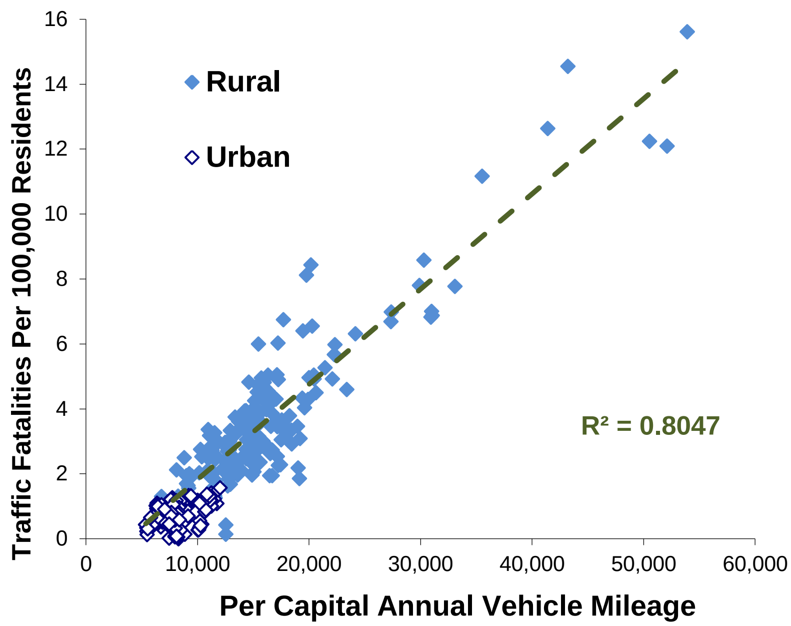


Among economically similar countries there is a strong positive relationship between per capita vehicle travel and traffic deaths.

This explains why the U.S. has the highest per capita traffic death rate among its peers.

Per capita traffic fatality rates tend to increase with vehicle travel among U.S. states, as indicated below.

Figure 8 **Vehicle Mileage Versus Traffic Fatalities in U.S. States** (FHWA 1993-2002 data)

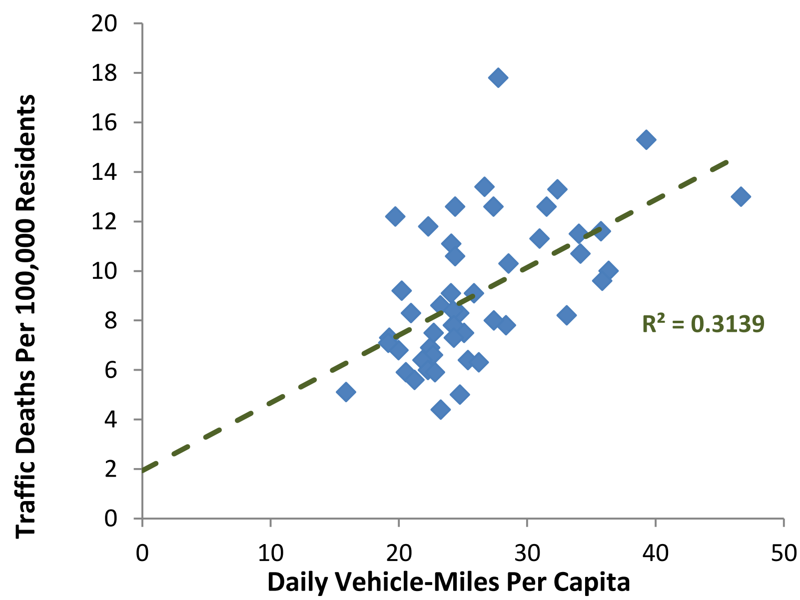


This figure shows various year's traffic fatality and annual mileage rates for urban and rural portions of U.S. states.

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

Similar patterns occur at smaller geographic scales. Figure 8 shows that regional traffic fatality rates tend to increase with vehicle travel, and other studies indicate that 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; Garrick and Marshall 2011; Welle, et al. 2015).

Figure 9 **Vehicle Mileage Versus Traffic Deaths** (FHWA and CDC data)



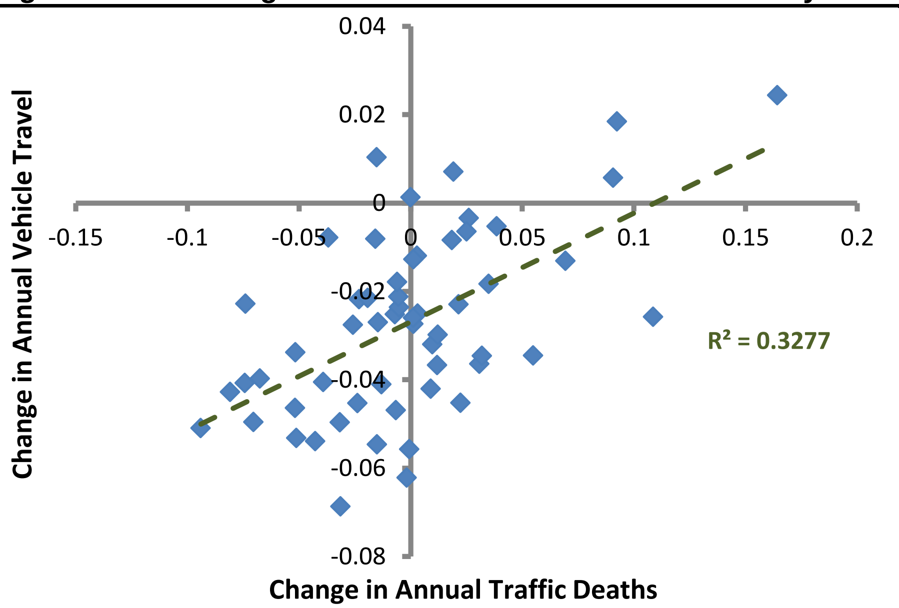
Per capita traffic fatality rates tend to increase with per capita vehicle-miles in U.S. Metropolitan regions.

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 1997 to 2013 to capture the effect of seven separate sets of factors that influence traffic risks: exposure, travel behavior, socioeconomics, macroeconomics, safety policies, and mitigating factors such as health care. Their results indicate that two variables, *Vehicle Miles Traveled* and *Vehicles per Capita*, have the strongest impact on per capita traffic fatality rates. Similarly, accounting for various geographic and demographic factors, Yeo, Park and Jang (2015) found that each 1% increase in per capita VMT is associated with a 0.549% increase in traffic deaths, and comprehensive analysis by 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.

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.

These impacts are dynamic. Figure 10 illustrates the relationship between annual changes in vehicle travel and traffic fatalities in the U.S. between 1960 and 2016. Years when vehicle travel increased tend to have similar increases in traffic deaths, and when vehicle travel declines so do deaths.

Figure 10 **Changes in Vehicle Travel and Traffic Fatality Rates** (FHWA 2015, Table FI-201)



Total U.S. traffic fatality rates tended to increase when total vehicle travel increased and decline when vehicle travel declines.

Quality of Transport Options

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

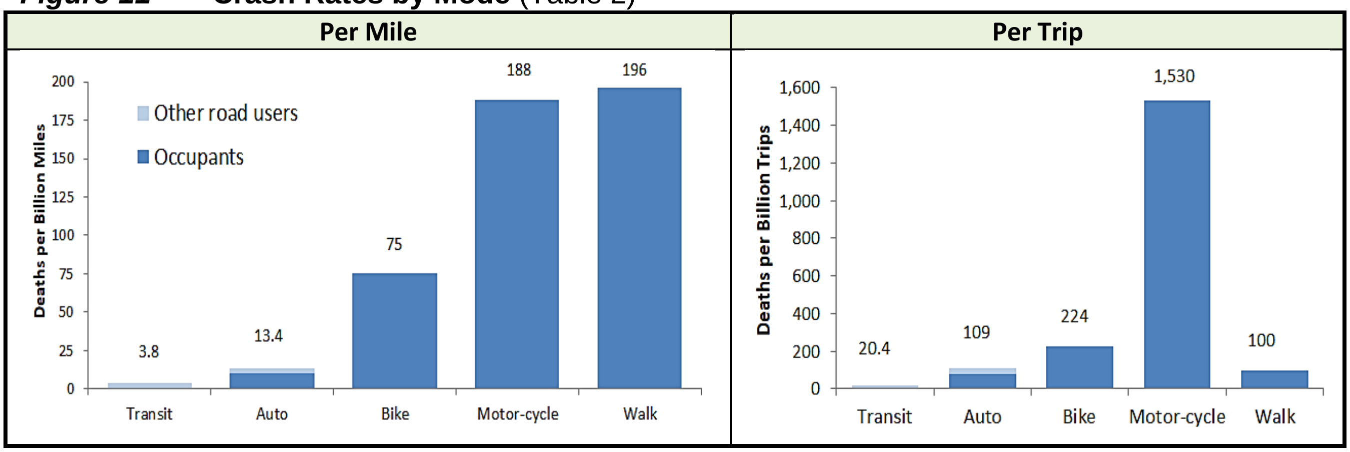
Table 2 **2009 Crash Rates by Mode** (NHTS and NHTSA data)

	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 11 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).

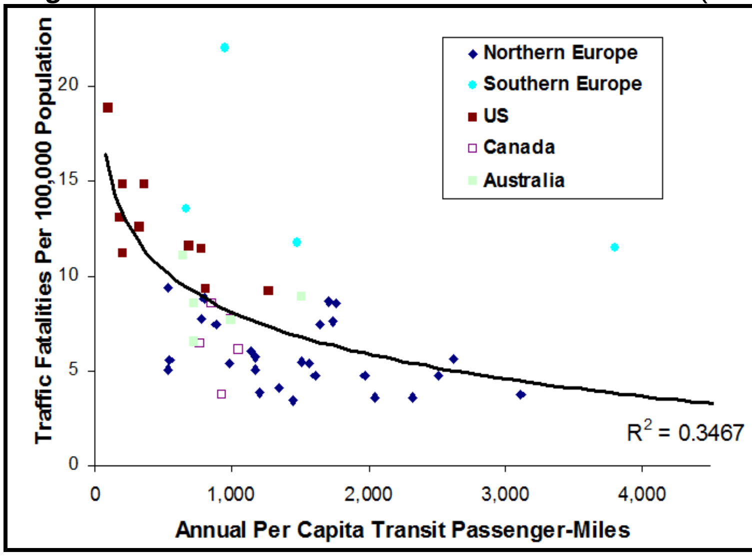
Figure 11 **Crash Rates by Mode** (Table 2)



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

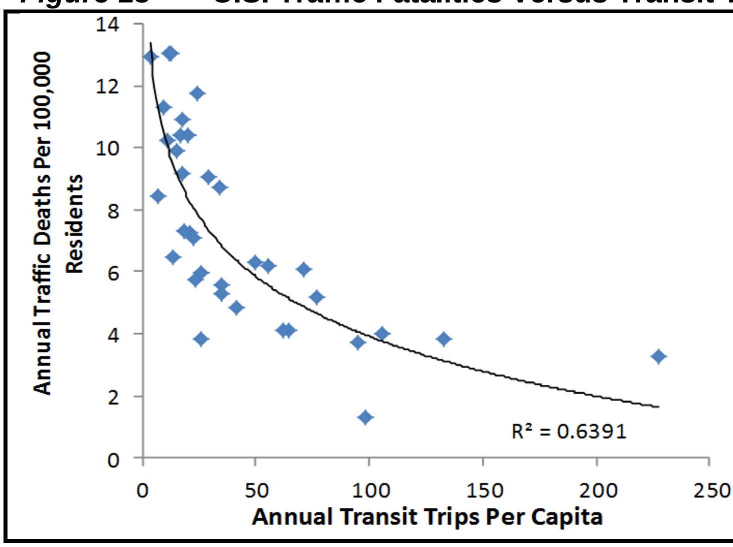
Figure 12 **Traffic Fatalities Vs. Transit Travel** (Kenworthy and Laube 2000)



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

Figure 12 and 13 illustrate the relationship between transit travel and death rates. 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, good walkability, carshare services and reduced parking supply, have synergistic effects that reduce vehicle travel and increase traffic safety.

Figure 13 **U.S. Traffic Fatalities Versus Transit Trips** (FTA 2012; NHTSA 2012)

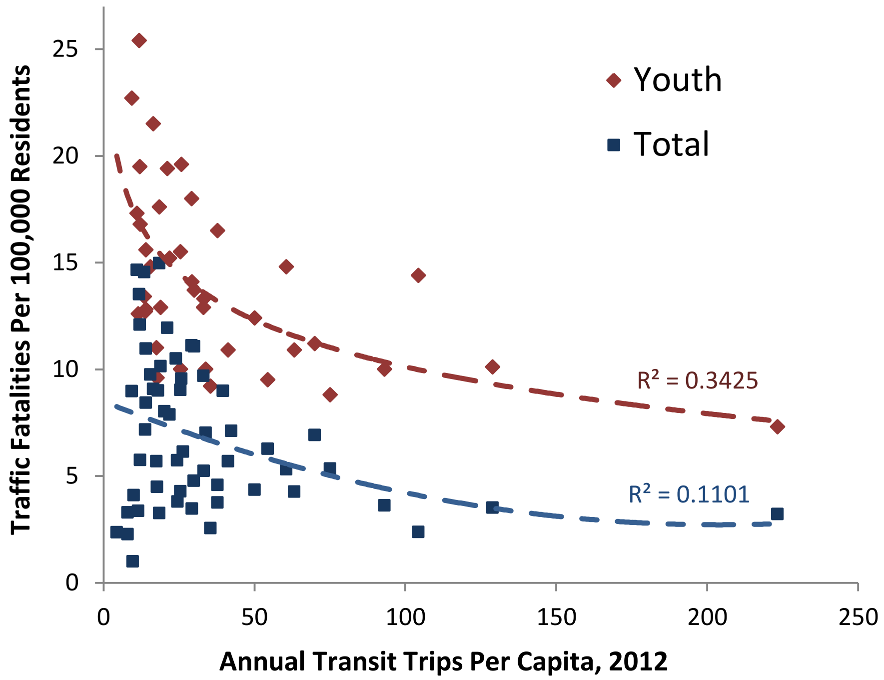


This graph illustrates the relationship between per capita transit ridership and total (including pedestrian, cyclist, automobile occupant and transit passenger) traffic fatalities for 35 large North American cities.

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

Figure 14 indicates that the statistical relationship between transit ridership and traffic safety is particularly strong for youths, age 15-25, 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 14 **Youth and Total Traffic Fatality Rates Compared to Transit Travel** (CDC 2012)

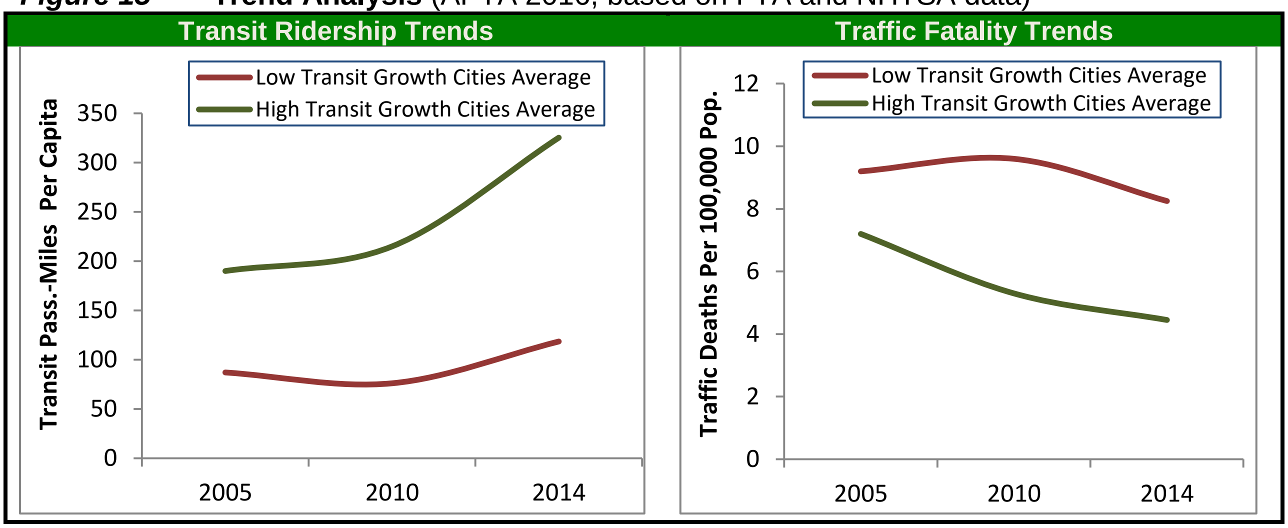


Youths (15-25 years old) have about twice the traffic fatality rates as the total population average, and both youth and total fatality rates tend to decline with increased transit ridership.

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

Trend data indicate that transit improvements tend to increase traffic safety. Figure 15 compares transit ridership and total (all mode) 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). The high transit growth cities had much larger crash rate declines (38% versus 10%), which suggests that increasing transit ridership tends to increase safety for all travellers.

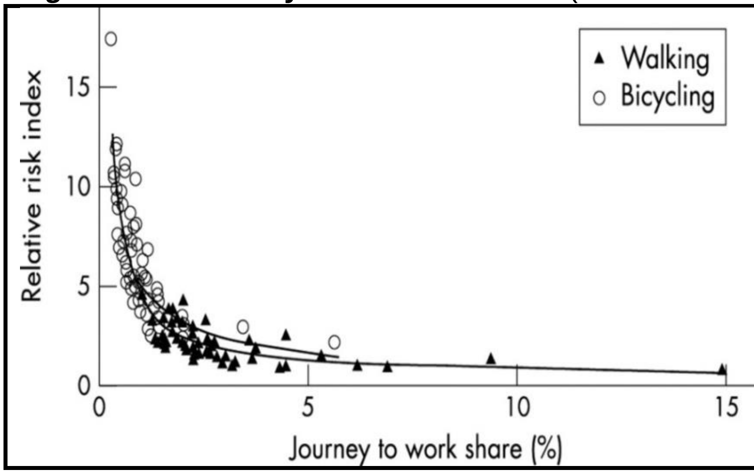
Figure 15 **Trend Analysis** (APTA 2016, based on FTA and NHTSA data)



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 distance-based 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 walking and bicycling increases in an area, an effect called *safety in numbers* (ABW 2016; Castro, Kahlmeier and Gotschi 2018; ECF 2012; NACTO 2016), as Figure 16 illustrates.

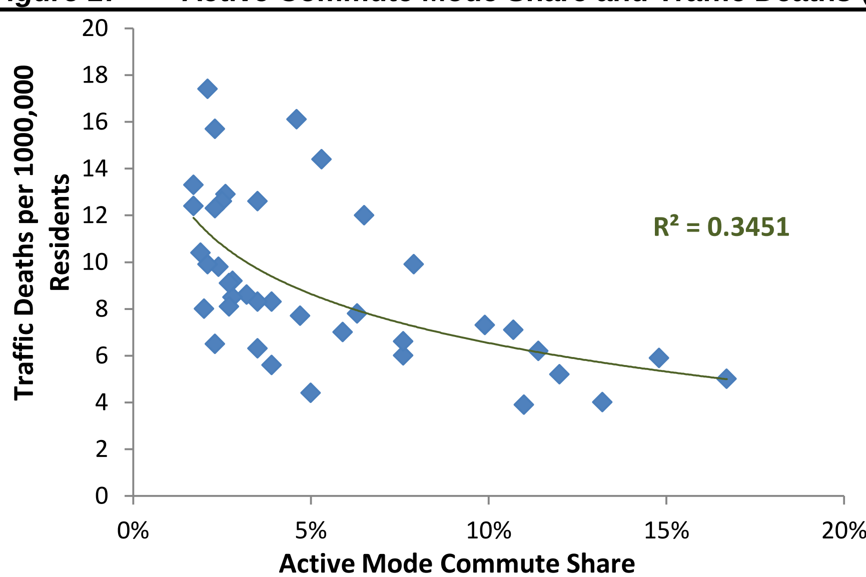
Figure 16 **Safety in Numbers Effect** (Jacobson 2003)



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.

Cities with active mode shares over 10% average about half the per capita traffic fatality rates as those with active mode shares under 5% (Figure 17). A comprehensive study by Marshall and Garrick (2011) found that in U.S. cities, total traffic fatality rates 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 17 **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 reductions in total crashes associated with more active transport:

- *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.* 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.
- *Vehicle ownership reductions*. Improving alternative modes can allow some households to reduce their vehicle ownership. Since motor vehicles are costly to own but relatively cheap to use, once households purchase an automobile they tend to use it, including some relatively low-value trips.
- *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 more walking and cycling occurs 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 their driving, increasing the effectiveness of safety programs such as graduated licenses, senior driver testing and anti-impaired and distracted driving campaigns. For example, public transit improvements reduce post-drinking driving (Greenwood and Wattal 2015).
- *Reduced risk to other road users.* Pedestrians and cyclists impose less risk on other road users.

Relatively modest investments can increase active mode travel and safety. 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). Similarly, 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, 2011 and 2013) 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) 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 (insurance premiums based directly on annual vehicle mileage). 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 should provide more than 10% reduction in crashes and claim costs).

Land Use Development Factors

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%.

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).

How Common Planning Practices Can Increase Risk

Many conventional transportation and land use planning practices tend to increase total vehicle travel and crash risk (DeRobertis, et al. 2014; Dumbaugh and Rae 2009). For example, development policies that separate land uses, minimum parking requirements in zoning codes and unpriced on-street parking tend to increase motor vehicle travel (CARB 2014). Common transport planning practices, often intended to increase traffic safety, often 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 (Garrick and Marshall 2011; Karim 2015; Noland and Oh 2004). 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.

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.

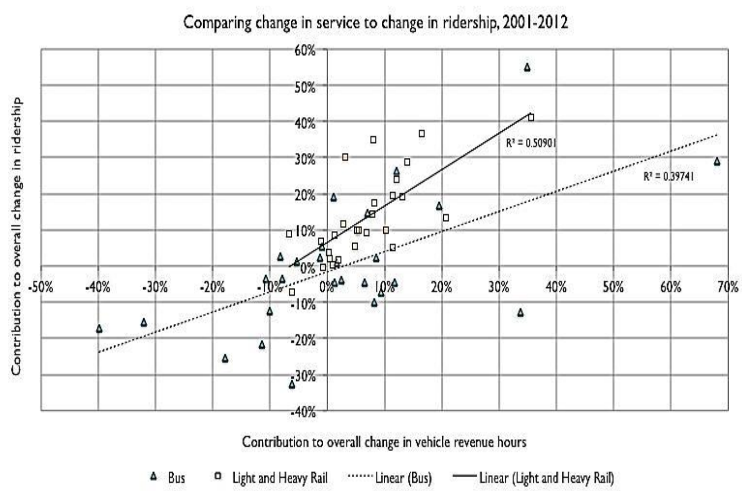
New Paradigm Safety Strategies

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

Transit Service Improvements

Public transit service improvements include more routes, service frequency, bus lanes, nicer waiting areas, nicer vehicles, improved user information and more convenient payment systems. Such improvements tend to increase transit ridership (Figure 18) and reduce automobile travel. Although public transit serves a relatively small portion of total travel in most cities, high quality transit (urban rail and bus rapid transit) often leverages additional vehicle travel reductions by encouraging 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 18 **Ridership Versus Service Hours** (Freemark 2014)



Increasing transit service hours tends to increase transit ridership and reduce automobile travel.

As previously described, increasing transit ridership can significantly reduce crash rates. For example, the four high transit growth cities shown in Figure 14 (Denver, Los Angeles, Portland and Seattle) experienced a 28% average reduction in per capita traffic fatality rates between 2005 and 2014, more than three times the 8% reduction experienced by the four low transit growth cities (Cleveland, Dallas, Houston and Milwaukee). 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.

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, so they are located in residential neighborhoods, priced by the hour, and marketed to local residents. Although carsharing may increase vehicle travel by households that otherwise lack motor vehicle access, can significantly reduce household vehicle ownership, which reduces vehicle travel (ITF 2015). In dense urban neighborhoods, households with carsharing membership own 40% fewer vehicles and drive 33% fewer annual miles than a control group (Clewlow 2015). This suggests that carsharing can provide large safety benefits in suitable areas. 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 are currently able to park without a fee at most destinations, due to unpriced on-street parking, and zoning codes that require that large numbers of parking spaces be included in most developments. As a result, most parking costs are borne indirectly through general taxes, building rents, and higher costs for retail goods. Parking facility annualized costs (total land, construction and operating costs calculated by the year) typically range from $500 for a basic parking lot on low-value land to more than $3,000 for structured and underground parking (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" (employees who use non-auto modes are offered cash benefits equivalent to the parking subsidies offered those who drive); 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, which is approximately equivalent to a 60% fuel price increase, although it is simply a different way of paying existing fees rather than a cost increase. Such a price change should reduce participating vehicles' average 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, and so would reduce their driving and crash risk more than 20%. 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 ($25-50 annually) and raises privacy concerns. Basic distance-based pricing only requires an odometer reading at the start and end of the policy term. 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 11,000 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%, accounting for the large mileage reductions by higher-risk drivers and overall reductions in traffic density.

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.

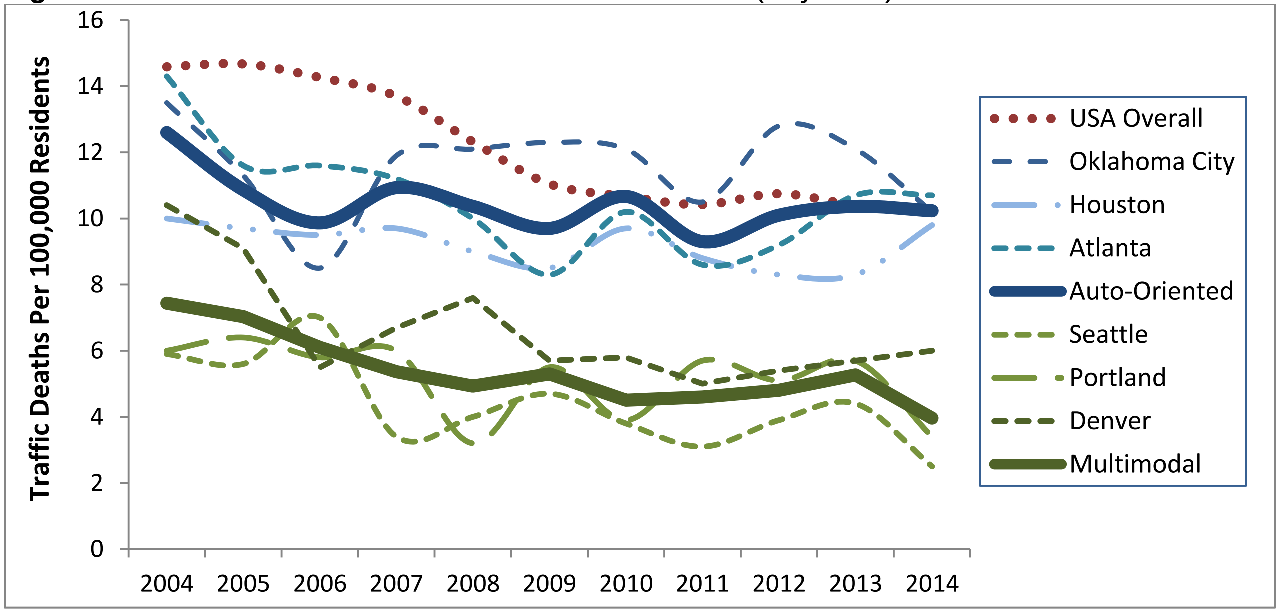
More Comprehensive and Multi-modal Planning

Conventional planning is biased in many ways that 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 compared with those that apply conventional, auto-oriented planning, illustrated in Figure 19.

Figure 19 **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%).

More Connected and Complete Streets

Roadways are often designed to maximize traffic speeds with wider lanes, minimum cross-street and wide clearzones. Although often justified as ways to increase safety, by increasing traffic volumes and speeds, these design factors can increase total crashes and crash severity (Dumbaugh and Rae 2009), particularly in urban areas (CALTRANS 2014; Larson 2018).

Table 3 **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 on higher-speed roads in rural areas, but by increasing vehicle traffic speeds, tends to increase crash severity in urban areas where more walking, cycling and cross traffic occurs.

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 cycling 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 roadways designed to accommodate diverse users and uses, including walking, cycling, public transit, automobile travel, nearby businesses and residents. This tends to increase travel safety, particularly for pedestrians and cyclists, and by improving active and public transportation, reduce total vehicle travel and accidents. 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 and Garrick 2011). Similarly, Mohan, Bangdiwala and Villaveces (2017) found that, all else being equal, more roadway junctions and fewer kilometers of arterial grade roadways are associated with lower motor-vehicle and pedestrian traffic death rates.

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 significantly 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) tends 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.

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 (Welle, et al. 2015).

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.

Table 4 summarizes these fifteen new paradigm safety strategies.

Table 4 **Fifteen New Paradigm Safety Strategies**

Strategy	Traffic Safety Impacts	Crash Rate Reductions
Shorter Term (less than three years)		
Transit service improvements (more routes, frequency, etc.).	Reduces vehicle travel directly, and often leverage additional reductions.	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 transport improvements (better sidewalks, crosswalks, bikelane, etc.).	Reduces walking and bicycling crash rates, and total per capita crash rates.	Comprehensive active transport improvements can reduce resident's total crash casualty rates 5-10%.
Expanded carsharing services	Reduces crashes by reducing car ownership.	Reduce total crashes 0.3-3%, with larger reductions in denser areas.
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 should reduce crash casualty rates 4-12%.
Efficient parking pricing (motorists pay directly for using parking spaces).	Charging motorists directly for parking typically reduces affected trips 10-30%, and may reduce vehicle ownership.	Each 10% increase in the portion of parking that is efficiently priced reduces crash casualties 1-3%.
Congestion pricing (road tolls that increase under congested conditions)	Reduces crashes by reducing automobile use, particularly in large cities.	Reduces affected area crash casualty rates 15-30%, with smaller reductions in nearby areas.
Distance-based vehicle insurance and registration fees.	Reduces vehicle use, especially higher risk driving.	Reduces affected vehicles' crashes by 10-20%.
Commute trip reduction programs.	Typically reduces affected commute trips 5-30%, and may cause some vehicle ownership reductions.	Can reduce affected commuters' crashes casualty rates 5-30% and total crashes 0.5-3%.
Mobility management marketing.	Encourages travellers to use 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	Supports more multi-modal transport planning and considers safety impacts.	Can lead to large vehicle travel and crash reductions.
More connected and complete streets.	Reduces crash frequency and severity by reducing vehicle travel, improving non-auto modes and reducing traffic speeds.	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 crashes by reducing vehicle ownership and use, and traffic speeds.	Can reduce crash rates 30-60% in affected areas and 10-30% region-wide
Smart Growth and Transit Oriented Development	Reduces crash frequency and severity by reducing vehicle travel, improving non-auto modes and reducing traffic speeds.	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.

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[6] Ironically, conventional zoning codes often apply very high minimum parking requirements to restaurants, bars and pubs, 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 5 **Comparing Analysis Frameworks**

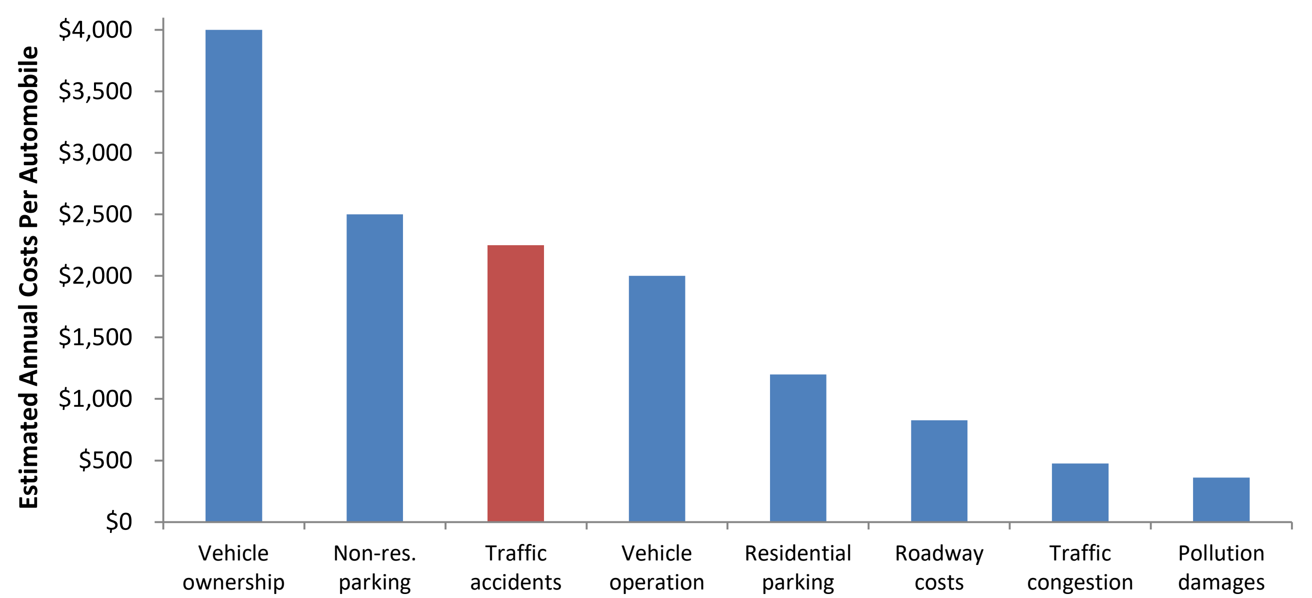
Factor	Old	New
Units of exposure	Distance-based units (e.g., casualties per 100 million vehicle-miles or billion vehicle-kilometers)	Per capita (e.g., casualties per 100,000 residents)
Perspective	Internal (user) impacts, such as casualties to vehicle occupants.	Internal and external impacts, such as 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 estimated that in 2010, U.S. traffic crashes caused $242 billion in direct economic losses, averaging about $1,000 per motor vehicle, and $836 billion in total costs including human suffering, averaging about $3,500 per motor vehicle (Blincoe, et al. 2015). Using a mid-point estimated of $2,250, annual crash costs are smaller than vehicle ownership costs (financing, depreciation, insurance, registration fees and scheduled maintenance, which average about $4,000 annually), and about equal to total non-residential parking (the 2-6 off-street parking spaces per vehicle provided at worksites, shops and other destinations), but larger in magnitude than most other costs including vehicle operation (about $2,000 for fuel and tire wear), residential parking (about $1,200 for a garage or carport), roadway costs (which totaled about $200 billion in 2010, or about $826 per vehicle), traffic congestion (estimated to total $115 billion in 2010, or $475 per vehicle), and motor vehicle air, noise and water pollution are estimated to average 3¢ per vehicle-mile or about $360 annually (some estimates are much higher). Figure 20 compares these costs.

Figure 20 **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 traffic safety programs (sobriety checks, new driver testing, advertising campaigns, etc.) are costly and provide few benefits besides safety, while most new paradigm safety strategies provide significant co-benefits. For example, improving non-auto modes, pricing reforms, Smart Growth 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 and traffic safety program decisions. For example, when comparing roadway expansion or public transit improvements as possible congestion reduction strategies, 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, or increases in per capita traffic casualty rates if the highway expansion 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 pedestrian and transit improvements, and more compact and multi-modal 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 the degree that current traffic safety programs consider new paradigm solutions.

Table 6 Review of Traffic Safety Programs (APTA 2016)

Program	VMT Reduction Safety Strategies
Countermeasures That Work, National Highway Traffic Safety Administration (http://bit.ly/2zMe3Dm)	None
Desktop Reference for Crash Reduction Factors, ITE (www.ite.org)	None
Developing Safety Plans: Manual for Local Rural Road Owners, Federal Highway Administration (http://bit.ly/2px3hIA)	None
Getting to Zero Alcohol-impaired Driving Fatalities: A Comprehensive Approach to a Persistent Problem (www.nap.edu/download/24951)	Recommends improving public transportation and ridehailing services
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, Governors Highway Safety Association (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
Traffic Safety Fundamentals Handbook, MDOT (http://bit.ly/2qbVVNq)	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, US Department of Transportation (http://bit.ly/2oFbz0j)	Recommends some vehicle travel reduction strategies.
World Report on Road Traffic Injury Prevention, Global Road Safety Partnership (www.grsproadsafety.org)	Recommends demand management strategies.
Getting to Zero Alcohol-Impaired Driving Fatalities National Academy Press (www.nap.edu/download/24951)	Supports increased travel options for drinkers who might otherwise drive
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 eighteen major traffic safety programs reviewed, only six mention 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.

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 increases 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.

New paradigm safety strategies often provide much greater safety gains and benefits than recognized by conventional analysis. For example, walking and bicycling have relatively high per-mile casualty rates, which implies that increasing use of these modes increases traffic risk, but many studies demonstrate that total crash rates tend to decline as active travel increases, due to a combination of increased caution, reduced risk to other road users, and reduction in total vehicle travel, resulting in safety in numbers. Similarly, relatively small increases in public transit ridership tend to leverage large traffic safety gains, suggesting that higher risk travellers often want to avoid driving, but can only do so if they have suitable mobility options. Table 7 lists various strategies that can provide synergistic traffic safety benefits.

Table 7 **Recipe for Multi-modalism**

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 program 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, they often remove existing market distortions, such as reducing minimum parking requirements that subsidized automobile travel, and allowing transportation funding to respond to consumer demands for non-auto modes. 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 an attached house (townhouse or apartments) 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*, the amount that people 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 assumes 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 favors multi-modal planning, TDM strategies and Smart Growth development policies.

Table 8 **Scope of Safety Programs**

Old Safety Programs	New Paradigm Safety Strategies
• Anti-impaired and distracted driving campaigns. • More testing for youth and senior drivers. • Roadway design improvements. • Vehicle design improvements. • Vehicle occupant crash protection.	• More multi-modal transport planning (improved walking, cycling, ridesharing and public transit). • More efficient transport pricing (distance-based vehicle insurance, parking pricing, road tolls, higher fuel taxes). • Smart Growth development and Complete Streets policies. • TDM programs (such as commute trip reduction).

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. New paradigm strategies tend to provide many co-benefits, including consumer savings and affordability, road and parking congestion reductions, improve mobility for non-drivers, and increase public fitness and health, and so are supported by more comprehensive evaluation.

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.

References

ABW (2016), *Bicycling and Walking in the U.S. Benchmarking Report*, Alliance for Biking & Walking, (http://abw.nonprofitsoapbox.com); at http://abw.nonprofitsoapbox.com/resources/benchmarking.

Evan Ackerman (2017), "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy," *Spectrum*, International Institute of Electrical Engineers (www.ieee.org); at http://bit.ly/2FJYJax.

Hamed Ahangari, Jason Outlaw, Carol Atkinson-Palombo and Norman Garrick (2014), "An Investigation into the Impact of Fluctuations in Gasoline Prices and Macroeconomic Conditions on Road Safety in Developed Countries," *Transportation Research Record 2465*, TRB (www.trb.org); summary at https://bit.ly/2zcwq1i.

Hamed Ahangari, Carol Atkinson-Palombo and Norman Garrick (2017), "Automobile Dependency as a Barrier to Vision Zero: Evidence from the States in the USA," *Accident Analysis and Prevention*, Vol. 107, pp. 77-85 (https://doi.org/10.1016/j.aap.2017.07.012); at https://bit.ly/2IMCfdc.

APTA (2016), *The Hidden Traffic Safety Solution: Public Transportation*, American Public Transportation Association (www.apta.com); at https://bit.ly/2bYqQpr.

Laurie F. Beck, Ann M. Dellinger and Mary E. O'Neil (2007), "Motor Vehicle Crash Injury Rates by Mode of Travel, United States: Using Exposure-Based Methods to Quantify Differences," *American Journal of Epidemiology*, Vol. 166, Is. 2, pp. 212–218 (https://doi.org/10.1093/aje/kwm064); at https://bit.ly/2zPxc8v.

Lawrence J. Blincoe, Ted Miller, Eduard Zaloshnja and Bruce Lawrence (2015), *The Economic and Societal Impact of Motor Vehicle Crashes, 2010. (Revised)*, Report No. DOT HS 812 013, National Highway Traffic Safety Administration; at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013.

Paul J. Burke and Shuhei Nishitateno (2015), "Gasoline Prices and Road Fatalities: International Evidence," *Economic Inquiry* (DOI: 10.1111/ecin.12171); at http://bit.ly/1QBY62Z.

CALTRANS (2014), *Main Street, California: A Guide for Improving Community and Transportation Vitality*, California Department of Transportation (www.dot.ca.gov); at https://bit.ly/1Ny89nY .

CARB (2014), *Research on Impacts of Transportation and Land Use-Related Policies*, California Air Resources Board (http://arb.ca.gov/cc/sb375/policies/policies.htm).

Alberto Castro, Sonia Kahlmeier and Thomas Gotschi (2018), *Exposure-adjusted Road Fatality Rates for Cycling and Walking in European Countries*, International Transport Forum (www.itf-oecd.org); at https://bit.ly/2PicN2u.

CDC (2012), *Motor Vehicle Crash Deaths in Metropolitan Areas — United States, 2009*, Center for Disease Control (www.cdc.gov); at www.cdc.gov/mmwr/preview/mmwrhtml/mm6128a2.htm.

Mikhail Chester, et al. (2015), "Parking Infrastructure: A Constraint on or Opportunity for Urban Redevelopment? A Study of Los Angeles County Parking Supply and Growth," *Journal of the American Planning Association*, Vol. 81(4), pp. 268-286 (doi: 10.1080/01944363.2015.1092879); at www.transportationlca.org/losangelesparking.

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

G. Chi, et al. (2011), *A Time Geography Approach to Understanding the Impact of Gasoline Price Changes on Traffic Safety*, TRB (www.trb.org); at http://nexus.umn.edu/Papers/TimeGeography.pdf.

G. Chi, et al. (2013), "Gasoline Price Effects on Traffic Safety in Urban and Rural Areas: Evidence from Minnesota, 1998–2007," *Safety Science*, Vol. 59, pp. 154-162; at http://bit.ly/2nkESVx.

City-Data (www.city-data.com).

Regina R. Clewlow (2015), *Carsharing and Sustainable Travel Behavior: Results from the San Francisco Bay Area*, Precourt Energy Efficiency Center, Stanford University; at https://bit.ly/2Lk8xxE.

Michelle DeRobertis, et al. (2014), "Changing the Paradigm of Traffic Impact Studies: How Typical Traffic Studies Inhibit Sustainable Transportation," *ITE Journal* (www.ite.org), May, pp. 30-35.

DfT (2017), *Transport Analysis Guidance*, UK Department for Transport (www.dft.gov.uk); at www.gov.uk/guidance/transport-analysis-guidance-webtag.

Eric Dumbaugh and Robert Rae (2009), "Safe Urban Form: Revisiting the Relationship Between Community Design and Traffic Safety," *Journal of the American Planning Association*, Vol. 75, No. 3, Summer (DOI: 10.1080/01944360902950349); at http://actrees.org/files/Research/dumbaugh_urbanform.pdf.

ECF (2012), *Safety in Numbers Fact Sheet*, European Cycling Federation (https://ecf.com); at https://ecf.com/files/wp-content/uploads/ECF_FACTSHEET4_V3_cterree_SafetyNumb.pdf.

Aaron Edlin and Pena Karaca-Mandic (2006), *The Accident Externality from Driving*, *Journal of Political Economy*, Vol. 114, No. 5, pp. 931-955; at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=424244.

John E. Evans and Richard H. Pratt (2005), *Vanpools and Buspools; Traveler Response to Transportation System Changes*, Chapter 5, TCRP Report 95, Transportation Research Board (www.trb.org); at www.nap.edu/download/13845.

Reid Ewing and Robert Cervero (2010), "Travel and the Built Environment: A Meta-Analysis," *Journal of the American Planning Association*, Vol. 76, No. 3, Summer, pp. 265-294; at https://bit.ly/1FLv9bB.

Reid Ewing and Eric Dumbaugh (2009), "The Built Environment and Traffic Safety: A Review of Empirical Evidence," *Journal of Planning Literature*, Vol. 23 No. 4, May, pp. 347-367; at http://bit.ly/2nkBhWR.

Reid Ewing and Shima Hamidi (2014), *Measuring Urban Sprawl and Validating Sprawl Measures*, Metropolitan Research Center, University of Utah (http://mrc.cap.utah.edu); at https://bit.ly/2I6StdG.

Reid Ewing, Shima Hamidi and James Grace (2016), "Urban Sprawl as a Risk Factor in Motor Vehicle Crashes," *Urban Studies*, Vol. 53/2, pp. 247-266 (doi.org/10.1177/0042098014562331); at https://bit.ly/2L9zGQT.

Joseph Ferreira Jr. and Eric Minike (2010), *A Risk Assessment of Pay-As-You-Drive Auto Insurance*, Department of Urban Studies and Planning, MIT (http://dusp.mit.edu); at https://bit.ly/2GtS8jy.

FHWA (2014), *Nonmotorized Transportation Pilot Program: Continued Progress in Developing Walking and Bicycling Networks – May 2014 Report*, John A Volpe National Transportation Systems Center, USDOT (www.fhwa.dot.gov); at https://bit.ly/1KakRWU.

FHWA (2015), *Highway Statistics*, Federal Highway Administration (www.fhwa.dot.gov); at www.fhwa.dot.gov/policyinformation/statistics/2015/fi200.cfm.

Lawrence D. Frank, et al. (2011), *An Assessment of Urban Form and Pedestrian and Transit Improvements as an Integrated GHG Reduction Strategy*, WSDOT (www.wsdot.wa.gov); at https://bit.ly/2KENrHa.

Yonah Freemark (2014), *Recent Trends in Bus and Rail Ridership*, The Transport Politic (www.thetransportpolitic.com); at http://bit.ly/2E1aCsf.

A. Fyhri, et al. (2017), "Safety in Numbers for Cyclists—Conclusions from a Multidisciplinary Study of Seasonal Change in Interplay and Conflicts," *Traffic Analysis and Prevention*, Vol. 105, pp. 124-133 (https://doi.org/10.1016/j.aap.2016.04.039).

Norman W. Garrick and Wesley Marshall (2011), "Does Street Network Design Affect Traffic Safety?" *Accident; Analysis and Prevention*, Vol. 43, No. 3, pp. 769-81, (DOI: 10.1016/j.aap.2010.10.024); draft at http://bit.ly/2Dw9Tlx.

David C. Grabowski and Michael A. Morrisey (2004), "Gasoline Prices and Motor Vehicle Fatalities," *Journal of Policy Analysis and Management* (www.appam.org/publications/jpam/about.asp), Vol. 23, No. 3, pp. 575–593.

David C. Grabowski and Michael A. Morrisey (2006), "Do Higher Gasoline Taxes Save Lives?" *Economics Letters*, Vol. 90, pp. 51–55; abstract at www.sciencedirect.com/science/article/pii/S0165176505002533.

Colin P. Green, John. S. Heywood and Maria Navarro (2015), *Traffic Accidents and the London Congestion Charge*, Lancaster University; at www.lancaster.ac.uk/staff/greencp/papers/CongestionChargeMar2015.pdf.

Allen Greenberg and Jay Evans (2017), *Comparing Greenhouse Gas Reductions and Legal Implementation Possibilities for Pay-to-Save Transportation Price-shifting Strategies and EPA's Clean Power Plan*, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/G&E_GHG.pdf.

Brad N. Greenwood and Sunil Wattal (2015), *Show Me the Way to Go Home: An Empirical Investigation of Ride Sharing and Alcohol Related Motor Vehicle Homicide*, Fox School of Business Research Paper No. 15-054; at http://dx.doi.org/10.2139/ssrn.2557612

GTKP (2018), *Integrating Road Safety into Existing Systems and Policy*, Global Transport Knowledge Practice (www.gtkp.com); at www.gtkp.com/themepage.php&themepgid=376.

Jessica Y. Guo and Sasanka Gandavarapu (2010), "An Economic Evaluation Of Health-Promotive Built Environment Changes," *Preventive Medicine*, Vol. 50, Sup. 1, January, pp. S44-S49; at https://bit.ly/2QYiEbb.

Shima Hamidi, et al. (2015), "Measuring Urban Sprawl and Its Impacts," *Journal of Planning Education and Research*, Vol. 35/1, pp. 35-50 http://journals.sagepub.com/doi/pdf/10.1177/0739456X14565247.

Susan Handy, et al. (2014), *Policy Brief on the Impacts of Network Connectivity Based on a Review of the Empirical Literature*, California Air Resources Board (http://arb.ca.gov/cc/sb375/policies/policies.htm).

Jeremy Hsu (2017), "When It Comes to Safety, Autonomous Cars are Still 'Teen Drivers,'" *Scientific American* (www.scientificamerican.com); at http://bit.ly/2j9gFPT.

Brett Hughes (2017), *A Comprehensive Framework for Future Road Safety Strategies*, PhD Dissertation, Curtin University (https://curtin.edu.au); at https://espace.curtin.edu.au/handle/20.500.11937/59647.

ICF (2010), *Current Practices in Greenhouse Gas Emissions Savings from Transit: A Synthesis of Transit Practice*, TCRP 84, TRB (www.trb.org); at http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_syn_84.pdf.

IIHS (2015), *State By State*, Insurance Institute for Traffic Safety (www.iihs.org); at www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/state-by-state-overview.

ITF (2015), *A New Paradigm for Urban Mobility: How Fleets of Shared Vehicles Can End the Car Dependency of Cities*, International Transport Forum (www.internationaltransportforum.org); at https://bit.ly/1YHQlLR.

Peter Jacobsen (2003), "Safety in Numbers: More Walkers and Bicyclists, Safer Walking and Bicycling," *Injury Prevention* (http://ip.bmjjournals.com), Vo. 9, pp. 205-209; at http://bit.ly/2yDG9gh.

Nidhi Kalra and David G. Groves (2017), *The Enemy of Good: Estimating the Cost of Waiting for Nearly Perfect Automated Vehicles*, Rand Corporation (www.rand.org); at https://bit.ly/2LfF1Jp.

Dewan Masud Karim (2015), *Narrower Lanes, Safer Streets*, CITE Annual Conference; at http://bit.ly/1GKiICo.

Tasha Keeney (2017), *Mobility-As-A-Service: Why Self-Driving Cars Could Change Everything*, ARC Investment Research (http://research.ark-invest.com); at http://bit.ly/2xz6PNV.

Jeffrey Kenworthy and Felix Laube (2000), *Millennium Cities Database For Sustainable Transport*, Institute for Sustainability and Technology Policy, International Union of Public Transport (www.uitp.com).

Kara Kockelman, et al. (2013), *The Economics of Transportation Systems: A Reference for Practitioners*, TxDOT Project 0-6628, University of Texas at Austin (www.utexas.edu); at https://bit.ly/2OdfPok.

Irem Kok, et al. (2017), *Rethinking Transportation 2020-2030: Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries*, RethinkX (www.rethinkx.com); at http://bit.ly/2pL0cZV.

Philip Koopman and Michael Wagner (2017), "Autonomous Vehicle Safety: An Interdisciplinary Challenge," *IEEE Intelligent Transportation Systems Magazine*, Vol. 9, No. 1; at https://bit.ly/2uJho1j.

Rich Kuzmyak, Jay Evans, and Dick Pratt (2010), "Employer and Institutional TDM Strategies," Chapter 19, *Traveler Response to Transportation System Changes*, Report 95 series, Transit Cooperative Research Program, Transportation Research Board (www.trb.org); at www.trb.org/Publications/Blurbs/162432.aspx.

Jon Larson (2018), *Forgiving Design Vs. the Forgiveness of Slow Speeds*, Strong Towns (www.strongtowns.org); at /journal/2018/2/2/forgiving-design-vs-the-forgiveness-of-slow-speeds.

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

Todd Litman (2009), *Transportation Cost and Benefit Analysis*, Victoria Transport Policy Institute (www.vtpi.org/tca).

Todd Litman (2012), "Pricing for Traffic Safety: How Efficient Transport Pricing Can Reduce Roadway Crash Risks," *Transportation Research Record 2318*, pp. 16-22 (www.trb.org); at www.vtpi.org/price_safe.pdf.

Todd Litman (2013), "The New Transportation Planning Paradigm," *ITE Journal* (www.ite.org), Vol. 83, June, pp. 20-28; at www.vtpi.org/paradigm.pdf.

Todd Litman (2014), "How Transport Pricing Reforms Can Increase Road Safety," *Traffic Infra Tech*, April-May 2014, pp. 68-71 (http://emag.trafficinfratech.com); at www.vtpi.org/TIT-pricesafety.pdf.

Todd Litman (2016), *The Hidden Traffic Safety Solution: Public Transportation*, American Public Transportation Association (www.apta.com); at https://bit.ly/2bYqQpr.

Todd Litman (2017), *Understanding Smart Growth Saving*, VTPI (www.vtpi.org); at www.vtpi.org/sg_save.pdf.

Todd Litman (2018), *Autonomous Vehicle Implementation Projections: Implications for Transport Planning*, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/avip.pdf.

Todd Litman and Steven Fitzroy (2016), *Safe Travels: Evaluating Mobility Management Traffic Safety Benefits*, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/safetrav.pdf.

Wesley E. Marshall and Norman W. Garrick (2011), "Evidence on Why Bike-Friendly Cities Are Safer for All Road Users," *Environmental Practice*, Vol 13/1, March; at https://bit.ly/2Li14in.

Wesley E. Marshall and Norman W. Garrick (2012), "Community Design and How Much We Drive, *Journal of Transport and Land Use*, Vol. 5, No. 2, pp. 5–21, doi: 10.5198/jtlu.v5i2.301; at https://bit.ly/2oVEwXG.

McKinsey (2016), *Automotive Revolution – Perspective Towards 2030: How the Convergence of Disruptive Technology-driven Trends Could Transform the Auto Industry* (www.mckinsey.de); at http://bit.ly/2zYBTfG.

Ronald T. Milam, et al. (2017), "Closing the Induced Vehicle Travel Gap Between Research and Practice," *Transportation Research Record 2653* (https://doi.org/10.3141/2653-02).

Dinesh Mohan, Shrikant I. Bangdiwala and Andres Villaveces (2017), "Urban Street Structure and Traffic Safety," *Journal of Safety Research*, Vol. 62, pp. 63–71 (https://bit.ly/2DKD2sl).

Michael A. Morrisey and David C. Grabowski (2011), Gas Prices, Beer Taxes and GDL Programmes: Effects on Auto Fatalities Among Young Adults in the US, *Applied Economics*, Vol. 43:25, pp. 3645-3654, (DOI: 10.1080/00036841003670796).

Brendan Murphy, David M. Levinson, and Andrew Owen (2017), "Evaluating the Safety in Numbers Effect for Pedestrians at Urban Intersections," *Accident Analysis & Prevention*, Vol. 106, pp. 181–190 (https://doi.org/10.1016/j.aap.2017.06.004); at http://bit.ly/2uO2mta.

Sage R. Myers, et al. (2013), "Safety in Numbers: Are Major Cities the Safest Places in the United States?" *Annals of Emergency Medicine*, Vol. 62, Is. 4, pp. 408-418.e3 (https://bit.ly/2znPtHx); at http://bit.ly/2p0E0Js.

Pooya Najaf, Jean-Claude Thill, Wenjia Zhang and Milton Greg Fields (2018), "City-level Urban Form and Traffic Safety: A Structural Equation Modeling Analysis of Direct and Indirect Effects," *Journal of Transport Geography*, Vol. 69, pp. 257-270 (https://doi.org/10.1016/j.jtrangeo.2018.05.003).

NAR (2017), *National Community and Transportation Preferences Survey*, National Association of Realtors (www.nar.realtor); at www.nar.realtor/reports/nar-2017-community-preference-survey.

NAS (2018), *Getting to Zero Alcohol-impaired Driving Fatalities: A Comprehensive Approach to a Persistent Problem*, National Academies Press (https://doi.org/10.17226/24951); at www.nap.edu/download/24951.

NACTO (2016), *Equitable Bike Share Means Building Better Places for People to Ride*, National Association of City Transportation Officials (https://nacto.org); at https://bit.ly/2LgfFuT.

NHTSA (2016), *2015 Motor Vehicle Crash Data from FARS and GES*, National Highway Traffic Safety Administration (https://nhtsa.dot.gov); at https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812384.

Robert B. Noland and Lyoong Oh (2004), "The Effect of Infrastructure and Demographic Change on Traffic-Related Fatalities and Crashes: a Case Study of Illinois County-Level Data," *Accident Analysis & Prevention*, Volume 36, Issue 4 (www.elsevier.com/locate/aap), July 2004, pp. 525-532; at http://bit.ly/2DnyAQq.

NSC (2017), *Road to Zero*, National Safety Council (www.nsc.org); at https://bit.ly/2h2AyY9.

NYCDOT (2012), *Measuring the Street: New Metrics for 21st Century Streets*, New York City Department of Transportation (www.nyc.gov/html/dot); at http://on.nyc.gov/1pRKn8P.

PBOT (2016), *Vision Zero Action Plan*, Portland Bureau of Transportation (www.portlandoregon.gov); at www.portlandoregon.gov/transportation/40390.

Sarah Jo Peterson (2017), *Seattle's Transportation Transformation*, Urban Land Institute (http://urbanland.uli.org); at http://bit.ly/2oyo5OD.

Christina Rudin-Brown and Samantha Jamson (2013), *Behavioural Adaptation and Road Safety: Theory, Evidence and Action*, CRC Press (www.crcpress.com).

Eric Scharnhorst (2018), *Quantified Parking: Comprehensive Parking Inventories for Five U.S. Cities*, Research Institute for Housing America, Mortgage Bankers Association (www.mba.org); at https://bit.ly/2LfNk4o.

SDOT (2016), *Vision Zero: Seattle's Plan to End Traffic Deaths and Serious Injuries on City Streets by 2030*, Seattle Department of Transportation (www.seattle.gov); at www.seattle.gov/visionzero.

Steven Shladover (2016), "The Truth About 'Self-Driving' Cars," *Scientific American* (www.scientificamerican.com); at http://bit.ly/2DGhSN5.

Michael Sivak and Brandon Schoettle (2010), *Toward Understanding the Recent Large Reductions in U.S. Road Fatalities*, University of Michigan Transportation Research Institute (www.umtri.umich.edu); at https://bit.ly/2rRoBf3.

SUTP (2014), *International Fuel Prices*, Sustainable Urban Transport (www.sutp.org); at https://bit.ly/2msRSJS.

Jim P. Stimpson, et al. (2014), "Share of Mass Transit Miles Traveled and Reduced Motor Vehicle Fatalities in Major Cities of the United States," *Journal of Urban Health: Bulletin of the New York Academy of Medicine*, (doi:10.1007/s11524-014-9880-9); at http://link.springer.com/article/10.1007%2Fs11524-014-9880-9.

Jonathan Sung, Krista Mizenko and Heidi Coleman (2017), *A Comparative Analysis of State Traffic Safety Countermeasures and Implications for Progress "Toward Zero Deaths" in the United States*, National Highway Traffic Safety Administration (www.nhtsa.gov); at http://bit.ly/2zQ1bcQ.

Ivana Tasic and Richard J. Porter (2018), "Modeling Spatial Relationships Between Multi-modal Transportation Infrastructure and Traffic Safety Outcomes in Urban Environments," *Safety Science*, Vo. 82, pp. 325-337 (https://doi.org/10.1016/j.ssci.2015.09.021).

Steven M. Teutsch, Amy Geller and Yamrot Negussie (2018), *Getting to Zero Alcohol-Impaired Driving Fatalities: A Comprehensive Approach to a Persistent Problem*, National Academy Press (www.nap.edu); at www.nap.edu/download/24951.

Katherine F. Turnbull, Herbert S. Levinson and Richard H. Pratt (2006), *HOV Facilities – Traveler Response to Transportation System Changes*, TCRB Report 95, Transportation Research Board (www.trb.org); at http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c2.pdf.

USDOT (2016), *Transportation and Health Tool*, US Department of Transportation (www.transportation.gov); at www.transportation.gov/mission/health/indicator-profiles.

USDOT (2017), *Safety Performance Management (Safety PM)*, US Department of Transportation (www.transportation.gov); at https://safety.fhwa.dot.gov/hsip/spm.

VTPI (2016), *Online TDM Encyclopedia*, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/tdm.

Jarrett Walker (2015), *Why is US Bus Service Shrinking as Demand is Rising?*, Human Transit (http://humantransit.org); at http://bit.ly/2mHUfZ5.

M. Wedderburn (2013), *Improving The Cost-Benefit Analysis Of Integrated PT, Walking And Cycling,* Research Report 537, NZ Transport Agency (www.nzta.govt.nz); at http://bit.ly/2DH9fyD.

Ben Welle, et al. (2015), *Cities Safer by Design: Urban Design Recommendations for Healthier Cities, Fewer Traffic Fatalities*, World Resources Institute (www.wri.org); at www.wri.org/publication/cities-safer-design.

Ben Welle, et al. (2018), *Sustainable & Safe: A Vision and Guidance for Zero Road Deaths*, World Resources Institute (www.wri.org); at www.wri.org/publication/safe-system.

WHO (2015), *Road Traffic Deaths*, World Health Organization (www.who.org); at http://apps.who.int/gho/data/node.main.A997?lang=en.

Jac Wismans, et al. (2017), *Economics of Road Safety – What Does it Imply Under the 2030 Agenda for Sustainable Development?*, Tenth Regional EST Forum in Asia (http://bit.ly/2mHZs1p); at http://bit.ly/2iLrgBT.

Jiho Yeo, Sungjin Park and Kitae Jang (2015), "Effects of Urban Sprawl and Vehicle Miles Traveled on Traffic Fatalities," *Accident Analysis and Prevention*, Vol. 16, No. 4, pp. 397-403 (https://bit.ly/2E0i9tV).