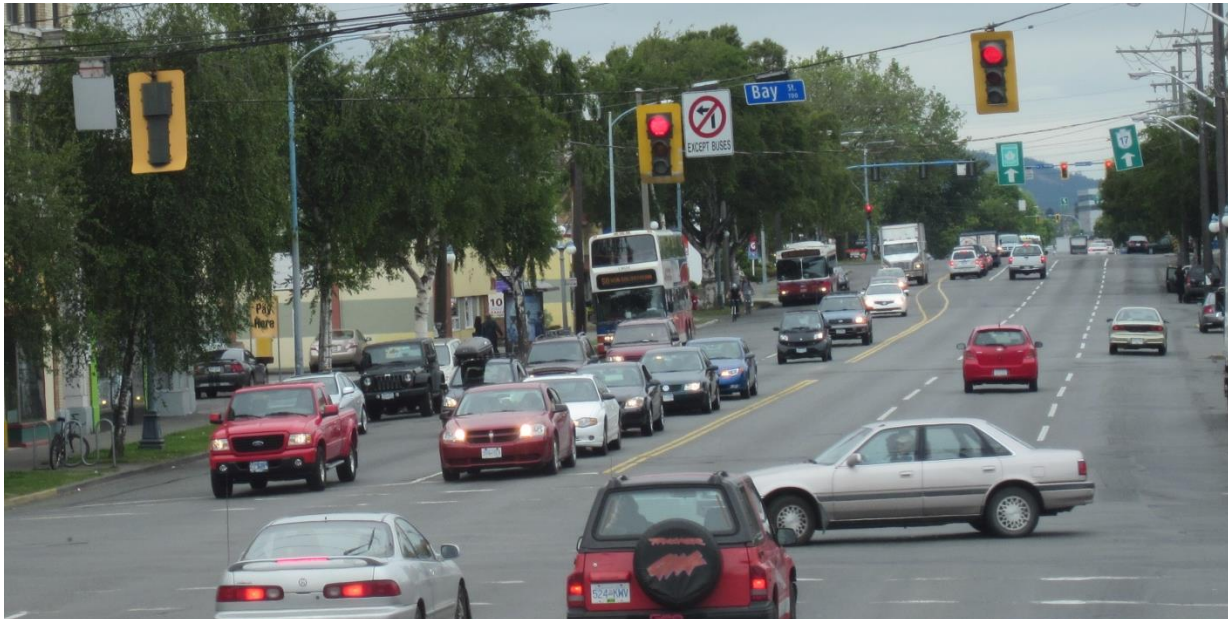


A New Traffic Safety Paradigm

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

Abstract

Despite large traffic safety program investments, motor vehicle accidents continue to impose high social costs. Crash casualty rates have ended their long-term decline and 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 current paradigm favors targeted safety programs that reduce special risks such as youth, senior and impaired driving. A new paradigm recognizes that all vehicle travel imposes risks, and so supports vehicle travel reduction strategies such as more multimodal planning, efficient transport pricing, Smart Growth development policies, and TDM programs. Many of these strategies provide significant co-benefits, in addition to safety. This report examines our emerging understanding of traffic safety and strategies that can provide large benefits.

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Introduction

Despite huge investments in traffic safety, motor vehicle crashes impose large costs. According to a National Highway Traffic Safety Administration study, in 2010 motor vehicle crashes in the United States caused damages estimated to be worth \$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 has ended and crash rates have started to increase, 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 new paradigm (Hughes 2017; Litman 2013).

In a word, the new paradigm recognizes *exposure* – the amount that people travel – as a risk factor. Total traffic crashes are the product of distance-based crash rates (such as casualties per 100,000 vehicle-miles) times travel distance; a change in either tends to cause proportional changes in total crashes. The current traffic safety paradigm focuses on distance-based crash rates, but generally ignores exposure as a risk factor, and so ignores the additional crashes that result from policies that increase vehicle travel, and the safety benefits of vehicle travel reduction strategies. The new paradigm considers both distance-based crash rates and mileage as risk factors, and so recognizes the safety benefits of transportation demand management (TDM) strategies such as more multimodal planning, efficient transport pricing, Smart Growth development policies and TDM programs. Since these strategies provide large co-benefits, besides safety, the new paradigm supports more comprehensive analysis that accounts for these impacts.

Table 1 compares the current and new traffic safety paradigms.

Table 1 Comparing the Current and New Traffic Safety Paradigms

| Factor | Current | 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 improvement Graduated licenses and 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 complete streets and connected roadways Smart Growth development policies Transportation demand management programs |
| Analysis scope | Program costs and traffic safety benefits | All economic, social and environmental impacts |

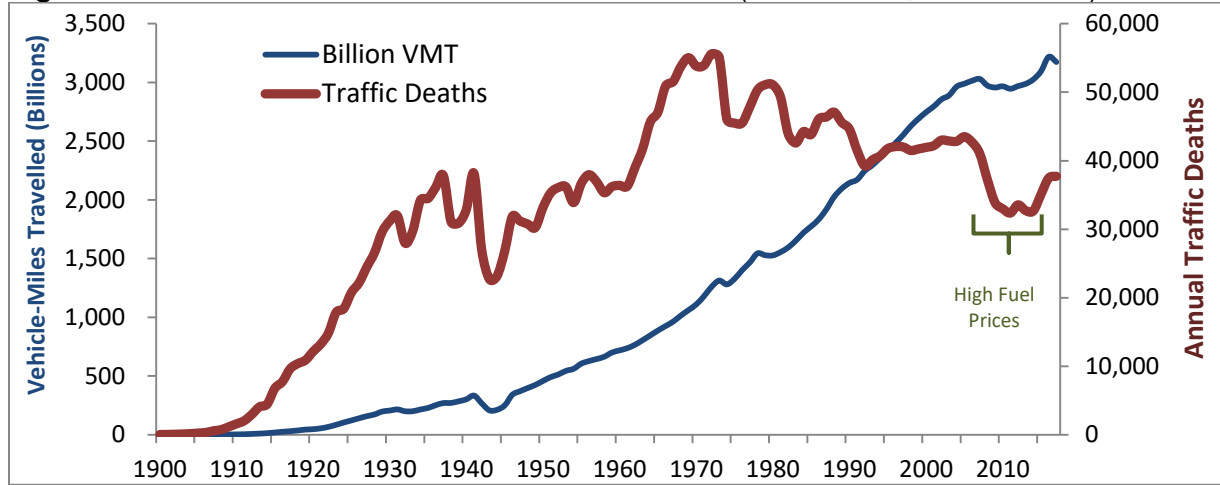
The current and new traffic safety paradigms differ in many ways.

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.

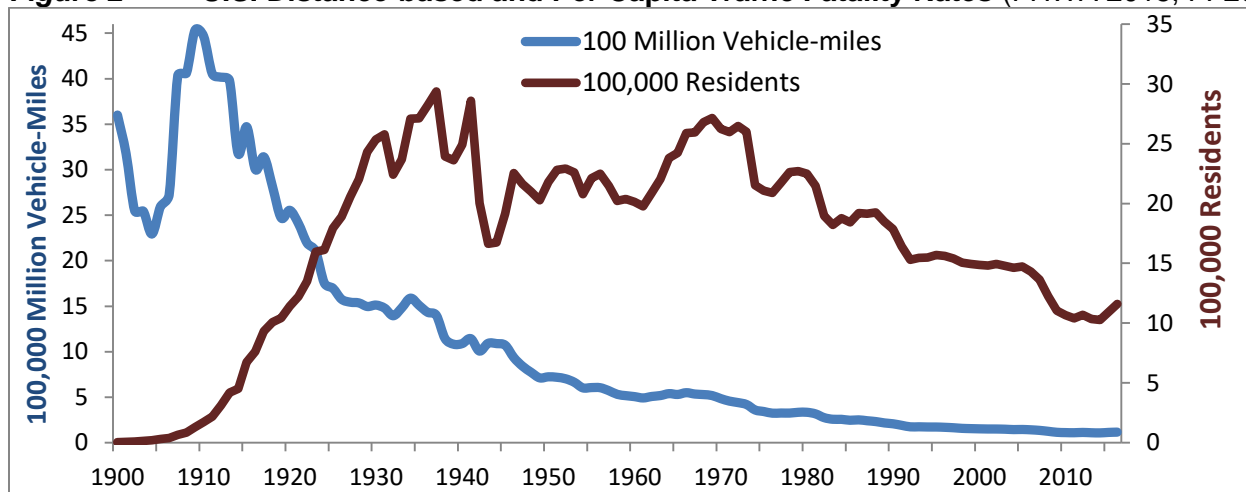
Figure 1 U.S. Annual VMT and Traffic Fatalities (FHWA 2015, Table FI-201)



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 U.S. annual vehicle travel and traffic deaths. Motor vehicle miles of travel (VMT) increased steadily during the Twentieth Century, but peaked in 2006, due in part to high fuel prices. 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; and when low fuel prices increased VMT after 2014, so did fatalities. Similarly, 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.

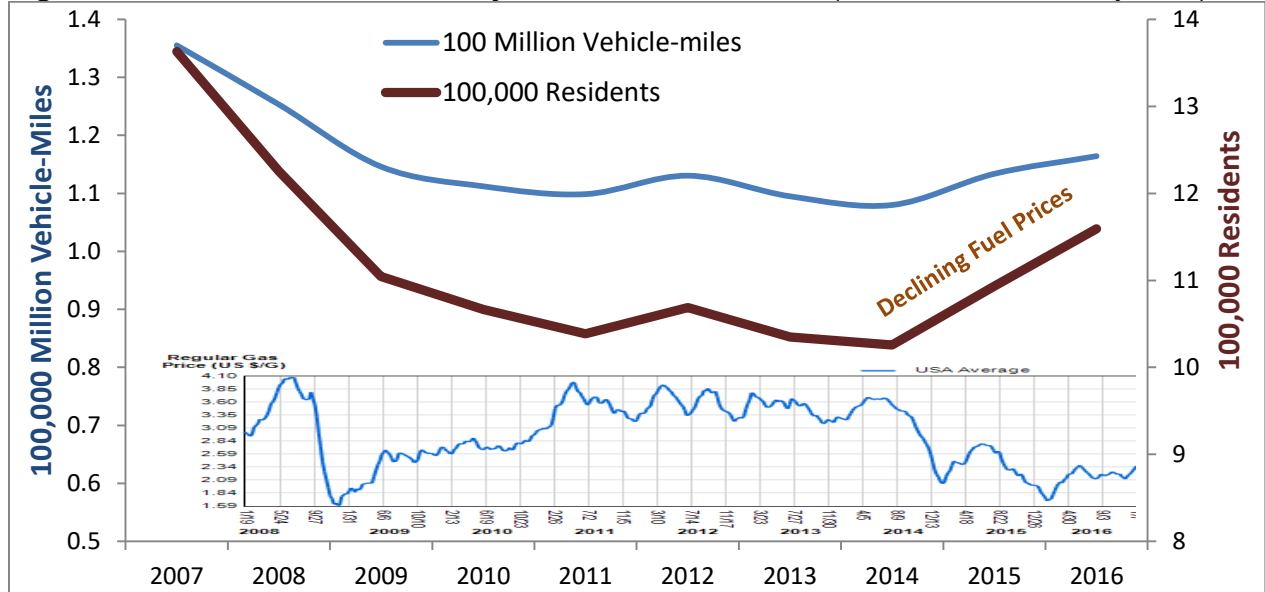
Figure 2 U.S. Distance-based and Per Capita Traffic Fatality Rates (FHWA 2015, FI-201)



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

Figure 3 shows 2007 to 2016 U.S. traffic fatality and fuel price trends. When fuel prices were high, traffic fatality rates declined, but when fuel prices declined in 2014-16, per capita vehicle travel and traffic death rates increased. This and other research described in this report illustrate how factors that affect per capita vehicle travel, and therefore crash exposure, affect crash rates.

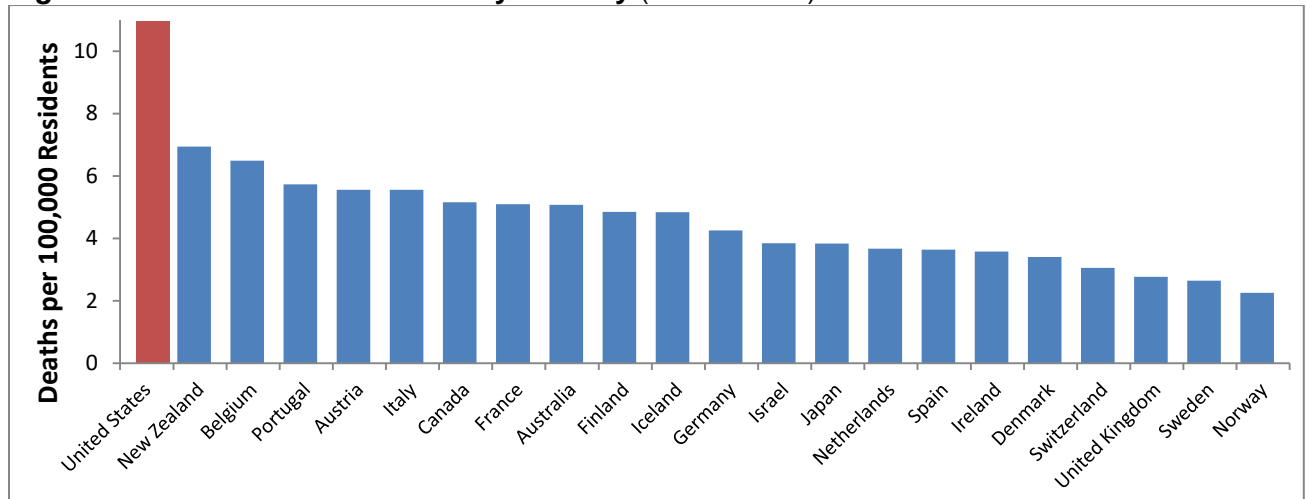
Figure 3 Recent Traffic Fatality and Fuel Price Trends (FHWA and GasBuddy Data)



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

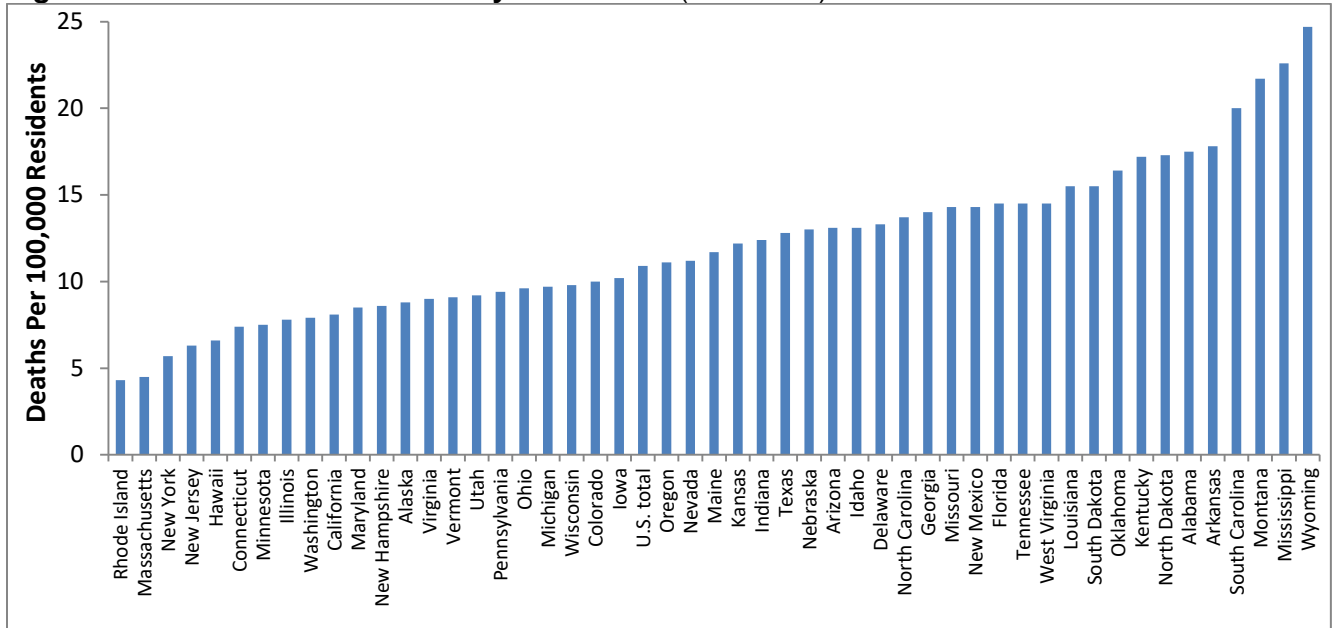
International comparisons indicate that large safety gains are possible. The U.S. has the highest per capita traffic fatality rate among its peers (Figure 4). Geographic factors are no excuse: Australia and Canada have lower population densities, and Sweden, Norway and Finland have more extreme weather, yet all have much lower traffic death rates, and reduced crash rates much faster 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 the averages of Australia and Canada and three times the average of European countries.

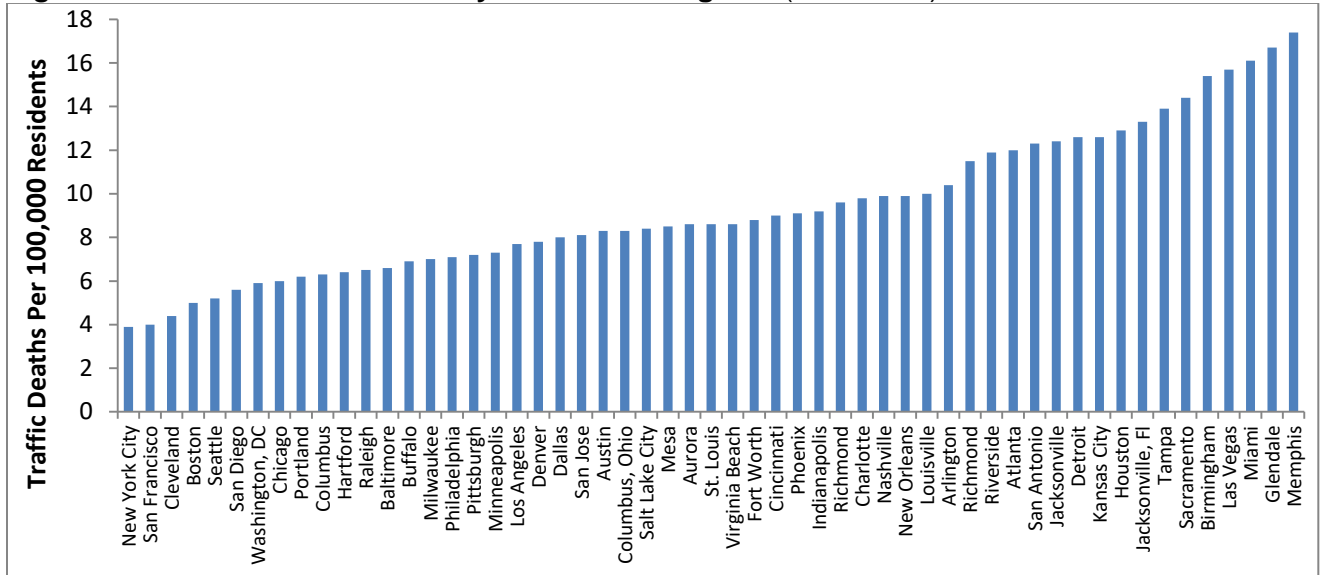
Figure 5 Traffic Death Rates by U.S. States (IIHS 2015)



Crash rates vary significantly between geographically similar states.

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 vehicle and roadway standards, and similar traffic safety programs. Evidence described in the next section of this report indicate 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. This indicates that urban policies affect crash risks.

Many people hope that new technologies will soon eliminate traffic risks. Advocates claim that within 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 mobile phone 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, which 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 take greater risks.
- *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 increased crashes severity.
- *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%, and their net safety benefits will depend on public policies that affect how they are programmed and their impacts on total vehicle travel. 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 programmed to drive slower and be more cautious in unexpected situations (resulting in more frequent delays for human instructions), and public policies, 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 their analysis indicates that net safety gains are significantly reduced if this technology increases 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

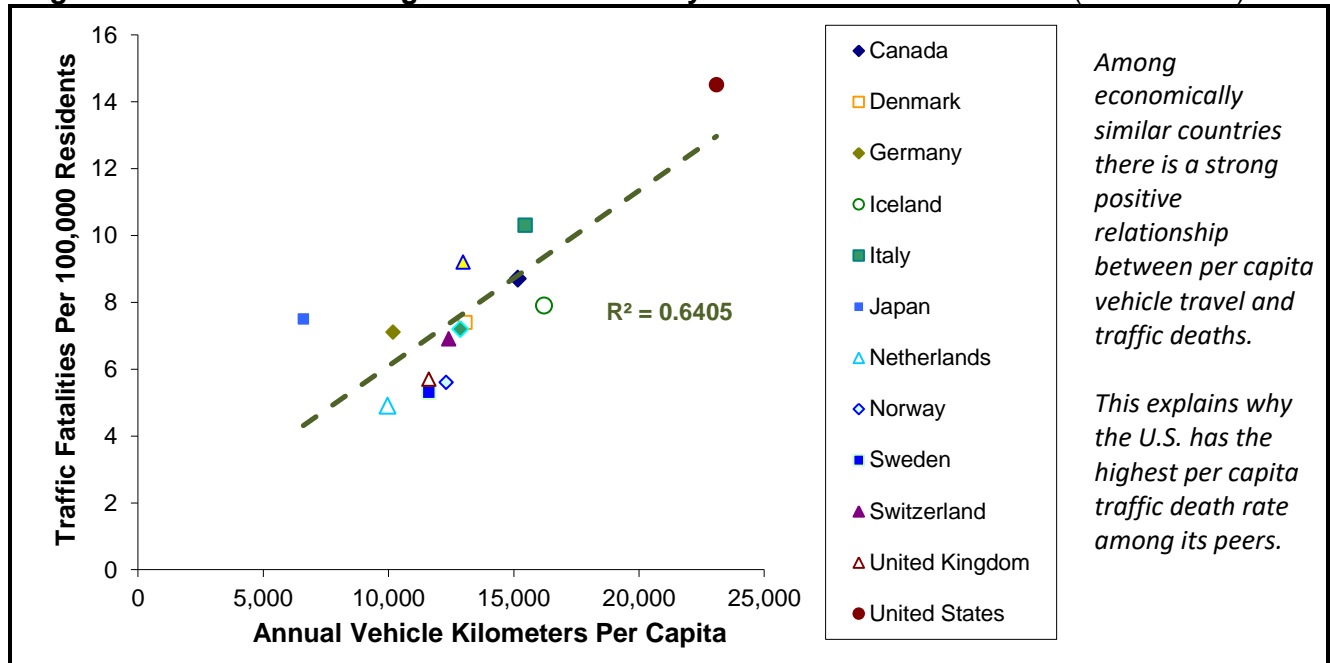
This section describes new research concerning how transport and land use factors affect crash risks. Also see Hamidi, et al. (2015); Litman and Fitzroy (2016); Sivak and Schoettle (2010); and Welle et al. (2018).

Total Vehicle Travel

Although many demographic, economic and geographic factors affect distance-based casualty rates, all else being equal, that is, for a given group or area, traffic casualties tend to increase when vehicle travel increases and decline when vehicle travel declines. For example, using sophisticated analysis of U.S. crash data, Ahangari, Atkinson-Palombo and Garrick (2017) found that the most important factors affecting an area's crash rate were *Vehicles per Capita* and *Vehicle Miles Traveled*. 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 tend to provide proportionately larger casualty changes, so each 1% vehicle travel reduction generally reduces total crash costs more than 1%, particularly in higher traffic density areas. 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.

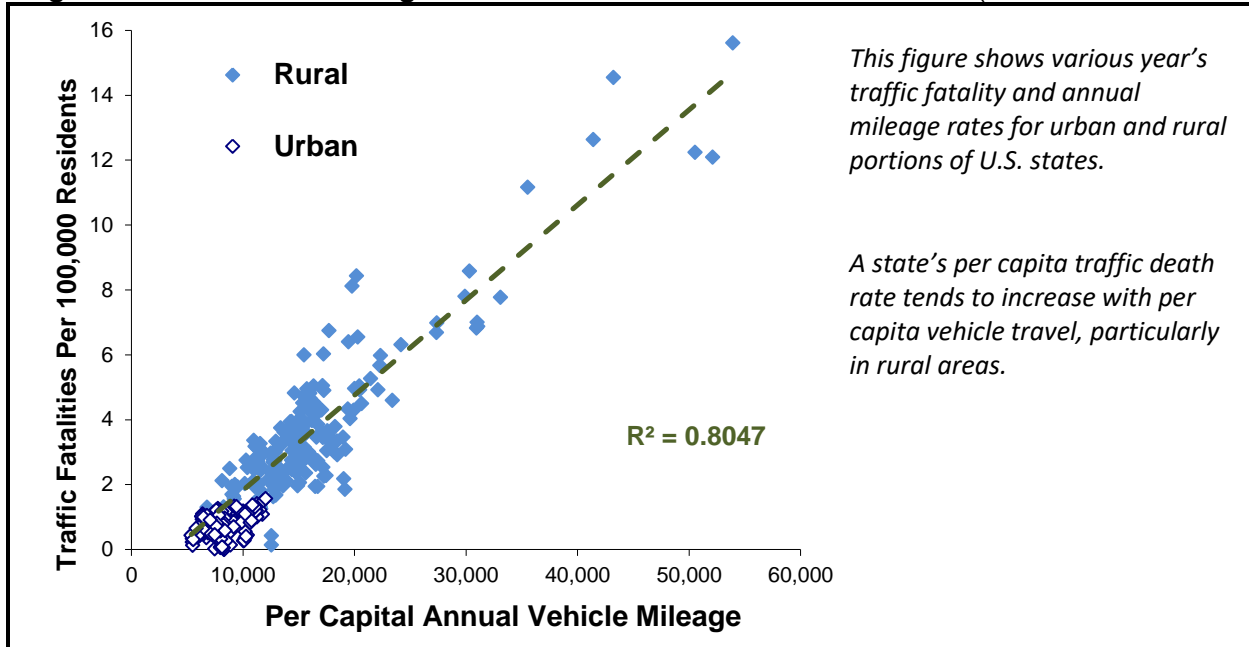
Among higher-income countries, per capita crash rates tend to increase with per capita vehicle travel, as illustrated in Figure 7. As previously mentioned, the U.S. has the highest traffic death rate among peer countries, which can be explained by it having the highest per capita annual mileage.

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



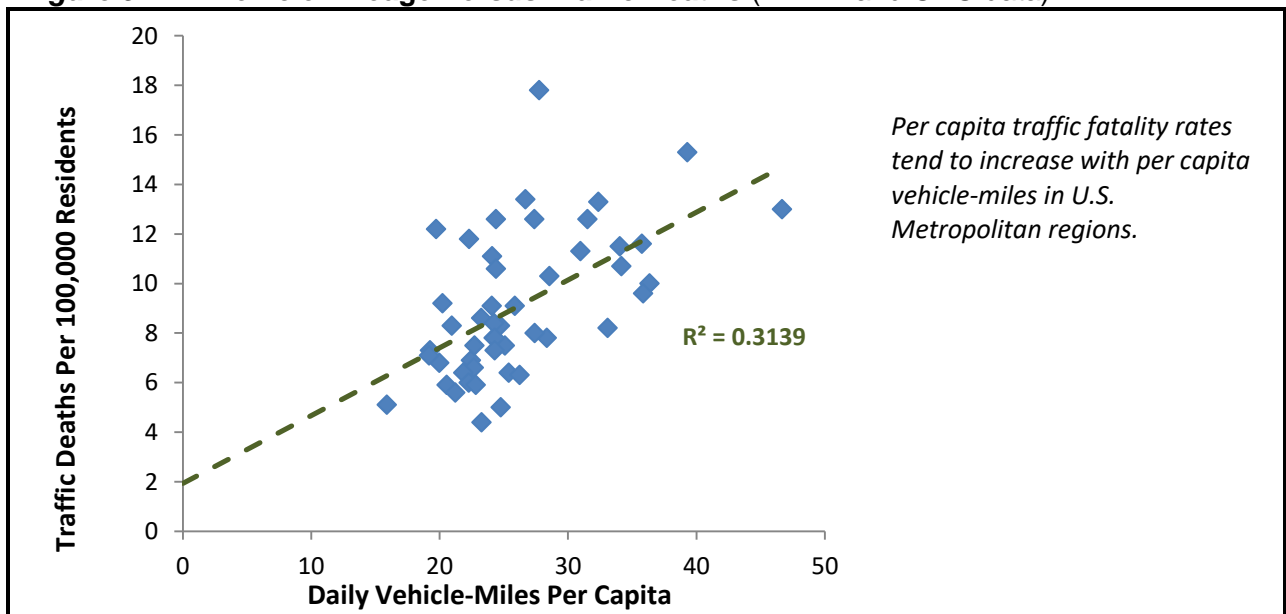
Per capita traffic fatality rates tend to increase with vehicle travel among U.S. states, as indicated below.

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



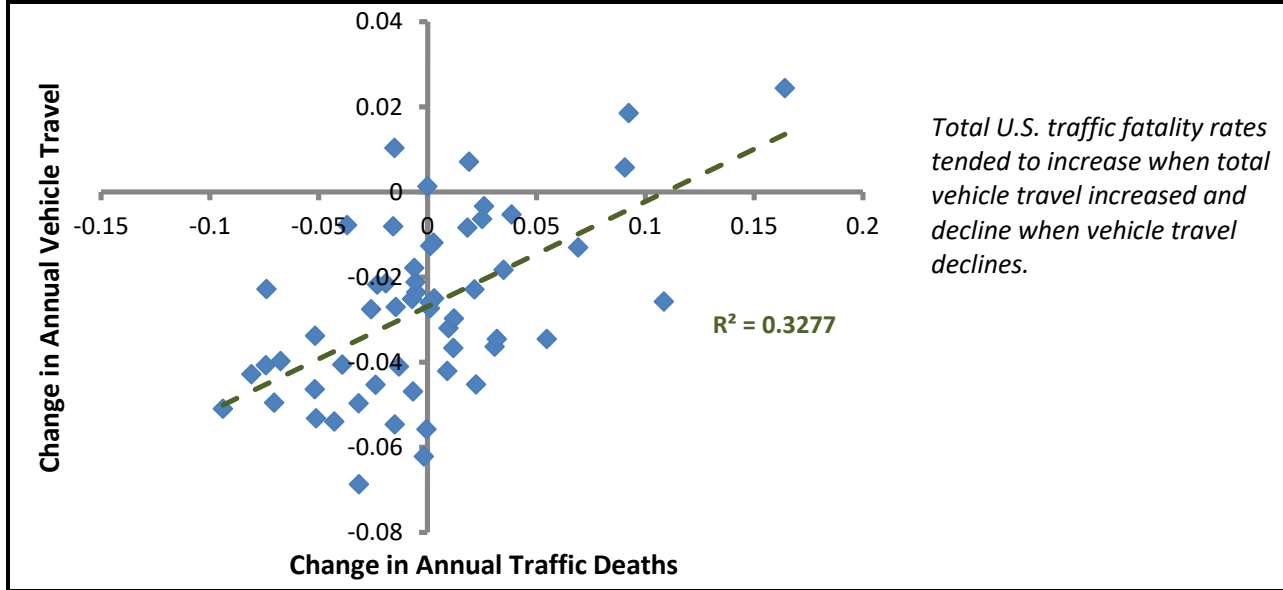
Similar patterns occur at smaller geographic scales. Figure 8 shows that regional traffic fatality rates tend to increase with vehicle travel, and other studies indicate that traffic casualty rates are much lower in compact, multimodal neighborhoods than in sprawled, automobile-dependent areas (Ewing 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)



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)



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.

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.

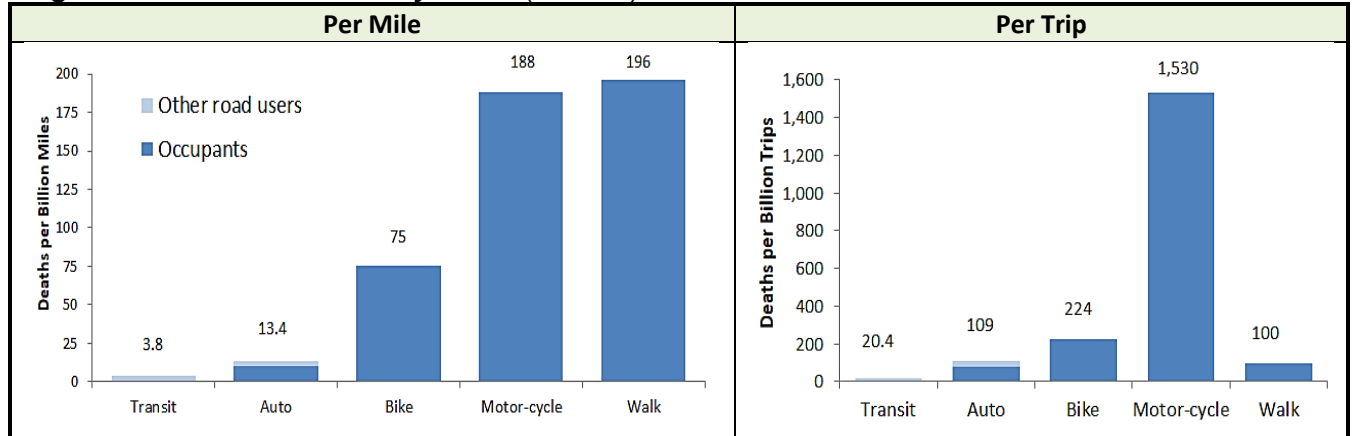
³ <http://nhts.ornl.gov/2009/pub/stt.pdf>. Excludes commercial vehicle travel.

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

Table 2 and Figure 11 show per mile and per trip crash rates by mode. More than three-quarters transit fatalities involve other road users, but even including these it had the lowest total death rate. About a quarter of automobile deaths involve other road users. Bike, motor-cycle and walk have relatively high per mile death rates 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 not much higher than 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.

These statistics suggest that shifts from automobile to transit should *reduce* traffic casualties, and shifts to active modes should *increase* casualties, leading 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, in practice total traffic casualty rates tend to decline in an area as *either* public or active transport increase.

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

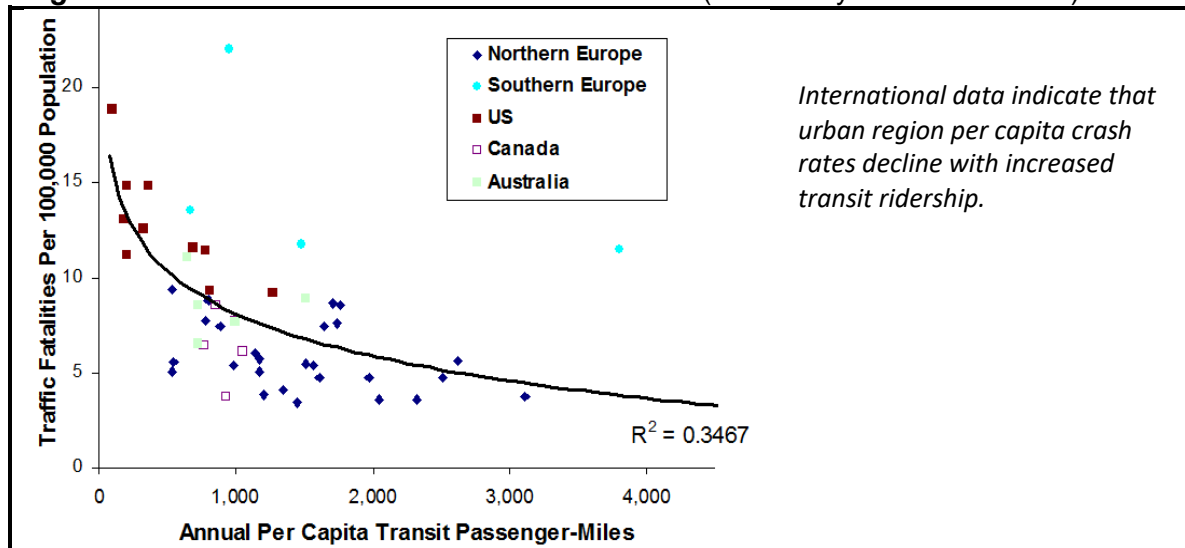


Figure 12 and 13 illustrate the relationship between transit travel and death rates. Regions where residents average more than 50 annual transit trips have about half the fatality rates as regions where residents take fewer than 20 annual trips. This represents a small increase in transit mode share, 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)

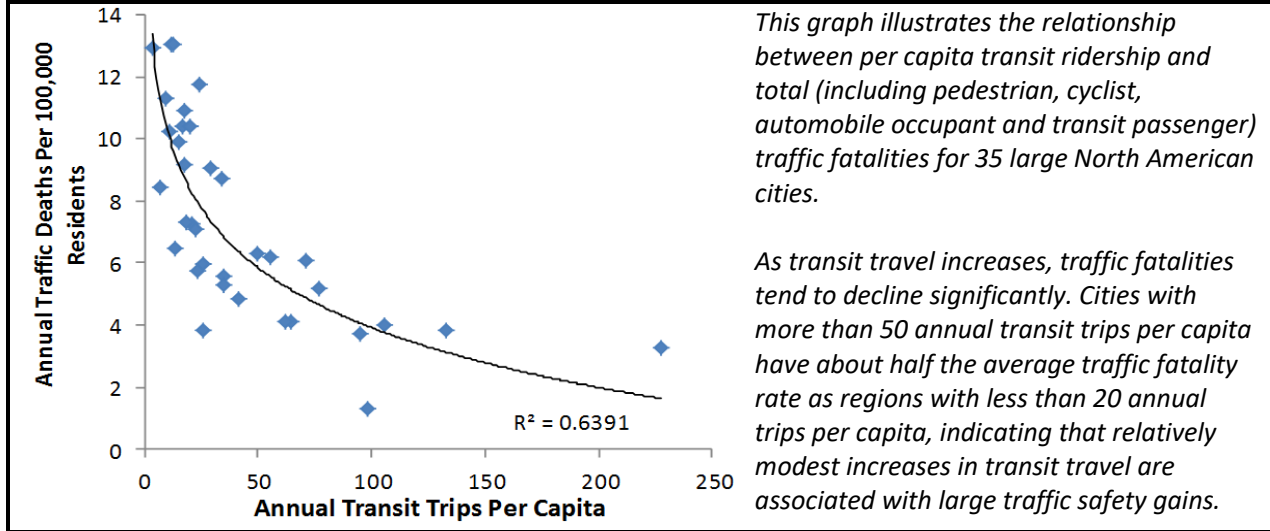
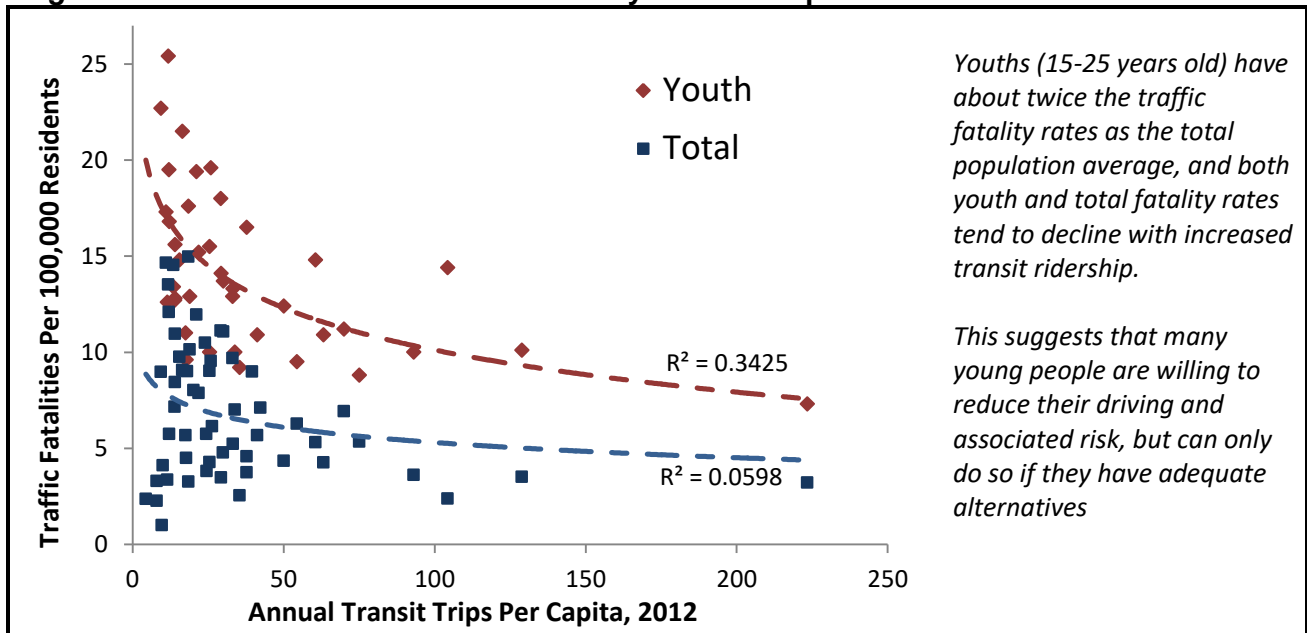


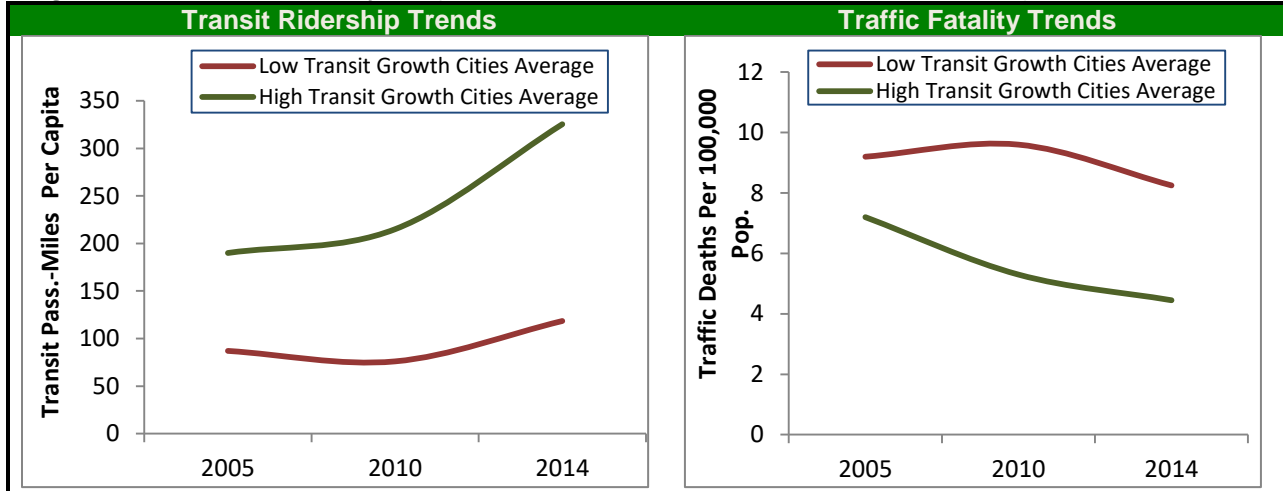
Figure 14 shows that the decline in traffic fatality rates in more transit-oriented communities is particularly significant for youths, age 15-25, which suggests that many young people are willing to reduce their driving and associated risk, but can only do so if they have adequate alternatives.

Figure 14 Youth and Total Traffic Fatality Rates Compared to Transit Travel



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.

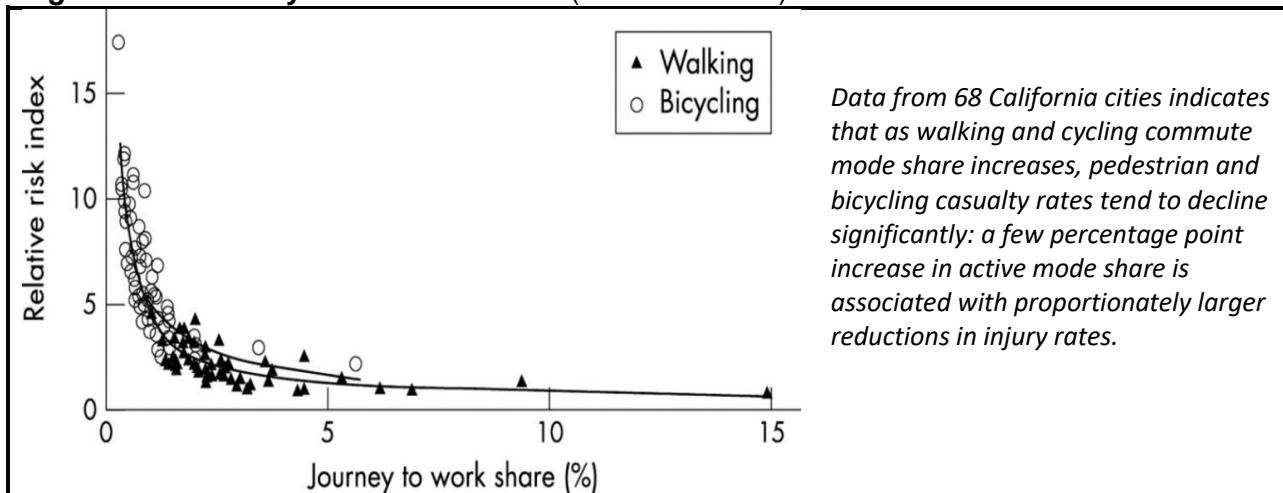
Figure 15 Trend Analysis (APTA 2016, based on FTA and NHTSA data)



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.

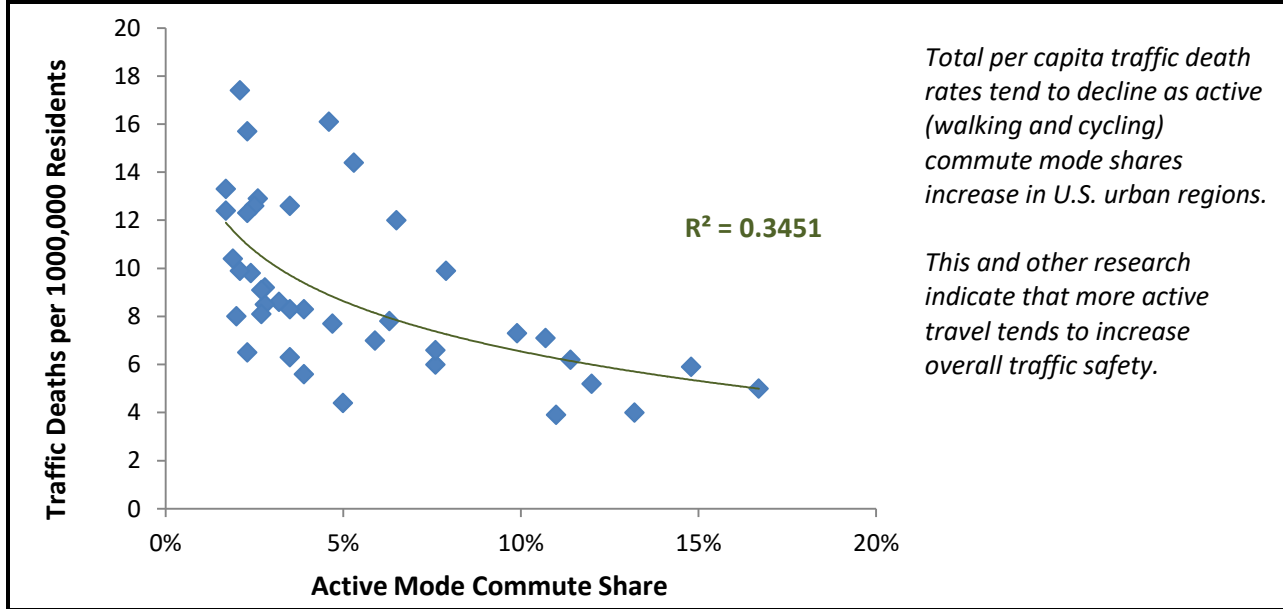
More active transport (walking and cycling) also tends to increase traffic safety. Numerous studies find that active mode and total (all mode) crash casualties tend to decline as walking and cycling increases in an area, an effect called *safety in numbers* (ABW 2016; ECF 2012; NACTO 2016), as Figure 16 illustrates. 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.

Figure 16 Safety In Numbers Effect (Jacobson 2003)



In addition, total (all mode) per capita traffic fatality rates tend to decline as active transport mode shares increase in U.S. urban regions, as illustrated below. Cities with active mode shares over 10% average about half the traffic fatality rates as those with active mode shares under 5%.

Figure 17 Active Commute Mode Share and Traffic Deaths (Census and CDC Data)



Various factors help explain the large reductions in total crashes associated with more active transport:

- *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.
- *Safer travel conditions.* Both active travel and the safety of these modes increases with improved sidewalks, crosswalks, cycling facilities, streetscaping, traffic speed control and education programs.
- *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 invested about \$100 per capita in pedestrian and cycling improvements in four typical U.S. communities, which caused walking trips to increase 23% and cycling trips to increase 48%, mostly for utilitarian purposes (FHWA 2014). Despite this increase in their 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 sidewalk coverage from a ratio of 0.57 (sidewalks on both sides of 30% of all streets) to 1.4 (sidewalks on both sides of 70% of streets) could reduce vehicle travel 3.4% and carbon emissions 4.9%. Guo and Gandavarapu (2010) found that completing the sidewalk network in typical U.S. communities would increase 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, reduce 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 and 600 air pollution deaths. Grabowski and Morrissey (2004 and 2006) estimate that each 10% fuel price increase reduces total traffic deaths 2.3%, with larger decline for drivers aged 15-21. Morrissey 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. They found:

- In the 8-square-mile charging zone vehicle travel declined 14% and traffic accidents by a third.
- Traffic accident rates within the zone declined from 4.51 to 3.51 per million vehicle-miles, a 22% reduction, and traffic casualties (somebody is killed or seriously injured), 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 total vehicle traffic and crashes, rather than shifting it elsewhere.

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).

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 can increase total crashes by increasing traffic speed and travel distances. For example, since grade-separated highways have lower per-mile traffic fatality rate than other roadways, highway agencies often justify road widening, straightening, grade separation and roadside clearance programs for safety sake. However, such treatments encourage motorists to drive faster and farther, which tends to increase total crash casualties (Karim 2015; Noland and Oh 2004). Traffic speed increases caused by roads that feel safer is called *risk compensation*, and the additional vehicle travel caused by increased travel speeds is called *induced travel* (CARB 2014; Milam, et al. 2017). As a result, roadway expansions often provide much smaller total crash reductions than predicted.

Changing a narrow, winding roadway into wider, grade-separated highways encourages households to move from more compact and multimodal neighborhoods to automobile-dependent, sprawled areas. In This tends to increase the distances household members must drive, and reduces travel options, which increases chauffeuring travel, for example, driving children to school and recreation activities. As a result, this not only increases vehicle travel on the grade-separated highway, where crashes per mile are low, but also increases travel on local streets where crashes per mile are higher.

Development policies that separate land uses, for example, locating commercial services and schools away from residential neighborhoods, tend to increase motor vehicle travel, as do minimum parking requirements in zoning codes, unpriced on-street parking, and other public policies that minimize motor vehicle ownership and operating costs (CARB 2014). Another common transportation planning practice that tends to increase vehicle travel and crash risks is the creation of hierarchical road systems, in which less connected local streets force traffic onto higher-speed arterials. This reduces traffic risk on the local roads, but reduces walkability, increases the distances that residents must travel to reach destinations, and increases the amount of travel that occurs on higher speed arterials (CARB 2014), which together increase traffic crash rates (Garrick and Marshall 2011).

Common transport planning and funding practices tend to overlook or undervalue non-auto travel demands. For example, public agencies often evaluate transportation system performance using roadway level of service (LOS), and have dedicated roadway funding that cannot be used to improve other modes or implement TDM strategies. Many planning practices unintentionally discourage walking and cycling, including wider roads with higher design speeds, dispersed development, and safety policies such as bike helmet mandates. Reducing active travel tends to reduce the *safety in numbers* effect.

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 traffic risk they cause. Comprehensive evaluation is particularly important when evaluating 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.

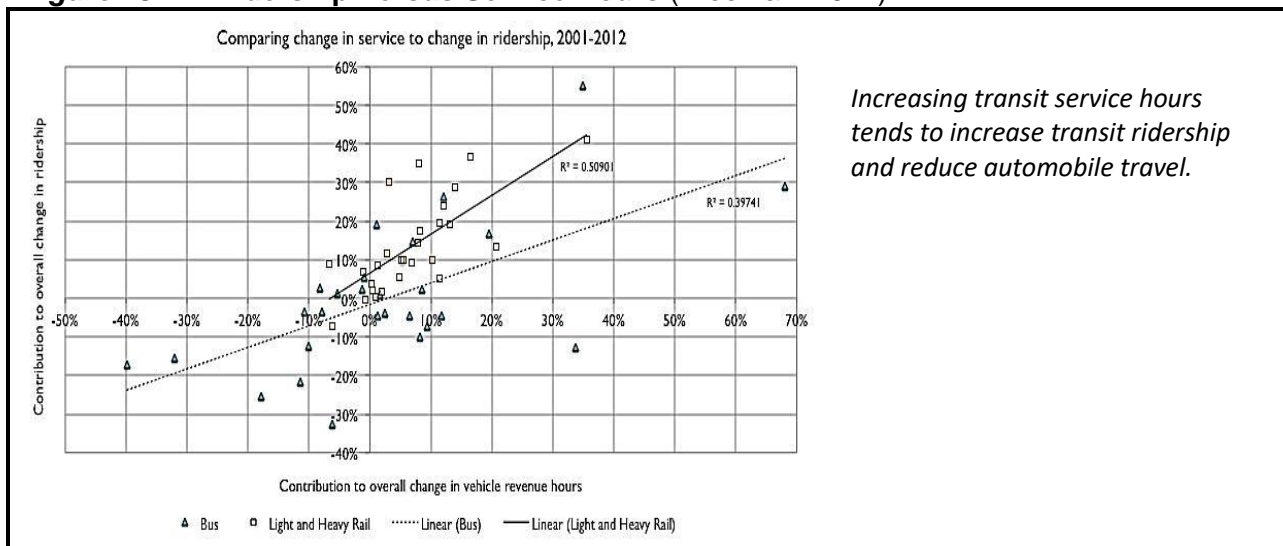
New Paradigm Safety Strategies

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)



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). Although most high transit growth cities developed urban rail systems, their ridership gains also result from bus service improvements such as dedicated bus lanes and better rider information (Peterson 2017; Walker 2015).

This suggests that in typical North American conditions, cost-effective transit service improvements (considering consumer savings, congestion reductions, road and parking facility cost savings, crash cost savings, emission reductions and the value of improved mobility for non-drivers) can significantly increase per capita transit travel, which provides greater than proportional crash rate reductions, so each 1% increase in transit ridership typically reduces per capita traffic casualties more than 1%. To be effective, they must be well planned and there must be consumer demand for those services.

Many transit service improvement and encouragement programs can be implemented in a few months, although major new transit lines often take many years to develop and attract maximum ridership.

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). Since about 20% of total vehicle travel is for commuting, this represents a 1-5% reduction in total vehicle travel. 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.

By reducing total vehicle travel and encouraging shift to transit, they reduce traffic crash risks, probably about proportional to mileage reductions. This suggests that HOV priority integrated with other TDM strategies such as Commute Trip Reduction programs and transit service improvements can reduce affected traveler's crash casualty rates 10-30% and total regional rates 1-5%. Rideshare programs, and some HOV priority systems (such as converting existing lanes to HOV or bus lanes) can be implemented quickly, but adding new HOV lanes often requires several years of planning.

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 aggregate evidence (Figure 15) 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%. Many improvements can be implemented in a few years, although a complete network may require a decade to complete.

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 consumption is more 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*.

In many countries, road user fees (road tolls, special fuel taxes and vehicle registration fees) are insufficient to finance total roadway costs (SUTP 2014). For example, in 2015 U.S. government agencies spent a total of \$235 billion on roadways, of which \$113 (48%) was from user fees and \$122 billion from general tax subsidies (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. Research indicates that each 10% fuel price increase typically reduces traffic deaths 2-6% (Ahangari, et al. 2014; Burke and Nishitatenno 2015), suggesting that a 50¢ per gallon tax should reduce fatalities by 4-12%.

Efficient Parking Pricing (Motorists Pay Directly For Using Parking Spaces)

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, resulting in parking costs being borne indirectly through general taxes, building rents, and the costs of other 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. For example, each 10% increase in the portion of destinations with efficiently priced parking reduces vehicle travel and crashes by 1-3%. Efficient parking pricing can often be implemented in a few months.

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 congestion fees reduced peak-period vehicle travel by 10% and crashes by 30% within the priced area, and reduced crashes in nearby areas declined by 16%. Since less than a third of total vehicle travel occurs under urban-peak conditions, this suggests that congestion pricing can typically reduce 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 vehicles; insurance premiums and registration fees are based directly on how much it is driven during the policy term. This gives motorists a new opportunity to save money if they reduce their vehicle travel (Ferreira and Minike 2010; VTPI 2016). Greenberg and Evans (2017) propose that vehicle purchase taxes also be converted into distance-based fees; so a \$1,000 tax becomes 1¢ per vehicle-mile.

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 a variety of services and incentives including information and encouragement activities, ridematching services, bicycle lockers, guaranteed rides home, flextime and telecommute options, transit encouragement, parking pricing, and financial incentives for non-auto commuters. 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 multimodal community.

About 20% of total personal travel is for commuting, and perhaps half of commuters are suited to such programs, so perhaps 10% of total travel could be reduced by 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.

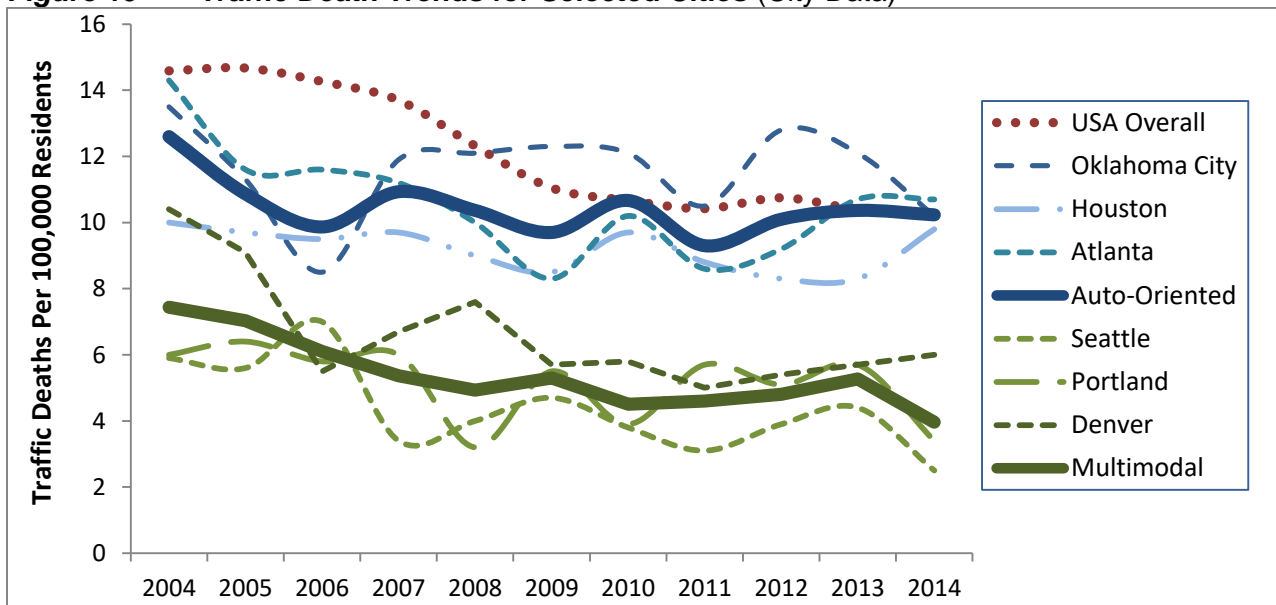
More Comprehensive and Multimodal Planning

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 multimodal planning accounts for other planning goals besides vehicle travel speed, such as traffic safety, mobility for non-drivers and local economic development, and recognizes impacts on non-auto modes (NYCDOT 2012). This is particularly important because, by focusing on automobile LOS and ignoring other accessibility factors, conventional planning discourages more compact and multimodal urban development, for example, by imposing traffic impacts fees on urban infill but not sprawled development.

In addition, current transportation funding practices favor investments in roads and parking facilities to the detriment of 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 than 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 multimodal planning provides a foundation for new paradigm safety strategies, including more support for non-automobile modes, TDM strategies, and Smart Growth policies. 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 multimodal planning compared with those that apply conventional, auto-oriented planning, illustrated below.

Figure 19 Traffic Death Trends for Selected Cities (City Data)



Between 2004 and 2014, three cities that emphasized multimodal planning (Denver, Portland and Seattle) experienced much larger traffic fatality rate reductions (47%) than three cities (Atlanta, Houston and Oklahoma City) with conventional, automobile-oriented planning (19%).

More Connected and Complete Streets

Street connectivity refers to street network density, such as intersections per square mile. Increased connectivity tends to reduce vehicle travel by reducing travel distances between destinations and by supporting alternative modes, particularly where paths provide walking and cycling shortcuts. Ewing and Cervero (2010) find that intersection density and street connectivity are the second greatest land use factor affecting vehicle travel, so a 10% increase in intersection or street density 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), and high intersection densities are related to much lower crash severities (Marshall and Garrick 2011).

Roadways are often designed to maximize traffic speeds with wider lanes, minimum cross-street and safety features such as clearzones. Although justified to reduce crash rates, by increasing traffic volumes and speeds, they can increase total crashes and crash severity (Dumbaugh and Rae 2009), particularly in urban areas, including small towns, where pedestrians, cyclists and driveways are common (CALTRANS 2014 Larson 2018).

Table 3 Forging Design Versus Slow Speeds (Larson 2018)

| Forgiving Design | Forgiveness of Slow Speeds |
|---|--|
| <i>Suitable for undeveloped rural areas</i> | <i>Suitable for more developed urban areas and towns</i> |
| 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 which can reduce crash severity on higher-speed roads in undeveloped areas, but by increasing vehicle traffic speeds tends to increase crash severity in urban areas with mixed development were there is more walking, cycling and cross traffic.

Complete streets are roadways designed to accommodate diverse users and uses, including walking, cycling, public transit, automobile travel, nearby businesses and residents. Complete streets planning recognizes that roadways often serve diverse functions including through travel, recreational walking, socializing, vending, and nearby living, which must be considered and balanced in roadway design and management. This tends to increase travel safety, particularly for pedestrians and cyclists, and by improving active and public transportation, reduce total vehicle travel and accidents.

Increased street connectivity and complete streets planning are major components of new urbanist (also called neo-traditional) urban design. Such planning tends to significantly reduce vehicle travel and increase traffic safety (Ewing and Dumbough 2009). 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).

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 create 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). 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 (Chester, et al. 2015). This suggests that local crash casualty rates decline 5-15% if reduced parking allows a community to become compact and multimodal. 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, multimodal 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%, and each additional big box store increased total crashes 6.6%, while pedestrian-scaled commercial or retail uses were associated with a 2.2% reduction in crashes); 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 authors conclude that many urban and roadway planning practices previously considered to increase traffic safety, such as separation of residential, commercial and recreational activities, and hierarchal road systems, actually increase total crash and fatality rates by increasing total vehicle travel and traffic speeds.

The most compact and multimodal 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 multimodal 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 multimodal 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 are 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%. |
| Commuter 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 multimodal planning | Supports more multimodal 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 are often affected by the analysis scale and perspective. Many of these strategies can significantly reduce vehicle travel and crash rates within a particular area or among a particular group so their total impacts depend on how broadly they are implemented and the amount of latent demand that exists for those options. For example, Commute Trip Reduction programs often reduce affected commute automobile travel by 5-30%, so their total impacts depend on the portion of workers affected by such programs, and 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, multimodal 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 ($85\% \times 90\% \times 95\% = 73\%$), 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 can support existing traffic safety programs. 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 functional alternatives to driving. As a result, traffic safety programs should identify transportation system gaps that make it difficult to get around without 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 multimodal 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 Multimodal planning, TDM and Smart Growth are the policy tools that allow this to occur.

⁶ Conventional zoning codes often apply the highest 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 prevents the development of neighborhood drinking establishments accessible by walking. Allowing more neighborhood restaurants, bars and pubs is an excellent way to 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 current 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 biases decisions in favor of automobile-oriented strategies over solutions that involve TDM and Smart Growth.

Table 5 Comparing Analysis Frameworks

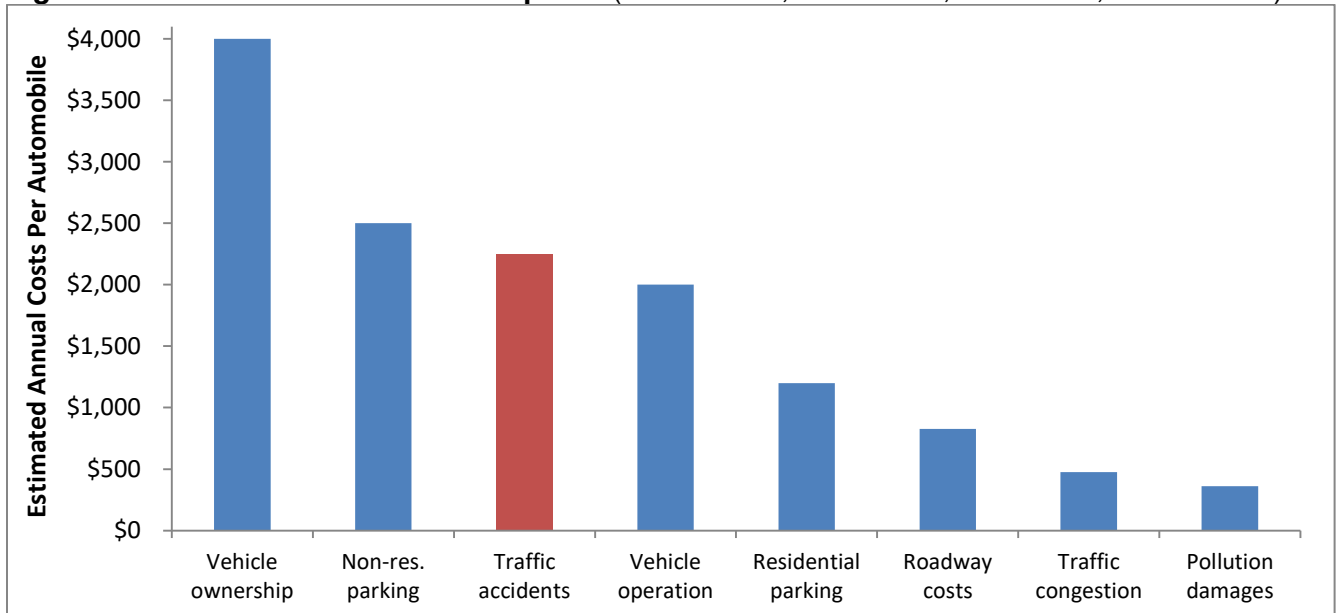
| Factor | Current | New |
|--------------------------|---|--|
| Units of exposure | Distance-based units (e.g., casualties per 100 million vehicle-miles or billion vehicle-kilometers) | Per capita (e.g., casualties per 100,000 residents) |
| Perspective | Internal (user) impacts, such as casualties 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. | 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 usually considers crash costs alone, the new paradigm considers all significant impacts caused by traffic safety strategies. 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 other co-benefits besides safety, while many new paradigm safety strategies provide multiple benefits. For example, improving non-auto modes, pricing reforms and Smart Growth development policies can 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 multimodal 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.

Most traffic safety programs reflect the current 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 seventeen major traffic safety programs considered in Table 6, only five mention vehicle miles of travel (VMT) reduction strategies, and none provide guidance on evaluating or implementing them.

Table 6 Review of Traffic Safety Programs (APTA 2016)

| Program | VMT Reduction Safety Strategies |
|---|---|
| <i>Countermeasures That Work</i> , National Highway Traffic Safety Administration (http://bit.ly/2zMe3Dm) | None |
| <i>Desktop Reference for Crash Reduction Factors</i> , ITE (www.ite.org) | None |
| <i>Developing Safety Plans: Manual for Local Rural Road Owners</i> , Federal Highway Administration (http://bit.ly/2px3hIA) | None |
| <i>Getting to Zero Alcohol-impaired Driving Fatalities: A Comprehensive Approach to a Persistent Problem</i> (www.nap.edu/download/24951) | Recommends improving public transportation and ridehailing services |
| <i>Global Status Report on Road Safety</i> , World Health Organization (http://bit.ly/1GsQ3Dl) | Recommends walking, cycling and transit improvements. |
| <i>Highway Safety Manual</i> , AASHTO, (http://bit.ly/2oF4Xix) | None |
| <i>Highway Safety Program Guidelines</i> , Governors Highway Safety Association (www.ghsa.org) | None |
| <i>Motor Vehicle PICCS</i> , CDC (www.cdc.gov/motorvehiclesafety) | None |
| <i>Roadway Safety Guide</i> , Road Safety Foundation (www.roadwaysafety.org) | None |
| <i>Safe Ride Programs</i> , Mothers Against Drunk Driving (www.madd.org) | None |
| <i>The Injury Research Foundation</i> (www.tirf.ca) | None |
| <i>Toward Zero Deaths</i> (www.towardzerodeaths.org) | None |
| <i>Traffic Safety Fundamentals Handbook</i> , MDOT (http://bit.ly/2qbVvNq) | None |
| <i>Transportation and Health Tool</i> , USDOT and CDC (www.transportation.gov/transportation-health-tool) | Recommends multimodal planning for safety and health. |
| <i>Transportation Planner's Safety Desk Reference</i> , US Department of Transportation (http://bit.ly/2oFbz0j) | Recommends some vehicle travel reduction strategies. |
| <i>World Report on Road Traffic Injury Prevention</i> , Global Road Safety Partnership (www.grsroadsafety.org) | Recommends demand management strategies. |
| <i>Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System</i> , (http://bit.ly/2nQZlmp) | Recommends some vehicle travel reduction strategies. |

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

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. TDM and Smart Growth are generally evaluated based on their congestion and emission reductions, safety benefits are often overlooked. Most traffic safety reference documents only consider targeted safety strategies; few mention TDM and Smart Growth strategies, and those that do provide little guidance for evaluating their safety impacts and benefits, or how they can be implemented.

Conventional traffic safety paradigm advocates point out that most crashes involve special risk factors, such as youth, senior or impaired driving, and so consider targeted safety strategies are most cost effective. From this perspective it seems inefficient and unfair to reduce total driving for safety sake, since this punishes all drivers for errors made by an irresponsible minority. However, so even a perfect driver who never errors increases safety by reducing mileage, and therefore their exposure to 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, each 1.0% reduction in average-risk mileage should reduce casualties by more than 1.0%, and even reductions in lower-risk driving tends to increase safety (Edlin and Karaca-Mandic 2006).

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 traffic 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 we already have sufficient information to make reasonable predictions of new safety strategy impacts.

New paradigm safety strategies often provide greater total safety gains and benefits than recognized by conventional metrics because their impacts are synergistic and provide external benefits. For example, because walking and cycling have relatively high crash casualty rates per mile or kilometer of travel, but by improving sidewalks, crosswalks, bikelanes, and calming traffic, their crash rates decline, and since they impose minimal risk on other road users, total crash rates tend to decline in a community as active mode shares increase. In addition, walking and cycling improvements support public transit use and encourage more compact development, and if implemented all together these changes encourage some households to reduce their vehicle ownership, which tends to leverage additional reductions in vehicle travel and crash risk. Table 7 lists various strategies that can provide synergistic traffic safety benefits.

Table 7 Recipe for Multimodalism

| 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 multimodal 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 distinction is arbitrary. Traffic safety programs now include road and vehicle design standards, law enforcement, business regulations, and extensive social marketing, there is nothing inherently different about TDM and Smart Growth strategies. These are sometimes criticized as *social engineering* which deprives residents of preferred travel options and reduces economic productivity, arguments that are generally false. In fact, many TDM and Smart Growth strategies remove existing market distortions, such as minimum parking requirements that subsidized automobile travel, and dedicated highway funding that underinvests in 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, and nearly 60% report driving due to inadequate alternatives. More multimodal planning responds to these consumer demands, which would increase safety among other benefits.

Another criticism is that major transport and land use changes take too long to achieve benefits, but as Table 3 indicates, many new paradigm strategies can be implemented in a few years. Experience indicates that communities can achieve significant safety gains within a few years by applying more multimodal planning, TDM and Smart Growth policies. As Figure 18 showed, between, 2004 and 2014, traffic fatality rates declined about 2.5 times more in cities with multimodal planning and Smart Growth policies than in cities with conventional planning and development policies (PBOT 2016; SDOT 2015), which suggests that in less than a decade, 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 have worked on conventional traffic safety programs; vehicle travel reduction safety strategies seem defeatist and a criticism of their previous efforts. These responses misrepresent the issues. The new traffic 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 are often justified.

Conclusions and Recommendations

After a half-century of progress, traffic casualty rates ended their downward trend and recently started to increase. This indicates that conventional safety strategies are becoming less effective so new approaches are needed to achieve ambitious safety goals.

Recent research improves our understanding of traffic risks and potential new safety strategies. Numerous studies using various methods and data sets indicate that *exposure*, the amount that people travel, is a critical risk factor: increased vehicle travel tends to increase crashes. Since most casualty crashes involve multiple vehicles, even a perfect driver who makes no errors increases safety by reducing mileage, because this reduces the chance that they will be a victim of another driver's mistake. A paradigm shift is needed to apply this knowledge.

The current paradigm assumes that most driving is safe, and so favors safety strategies that target special risk factors. 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 traffic safety. This recognizes the safety benefits provided by vehicle travel reduction strategies that reduce exposure.

Table 8 **Scope of Safety Programs**

| Conventional Safety Programs | New Paradigm Safety Programs |
|---|--|
| <ul style="list-style-type: none"> • Anti-impaired and distracted driving campaigns. • More testing for youth and senior drivers. • Roadway design improvements. • Vehicle design improvements. • Vehicle occupant crash protection. | <ul style="list-style-type: none"> • More multimodal 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 affect policy and planning decisions. The old paradigm relies on distance-based risk indicators, and so ignores the additional crashes caused by policies which induce additional vehicle travel, and the safety provided by vehicle travel reductions. New Paradigm strategies tend to provide many co-benefits, and so are supported by comprehensive analysis. For example, many vehicle travel reduction strategies can reduce consumer costs, traffic congestion, roadway costs and pollution emissions, plus improve mobility for non-drivers and increase public fitness and health.

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

This is not to suggest that automobile travel should be eliminated for safety sake. However, there is evidence 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 multimodal planning, Smart Growth policies, and TDM programs. This research suggests that the traffic safety can be one their greatest benefits.

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