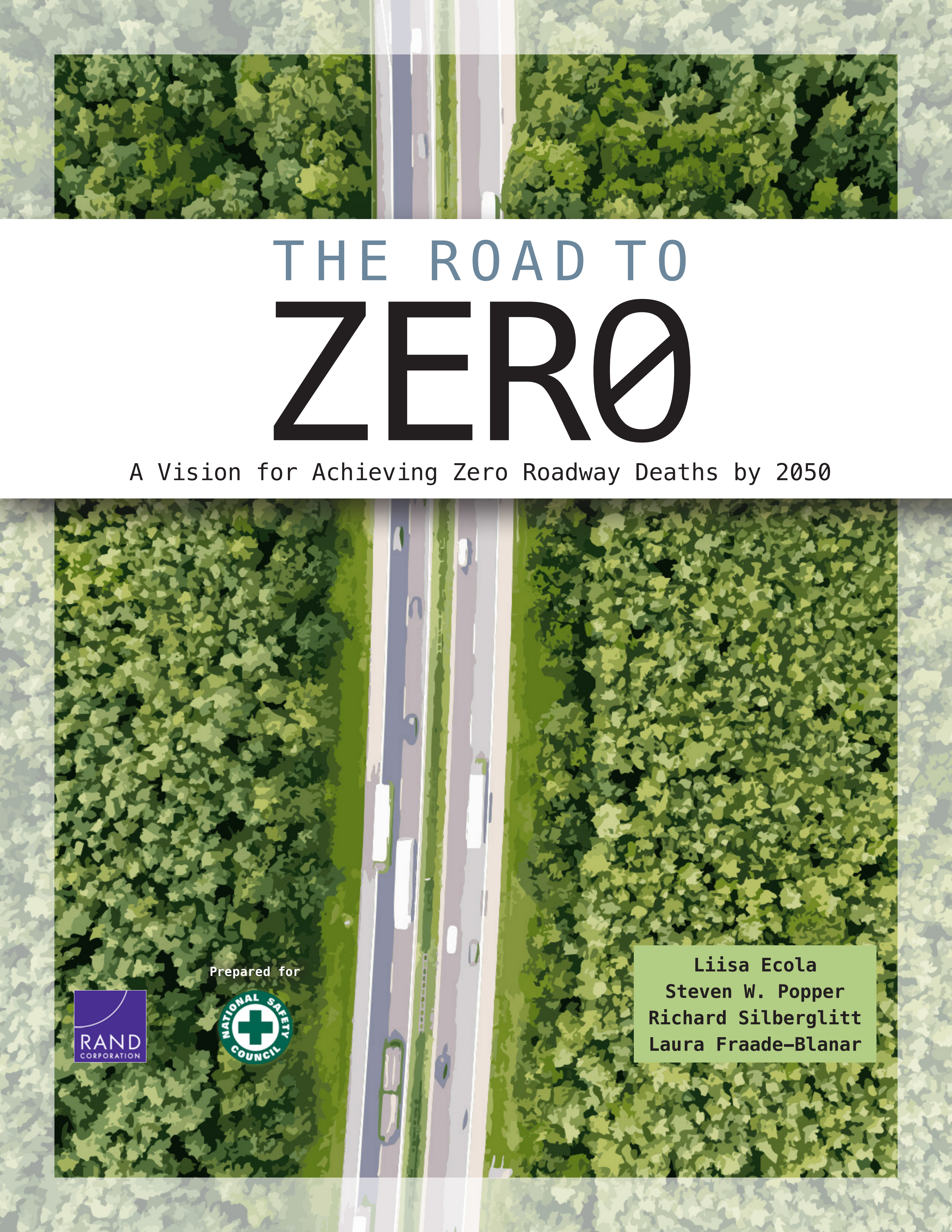


THE ROAD TO ZERO

A Vision for Achieving Zero Roadway Deaths by 2050

Liisa Ecola
Steven W. Popper
Richard Silberglitt
Laura Fraade-Blanar

Prepared for
NATIONAL SAFETY COUNCIL

RAND CORPORATION

For more information on this publication,
visit **www.rand.org/t/RR2333**

Published by the RAND Corporation, Santa Monica, Calif.

Preface

With this report, RAND continues a history of work in both traffic safety and scenario development and analysis. This report develops a scenario for the year 2050 in which not a single person in the United States dies in a traffic crash. This scenario is intended to inform and help coordinate future efforts in traffic safety across multiple stakeholders. We developed this scenario based on the results of three stakeholder workshops, held in 2017, that brought together participants in the recently instituted Road to Zero Coalition who represent a variety of stakeholders in traffic safety—professional engineering and planning organizations, public-sector organizations, safety advocates, vehicle manufacturers, technology developers, public health, emergency medical and trauma organizations, and law enforcement and judicial system representatives. This report does not necessarily represent the views of each coalition member or organization or individual that participated in the three stakeholder workshops.

This work was sponsored by the National Safety Council, which also convened the Road to Zero Coalition. It will also be of particular interest to any of the types of stakeholders listed above, in addition to local, state, and federal elected officials with responsibility for traffic safety.

The research reported here was conducted in the RAND Science, Technology, and Policy program, which focuses primarily on the role of scientific development and technological innovation in human behavior, global and regional decisionmaking as it relates to science and technology, and the concurrent effects that science and technology have on policy analysis and policy choices. The program covers such topics as space exploration, information and telecommunication technologies, and nano- and biotechnologies. Program research is supported by government agencies, foundations, and the private sector.

RAND Justice, Infrastructure, and Environment conducts research and analysis in civil and criminal justice, infrastructure development and financing, environmental policy, transportation planning and technology, immigration and borders protection, public and occupational safety, energy policy, science and innovation policy, space, telecommunications, and trends and implications of artificial intelligence and other computational technologies.

Questions or comments about this report should be sent to the project leader, Liisa Ecola (liisa_ecola@rand.org). For more information about RAND Science, Technology, and Policy, see www.rand.org/jie/stp or contact the director at stp@rand.org.

Contents

APPENDIXES

Figures and Tables

Figures

Tables

Summary

2050: The Year of Zero Roadway Deaths

Imagine yourself in 2050, the first year in which not a single person in America died in a traffic crash.

How can that be? The United States' population has exceeded 400 million. The demand for mobility has increased with the population and improved access to transportation, especially for groups that previously had limited mobility options.

It's thanks to some amazing strides we've made since the 2010s in several different areas. Nearly all vehicles, including motorcycles, now have high levels of vehicle automation, whether they are self-driving or human-driven. Almost all cars now brake automatically, warn drivers about objects in their blind spots, park themselves, adjust their speed, and stay in their lanes. While crashes still happen, there are many fewer of them.

In 2050, those crashes are less severe, in part because of changes to how we build roads. Roadways are designed to reduce speed in safety-critical areas and lessen the chances of the most severe crash types, such as head-on collisions, while allowing faster travel in areas that are safer and where there are few potential conflicts among vehicles or between vehicles and pedestrians or cyclists. Over the past decades, planners and engineers have prioritized changes to the highest-risk roads, which are identified by collecting and analyzing detailed data.

Roadway design has also evolved, becoming entirely performance-based, resulting in more-innovative configurations leading to improved safety. Techniques that are routine in 2050 include physical separation of opposing traffic lanes, safer pavements that eliminate edge drop-offs, and surfaces that help prevent skidding. The United States has been using these techniques to build new roads and redesign or retrofit existing ones for several decades now, allowing vehicles, bicyclists, and pedestrians to share the road more safely.

Remote rural roads are still more hazardous—they always have been—but safety technologies are particularly effective in preventing the most dangerous rural crashes, such as head-on collisions and single-vehicle run-off-the-road crashes. Safety on rural roads, where emergency response times are higher than on city streets, has been further enhanced by improvements in trauma care, including increased investment in emergency response, together with enhanced connectivity for faster crash notification, improved injury prediction, better communication with 911 and first responders, and more-effective emergency medical care.

Improvements in digital infrastructure in rural areas, together with widespread adoption of vehicle-to-vehicle communication, have also meant reductions in crashes, because vehicles can share safety information with one another and with their environment and use this information to avoid collisions. Although the safety gap between rural and urban areas has not quite closed, thanks to technology, it is narrower now than ever.

The safety effects of these changes have been extended by policies and practices that protect the most-vulnerable road users and incentivize safe driving and adoption of advanced safety technology. Reducing speeds in cities has helped reduce pedestrian and cyclist deaths. Insurance companies have incentivized use of automated vehicles, especially by high-risk drivers. Some cities and companies that manage a variety of mobility options through a single account—"mobility services"—have made it easy to get around without having to drive, and they have been early adopters of advanced safety technology.

A wide variety of groups involved with traffic safety committed to implementing evidence-based safety measures and began adopting a "Safe System" approach in the first decades of the 21st century. This turned the traditional thinking about safety on its head—instead of seeing humans as the offenders, responsible for most crashes because of their bad habits, planners and engineers began thinking that the system itself needs to be safe.

Given that it's impossible to eliminate human error entirely, planners and engineers began thinking of ways to design roads and vehicles to accommodate human error to make the entire system safer. This was paired with efforts toward creating a "safety culture" that emphasizes the value of safety in every decision made by every person. Safety has become a shared responsibility among those who use the system and those who design and operate the system. A whole generation is now using these approaches.

In 2050, businesses are investing in safety and sharing in the benefits of healthier employees and a more supportive community. Innovative finance methods, such as social impact bonds that pay investors for positive outcomes, have created opportunities for large-scale renewal and improvement projects. Other forms of public-private collaborations—not unlike the push for electrification of rural areas in the early 20th century—have helped upgrade safety in rural areas.

As the number of crashes began to fall, individual attitudes about road safety and personal responsibility changed substantially. In much the same way that people changed their minds about alcohol-impaired driving in the 1980s and 1990s, drivers in 2050 feel that their communities expect them to comply with speed limits and to not drive distracted. Widespread community road-safety action programs have connected individuals with the larger movement and resulted in a further dramatic advance in norms and social expectations—for example, that nobody drives impaired and everybody wears a seat belt.

Eliminating roadway deaths has lifted Americans' quality of life in very obvious ways. On an individual level, parents no longer worry about teens driving, adults don't fret about "taking the keys away" from an aging mom or dad, and people going home after a night on the town call an automated vehicle to drive them home. On the broader level, the financial effects and time savings are considerable. In 2010, it was estimated that crashes cost the U.S economy roughly $835 billion, and there were 15,000 crashes per day. Now, 40 years later, police and emergency responders can shift attention to other needs, states and insurance companies can spend less on medical expenses, and the federal government can spend less on disability payments. Reaching zero fatalities on our roadways is a crusade that was once thought quixotic, but it's the world of 2050.

Why Zero? Is This Really Possible?

Back in the world of 2018, the idea of a future with literally zero roadway deaths seems like a pipe dream. Roadway deaths—deaths due to traffic crashes—have been increasing, not decreasing, over the past two years. In 2016, more than 37,000 Americans died on the roads—5,000 more people than died in 2011.

The United States has made good progress in road safety over the long run, despite this recent backsliding, but incremental progress is no longer acceptable given the increasingly rapid advances in technology and the wealth of knowledge about how to prevent crashes. Inspired by the goals and progress in other countries, the broader traffic safety community is now working together to achieve a common vision—that by 2050, nobody would be killed in a traffic crash on U.S. roads.

Why zero? That raises the question, "What level of death on the roads should we as a society accept?" How many of our own family members, classmates, neighbors, or people in our community losing their lives to crashes would be considered an appropriate number? These deaths are preventable—the safety community deliberately calls them *crashes*, not *accidents*, for this very reason. *Accident* implies unforeseeable circumstances or a twist of fate, but crashes can be prevented. The number of roadway deaths has long been accepted as a "price" of mobility, but 37,000 deaths is more than 100 Americans killed per day. Imagine the outcry if plane crashes or natural disasters killed 100 Americans every day.

As to whether this is possible, the country has seen enormous improvements in safety in other areas. As of 2017, no commercial U.S. airline passenger flight has had a fatal crash since 2009, thanks in large part to a collaborative government/industry safety management system. The number of people who smoke has fallen by more than half in 50 years, thanks to education campaigns and laws limiting where people can smoke.

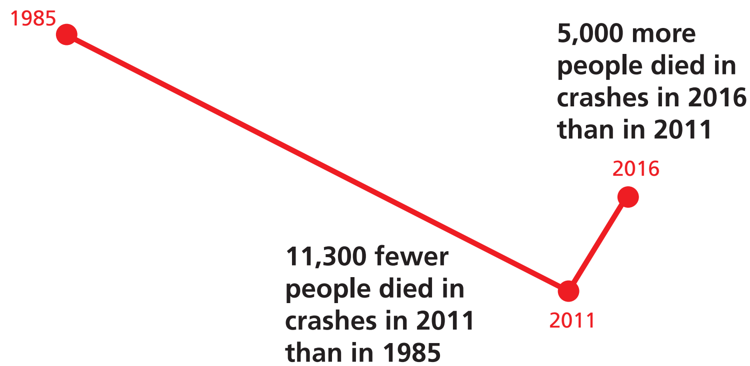
In addition, the experiences of other high-income countries show that more-significant change is feasible. In 2013, the U.S. roadway death rate was more than twice the average of other high-income countries, and almost all of those countries have seen greater improvement than the United States over the past two decades. Sweden, where the idea of Vision Zero began, has seen declines in its crash death rates of 50 percent or more, using the Safe System approach. A number of U.S. cities and states have also embraced this Vision Zero strategy.

While it will take a generation, the success of other countries and some U.S. cities demonstrates that a combination of approaches makes this an achievable goal.

The Urgency: Roadway Deaths Are Moving in the Wrong Direction

The more than 37,000 people killed in crashes in 2016 represent a troubling reversal in previous progress. For the past several decades, all the important measures of roadway deaths—the total number, the number per population, the number per miles driven—were going down as a result of several factors, including changes in driving patterns, increased seat belt use, improvements in vehicle design, more-forgiving roadway designs, and stronger graduated driver's license programs for teen drivers. After reaching an all-time low in 2011, these trends began reversing in 2015, and got even worse in 2016. Figure S.1. shows the extent of the problem.

Figure S.1
Decades-Long Progress in Reducing Roadway Deaths Has Begun Reversing in the Past Five Years



SOURCE: National Highway Transportation Safety Administration, no date.
RAND *RR2333-S.1*

We Know Who Is Dying and Why

Who dies on U.S. roads, and why? While crashes affect every state, type of road user, and demographic group, three groups are more frequently affected than others:

- **Young people** are affected disproportionately, as crashes are the leading cause of death for people age 15 to 24. Because so many victims are young, crashes are also a leading cause of years of life lost—that is, the number of years people would have lived had they not died of an illness or injury. Crash risks for teen drivers are higher than for any other age group.
- **Men** die more often in crashes than women, in all categories of crashes; 71 percent of people killed in crashes are men. By crash type, the percentage of fatalities that are men ranges from 49 percent of car passenger deaths to 99 percent of large truck deaths.
- **Rural road users** are disproportionately affected as well. In 2015, an estimated 19 percent of the U.S. population lived in rural areas, yet almost half of roadway deaths occurred on rural roads. Rural roads are more dangerous than urban ones; for the same number of miles driven, more than twice as many people die in rural areas.

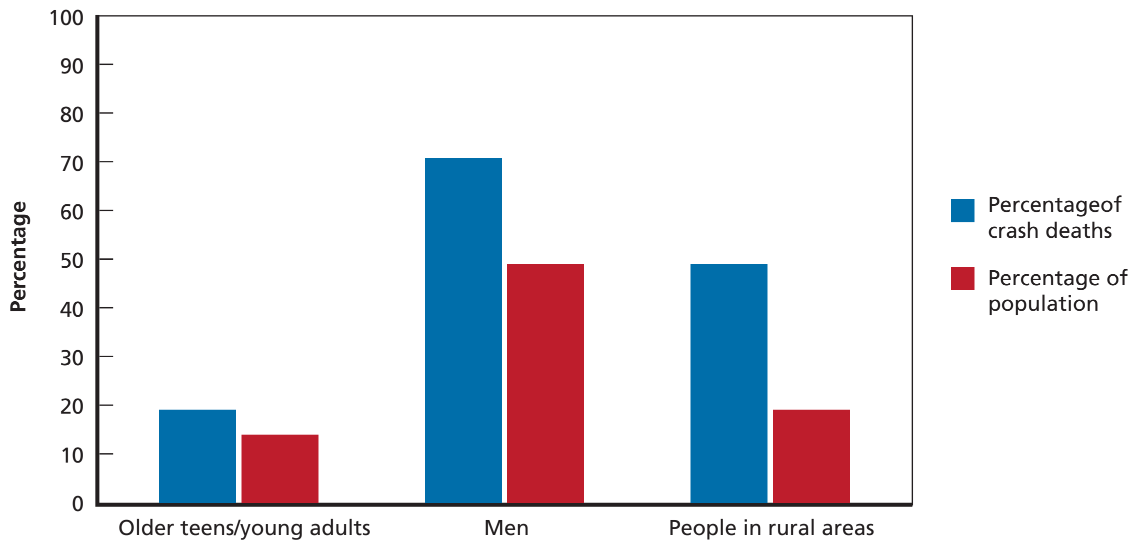
Figure S.2 shows these comparisons.

While not a demographic category, pedestrian risk has increased dramatically in recent years. Of the 5,000 more people who died in motor vehicle crashes in 2016 than in 2011, 1,500 were pedestrians. In 2015, pedestrian deaths accounted for 15 percent of all traffic fatalities, and about three-quarters of pedestrian deaths occurred in urban areas.

In terms of why, we can classify the reasons that people die in car crashes in three ways:

1. **What causes the crash:** Crashes stem from many factors. A main one is that current vehicle and roadway designs require that drivers be constantly alert and vigilant. However, drivers predictably become distracted, inattentive, tired, or otherwise impaired. This misalignment between human behavior and system design underlies the great majority of fatal crashes.

Figure S.2
Proportion of U.S. Roadway Deaths Relative to Proportion of Population



SOURCES: Older teen/young adult crashes: Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, no date (b); Men: Insurance Institute for Highway Safety, 2017a; People in rural areas: NHTSA, 2017b; Population: Howden and Meyer, 2011.
NOTE: Crash data for 2015; proportion of population from 2010 Census.
RAND *RR2333-S.2*

2. **Who survives the crash:** Many factors determine crash survival. The presence and use of safety features in cars—seat belts, airbags, improved door locks, and many others—are responsible for saving tens of thousands of lives each year. Roadside safety hardware, such as breakaway sign poles and smoother redirecting guardrails, makes crash outcomes less severe. Occupants that buckle up are more likely to survive crashes. Motorcycle helmets save lives as well. Speed is also an important factor in surviving a crash, whether inside or outside the vehicle—the lower the speed, the less severe the outcomes.
3. **Who gets medical treatment:** Of all crash fatalities, about half survive the initial crash but later die from their injuries. Enhanced emergency medical personnel capabilities, use of a medical helicopter, and reaching an appropriate trauma center can improve crash survival.

We Know How to Reduce Roadway Deaths

The substantial improvements in road safety that the United States has seen over the past several decades can be attributed to many factors. One is better vehicle technologies developed by automakers, better in terms of avoiding crashes and protecting those in the vehicle—such technologies save 27,000 lives every year. Technologies such as airbags and electronic stability control are already standard, but advanced driver assistance systems (ADAS), such as automatic emergency braking, blind spot monitoring, and lane departure warning, are being offered on more and more vehicles.

Another factor involves the ways in which roads are designed and constructed to increase road safety. In more-rural areas, these include designs for roadsides that reduce the number of obstacles that cars would strike if they run off the roads, pavements that reduce skidding, and increased use of rumble strips, crash cushions, and guardrails. In more-urban areas, they include designs for urban intersections that reduce the speed of turning cars, broad use of roundabouts to bring down vehicle speeds in intersections, and shorter pedestrian crossing distances that make it safer and easier for people to cross busy streets.

Credit is also due to a wide range of safety experts: engineers, researchers, and public safety and public health professionals who have garnered extensive evidence on which countermeasures are most effective. Strong leadership from safety-minded policymakers at the local, state, and federal levels has resulted in the adoption of laws, regulations, and funding for effective policies. Examples of effective policies include increasing the minimum drinking age from 18 to 21 years old and reducing the legal blood alcohol level to 0.08 percent. When coupled with education and enforcement, such policies cut the number of alcohol-impaired driving deaths by half. The enactment and enforcement of mandatory seat belt use laws in nearly every state have increased seat belt use from less than 20 percent to 90 percent.

Further safety gains can be made with current safety approaches, as some of the most effective policies have not been used to their full potential. However, with 260 million registered vehicles, 215 million drivers, 4 million miles of roads, and steadily increasing annual vehicle mileage, the cumulative risk on U.S. roadways will outpace past and current countermeasures unless we double down on our efforts.

In recent years, more attention has been given to two fundamental concepts, *safety culture* and the *Safe System* approach. Safety culture is the broad set of attitudes and beliefs that underlie people's decisions. Safety culture affects judgment about priorities in individual behavior and support for collective decisions about what is most important in our communities. Getting to zero deaths will involve countless individual and collective decisions, and a strong safety culture is an essential prerequisite.

The Safe System approach is integral to the Vision Zero movement that started in Sweden in the 1990s and began spreading to the United States a decade later. Vision Zero begins with a commitment to focus on the changes necessary to eliminate roadway deaths rather than being satisfied with incremental progress, and goes on to include the creation of a transportation system that accommodates predictable human error without resulting in roadway deaths.

In the United States, the *Toward Zero Deaths National Strategy* was launched in 2014, adopting the zero-focused imperative along with a strong commitment to creating a safety culture, and the strategy has since been adopted by many states. More recently, a number of U.S. cities have adopted the Vision Zero approach with particular dedication to building a Safe System.

Both the safety culture and Safe System movements are potentially powerful tools for achieving the changes needed to reach zero roadway deaths.

With the Right Policies, Technologies, and Strategy, We Could Prevent All Roadway Deaths

From 1985 to 2011, roadway deaths per 100,000 population declined in the United States by more than 40 percent and deaths per mile traveled by more than half. What would it take to eliminate roadway deaths altogether?

We know that full deployment of the most-effective safety policies, including laws and enforcement, can reduce roadway deaths. But so far, the combined potential of all our safety efforts has not been sufficient to achieve zero roadway deaths. However, that situation is changing with the emergence of advanced vehicle technology: For the first time, achieving zero roadway deaths by 2050 seems feasible. Advanced technology could close the gap in a 30-year period, but it must be supported by policies and programs that are known to be proven effective.

In the near term, technologies that are already in production or nearing introduction promise dramatic safety benefits. Up to 10,000 lives could be saved if currently available ADAS, such as automatic emergency braking, lane departure warning, and blind spot detection systems, were fully effective and on every vehicle. Passive alcohol impairment detection systems, such as the Driver Alcohol Detection System for Safety (DADSS), could save more than 7,000 lives annually if all cars were so equipped.

In the longer term, when vehicles with high levels of automation are fully developed, self-driving systems promise to have a tremendous impact on safety. Automated vehicles are not likely to have reached their full potential by 2050, but they are very likely to provide a significant safety benefit. Because cars today are lasting longer than ever before—the average age of a passenger car is 11.5 years—full fleet penetration will take decades.

While preventing crashes is the highest priority, improving post-crash response also represents a significant opportunity for saving lives. Twenty percent of trauma deaths could be prevented with optimal trauma care. Improved trauma care will be essential in addressing both fatalities and severe injuries in motor vehicle crashes.

Reducing roadway deaths to zero in 30 years is feasible. It could be achieved by doubling down on efforts to deploy the safety and medical approaches now available, accelerating the implementation of advanced technologies, and prioritizing safety in both individual and collective decisions.

The Road to Zero Coalition Has Taken on This Challenge

The Road to Zero Coalition was established by assembling a wide-ranging group of stakeholders to provide a major push to achieve zero roadway deaths. This is the largest and broadest coalition that has ever focused on roadway safety in the United States. The RTZ Coalition was launched in 2016 in reaction to sharp increases in roadway deaths and has brought together more than 650 professional associations, businesses and industry associations, safety groups, government agencies, and nonprofit organizations. With a clear, compelling, and unifying vision, the RTZ Coalition is a powerful force for change.

The National Safety Council commissioned the RAND Corporation to develop a process for the RTZ Coalition to create an overall vision and strategy to reach zero deaths. The process included convening three intensive workshops in 2017 to bring together disparate stakeholders to discuss vision, goals, obstacles, approaches, strategies, tactics, and ultimately a scenario of how zero deaths could be achieved by 2050 and what that future might look like. This report is the result of that process. While this report presents one of potentially many scenarios, it incorporates the perspectives and suggestions of a wide variety of road safety stakeholders.

The Overall Strategy Combines Three Approaches

To reach zero, the RTZ Coalition determined that three interrelated approaches are needed:

1. Double Down on What Works

The United States has both an accumulated body of evidence-based countermeasures and a well-established network of experts who can deploy them. The RTZ Coalition envisions engaging political leaders and decisionmakers to support policies and identify new or shared resources for research, roadway design and construction, vehicle engineering, law enforcement, consumer education, and trauma care. Because motor vehicle crashes represent the single largest cause of workplace fatalities, the RTZ Coalition will look to establish partnerships with businesses at the state and community levels as an important source of new energy for such change.

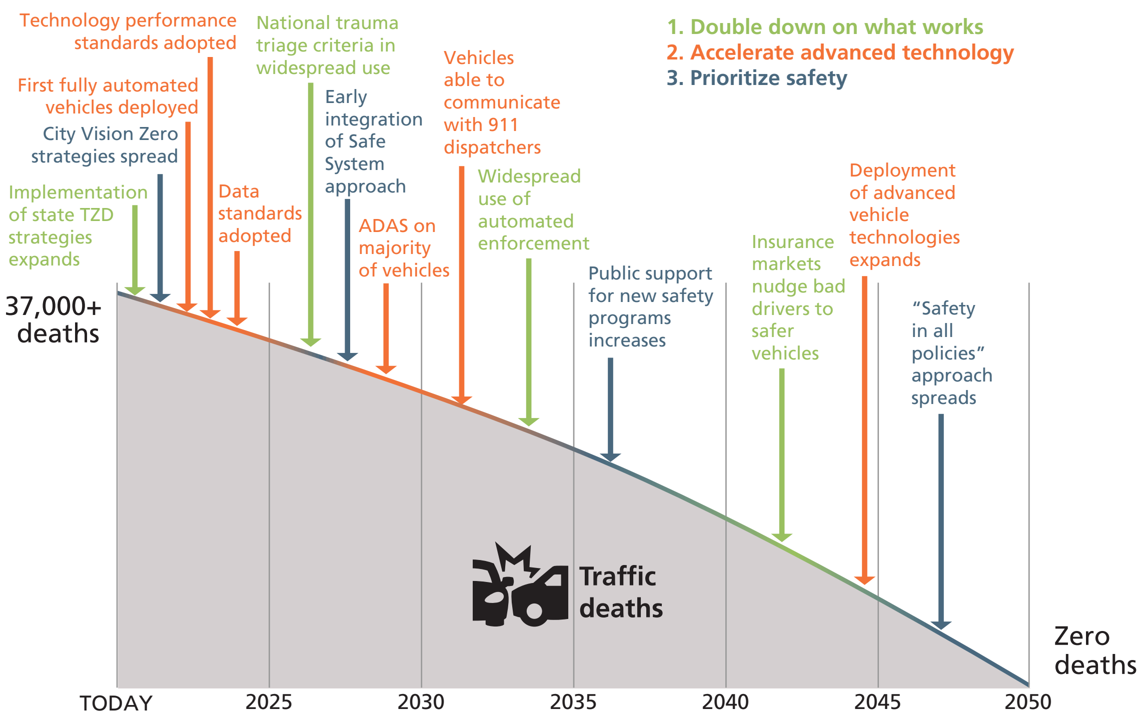
2. Accelerate Advanced Technology

Existing and emerging technologies promise large advances in safety. ADAS—such as automatic emergency braking, adaptive cruise control, and lane-keeping—are already being introduced into the fleet. Each year, these technologies are offered on a greater number of new vehicles and their safety performance improves. The rate of technology development, both in vehicle systems and in overall connectivity, is expected to increase rapidly. To accelerate the deployment of these vehicle and infrastructure technologies and maximize their potential reach in a 30-year timeframe, the RTZ Coalition envisions new partnerships among manufacturers, technology providers, emergency medical and trauma systems, public safety/health groups, and the public sector to identify and prioritize safety applications and opportunities, to evaluate safety benefits, and to increase consumer interest and adoption through education and incentives.

3. Prioritize Safety

The third approach focuses on methods to facilitate change. Key among these are creating a safety culture and adopting a Safe System approach. A pervasive safety culture is an essential ingredient for reaching zero roadway deaths and can be nurtured through awareness, education, and constant reinforcement. Safety needs to be among the highest priorities in decisions ranging from where to cross the street to where to devote federal funds. There are many opportunities to nurture a safety culture. For example, fostering development of community road safety action programs may prove effective in engaging citizens, corporations, and governments and changing social norms. Adopting the Safe System approach involves a fundamental shift from the common assumption that crashes generally happen because of people's behavior. Instead, a Safe System approach assumes that people will occasionally, but inevitably, make mistakes behind the wheel and that the overall transportation system should be designed to be forgiving so that these mistakes do not lead to fatal outcomes. The Safe System approach also involves commitment to analyze safety problems, identify changes that bring the best return on investment, and implement these improvements throughout the system to prevent further occurrences.

Figure S.3
Three Approaches Working Together to Reduce Roadway Deaths to Zero



NOTE: TZD = Toward Zero Deaths.
RAND *RR2333-S.3*

These three approaches are essential and interconnected; none of the three will work effectively independent of the others. They are complementary, mutually dependent, and synergistic. (See Figure S.3.) For example, a growing safety culture will foster safe behaviors, such as driving sober and within the speed limit, and create a strong market for advanced safety technologies (including automated vehicles). As people become accustomed to the safety benefits of advanced technology and improved roads, they will become less tolerant of risky behavior and more supportive of the changes needed to build a Safe System. The effect of each change is intertwined with the others and mutually supportive—a "virtuous cycle."

Actions Taken Now Can Lay the Groundwork

Each of the actions listed below will further the goal of reaching zero roadway deaths. These actions can be championed by members of the RTZ Coalition and others who are dedicated to eliminating preventable deaths on our roadways. Although traveling the full length of the Road to Zero will take time, a number of short- and mid-term actions will show immediate benefit and build momentum toward zero deaths. The strength of this movement is in the diversity of partners and in their dedication to working individually and collectively to overcome the persistent social burden of roadway death and injury.

Federal officials:

- Provide leadership that prioritizes achieving zero roadway fatalities by 2050.
- Promote and support best practices that reduce roadway fatalities, particularly those identified in the *Toward Zero Deaths National Strategy*.
- Encourage consistent adoption of safety policies and practices where essential for efficiency and interoperability.
- Encourage public-private partnerships at the state and city levels to address local safety problems.
- Work with industry to facilitate the development and safe deployment of advanced safety technologies, such as the public-private partnership that is developing the DADSS technology.
- Use incentives and standards as appropriate to accelerate effective safety technology into the market.
- Support new methods for achieving change, including promotion of a safety culture, support for the Safe System approach and Vision Zero principles, public-private partnerships, and innovative funding strategies such as social impact bonds.
- Support efforts to achieve safety goals in rural areas.
- Explore opportunities to align safety and research and development funding with state and local needs and improve return on investment.
- Partner with industry and other stakeholders to develop platforms and systems to collect and analyze data that will generate the information needed to target safety interventions.
- Assess strategies for improving vehicle safety, including partnerships and incentives as well as regulation.
- Encourage consumer education to accelerate adoption of vehicle safety technologies.

State and local officials:

- Provide leadership that prioritizes achieving zero roadway fatalities by 2050.
- Commit to adopting best practices in safety laws, programs, and other investments, particularly those identified in the *Toward Zero Deaths National Strategy*.
- Provide leadership and guidance for creating a safety culture and advancing Safe System and Vision Zero principles in government, industry, and communities.
- Enact and provide adequate resources for the enforcement of strong traffic safety laws.
- Coordinate efforts to ensure consistent state-to-state approaches to deploying automated vehicles in traffic.
- Work with business to identify priority safety needs, support new policies, and align resources.
- Incorporate Safe System principles to identify problems, allocate resources and develop policies, and adjust policies as necessary to accommodate important Safe System changes, such as adjustments in speed limits.
- Take advantage of evidence-based safety and trauma care methods, such as those identified in recent national reports.
- Consider consumer education and other incentives to accelerate adoption of advanced vehicle safety technologies.
- Take advantage of financial incentives provided at the federal level.

- Take more ownership of safety issues that can be addressed at the state level.
- Examine insurance laws to enhance data sharing and permit risk-based pricing where appropriate.

Auto manufacturers and technology developers:

- Work with stakeholders to identify priority safety needs and accelerate widespread adoption of the most-promising life-saving technologies as quickly as possible.
- Work with governments and other stakeholders on adoption of the Safe System approach and promotion of a strong safety culture.
- Participate in efforts to improve data sharing, while enhancing privacy and cybersecurity for the common benefits of product development and research.
- Work with stakeholders to educate consumers about the safety benefits and the safe use of advanced technologies.
- Continue investing in emerging safety technology research.
- Address vulnerable road users in safety research and design.

Emergency medicine and trauma academics, practitioners, and advocates:

- Prioritize investment in trauma system needs and identify methods with greatest return on investment, especially for rural areas.
- Work with local and state governments to prioritize trauma system investments and improve trauma care.
- Participate in forums about data and emergency communications.
- Adopt national trauma triage criteria for crash victims.
- Collaborate with government and business on adopting the Safe System approach and promoting a strong safety culture.

Safety researchers and advocates:

- Educate policymakers at the local, state, and federal levels about the potential of dramatic reductions in motor vehicle deaths and opportunities for change, and when appropriate, urge the adoption of strong laws and regulations.
- Educate consumers about the far-reaching effects of traffic crashes, injuries, and deaths, and about the potential for change.
- Educate professionals who are engaged in managing the transportation system about the need for a safety culture and the Safe System approach.
- Encourage adoption of the safety laws and programs and initiatives identified in the *Toward Zero Deaths National Strategy*.
- Coordinate with other advocacy groups and stakeholders on major safety campaigns.
- Develop partnerships with industry groups on issues of common interest.
- Continue research into evidence-based countermeasures that will reduce crashes and their severity.

Business community and fleet owners:

- Work with local and state governments to utilize the full range of data sources to identify regional safety problems, select solutions, and create change.
- Adopt and enhance safety policies for employees and fleets.
- Adopt and maintain a strong safety culture.
- Demonstrate new technologies and increase consumer interest and acceptance through early adoption.

Insurance companies:

- Work with governments and industry to create a strong safety culture and support implementation of the Safe System approach.
- Participate in forums about data sharing and protecting consumer privacy.
- Educate consumers about the need for improved safety laws and programs, as well as the benefits of advanced safety technologies.
- With better streams of data and regulatory flexibility, differentiate individual drivers and vehicles more precisely and tailor incentives accordingly.

Law enforcement and judicial system:

- Enhance enforcement of existing and new safety laws.
- Participate with local leaders in supporting the safety initiatives identified in the *Toward Zero Deaths National Strategy* and in local Vision Zero efforts.
- Incorporate the latest standardized crash reporting protocols and share data as possible with other city, state, and federal agencies.

Acknowledgments

Many people were involved in the development of this report and the workshops that helped develop it. The work was sponsored by the National Safety Council (NSC), with Jane Terry serving as our primary contact and liaison with the Road to Zero (RTZ) Coalition. NSC CEO Deborah Hersman provided guidance about our work with the RTZ Coalition and inspired workshop participants to think broadly and creatively about a future with zero roadway deaths. Susan Crotty handled the communications and meeting logistics of the expanding RTZ Coalition. Other NSC staff who participated in the workshops included Kelly Nantel and Julian Hoffman.

At the U.S. Department of Transportation, we thank the staff and senior officials who worked with the NSC on thinking through the scenario ideas and to make arrangements to host one of the workshops.

Special thanks is deserved by Matts-Åke Belin of the Swedish Transport Administration, who actively contributed to the process and lent both his academic expertise and his practical experience developing this scenario.

We also thank the many members of the RTZ Coalition Steering Group, who participated in the workshops, provided helpful feedback on interim products, and contributed their many thoughtful and disparate viewpoints to the process. The Steering Group includes Jackie Gillan and Allison Kennedy, Advocates for Highway and Auto Safety; Ian Grossman, American Association of Motor Vehicle Administrators; King Gee and Kelly Hardy, American Association of State Highway and Transportation Officials (AASHTO); Jill Ingrassia and Jennifer Ryan, American Automobile Association (AAA); John Bozzella and Paul Scullion, Association of Global Automakers, Inc.; Collin Mooney and Adrienne Gildea, Commercial Vehicle Safety Alliance; Jonathan Adkins and Russ Martin, Governors Highway Safety Association; Jeffrey Paniati and Jeff Lindley, Institute of Transportation Engineers; Adrian Lund and Jessica Cicchino, Insurance Institute for Highway Safety; Catherine McCullough, Intelligent Car Coalition; Domingo Herraiz and Jennifer Rolfe, International Association of Chiefs of Police; Debbie Weir and J. T. Griffin, Mothers Against Drunk Driving; Linda Bailey, National Association of City Transportation Officials; Brian Roberts, National Association of County Engineers; Dia Gainor, National Association of State Emergency Medical Service Officials; and Leah Shahum, Vision Zero Network. We also appreciate the dozens of other RTZ members who participated in the workshops; too numerous to name here, they are listed by name and affiliation in Appendix E.

Hosting three multi-day workshops required substantial administrative support. At RAND, we thank Adwoa Amofa, Stacey Haughton, Laura Poole, Laurie Rennie, and Beth Seitzinger for their administrative prowess, along with Leanna Shrader and Mo Muhammad of RAND's facilities services. At AASHTO, which hosted our third workshop, we thank Rosemary TenEyck for setting up the arrangements with the State Services Organization in the Hall of the States.

Finally, we thank Marjory Blumenthal, director of RAND's Science and Technology Policy Program, for providing thoughtful advice and review along the way. Our external reviewer, Zachary Doerzaph, director of the Center for Advanced Automotive Research at the Virginia Tech Transportation Institute, and internal reviewer, Charlene Rohr, contributed many helpful comments to the final report.

Abbreviations

3HF	Three-Horizons Foresight
AACN	advanced automatic crash notification
AASHTO	American Association of State Highway and Transportation Officials
ABP	assumption-based planning
ADAS	advanced driver assistance systems
AEB	automatic emergency braking
AV	automated vehicle
CDC	Centers for Disease Control and Prevention
DADSS	Driver Alcohol Detection System for Safety
DOT	U.S. Department of Transportation
ED	emergency department
EMS	emergency medical services
FARS	Fatality Analysis Reporting System
HAV	highly automated vehicle
IIHS	Insurance Institute for Highway Safety
NHTSA	National Highway Traffic Safety Administration
NSC	National Safety Council
RTZ	Road to Zero
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything

CHAPTER ONE

Roadway Deaths: Current Trends and Future Directions

Americans Are Still Dying on the Roads

Despite many advances in road safety over the past decades, more than 100 Americans die in motor vehicle crashes every day. In 2016, the number of Americans killed on the roads—including car and truck drivers and passengers, as well as pedestrians and bicyclists killed in crashes with vehicles—exceeded 37,000 (National Highway Traffic Safety Administration [NHTSA], 2017c).[1] While the exact numbers vary year to year, the death toll is more than 350,000 preventable deaths every decade, making roadway deaths a substantial public health concern.[2]

This number is troubling for two reasons:

Many of the dead are young. Traffic crashes are the leading cause of death for older teenagers and young adults (15 to 24 years old), and the second leading cause of death for children 5 to 14 years old (Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, no date [a] and [b]).[3] Almost one-quarter of those killed are under age 24 (NHTSA, no date).

The trend is going in the wrong direction. For the past several decades, all the important measures of roadway deaths—the total number, the number per 100,000 population, the number per miles driven—were going down. After reaching an all-time low in 2011, these trends began reversing in 2015, and got even worse in 2016 (see Table 1.1).[4]

In 1985,[5] Americans experienced 18.5 crash fatalities per 100,000 population, or 2.5 fatalities per 100 million miles driven. In 2011, the year with the fewest deaths, those numbers

1 Multiple organizations produce annual counts of roadway deaths. This report uses figures published by NHTSA from its Fatality Analysis Reporting System (FARS), since FARS collects extensive information on crash location and contributing factors for every fatal crash. These figures include all persons killed in crashes, on public roads involving any type of motor vehicle, who died within 30 days of the crash. The National Safety Council and the Centers for Disease Control and Prevention (CDC) also publish annual figures but use different definitions that are more inclusive and result in slightly higher numbers.

2 We use the term *roadway death* to mean any death that occurs on a roadway as the result of a traffic crash that involves a motor vehicle. This includes single-vehicle crashes (car, truck, bus, motorcycle), crashes between two or more motor vehicles, and collisions of motor vehicles with pedestrians and bicyclists.

3 These two sets of 2015 CDC figures show that, while unintentional injury (which also includes drowning and fires) is the leading cause of death for children in both age groups 5 to 9 and 10 to 14, the number of children killed in traffic crashes is lower than the number who died of cancer (malignant neoplasms).

4 Figures for 2017 were not available at the time this report was written. An early estimate of the first quarter of 2017 suggested a decline of about 1 percent from 2016 (NHTSA, 2017d).

5 Throughout this report, we use 1985 as a reference point, since it represents a baseline of about 30 years ago, whereas this report looks ahead about 30 years.

Table 1.1
Three Indicators of Roadway Deaths Have Worsened Since 2011

	1985	2011 (lowest point)	2016
Population	237 million	311 million	323 million
Number of people killed in crashes	43,800	32,479	37,461
Number of people killed per 100,000 population	18.5	10.4	11.6
Miles driven	1.7 trillion	2.9 trillion	3.1 trillion (2015)
Number of people killed per 100 million miles driven	2.5	1.1	1.2

SOURCES: NHTSA, 2017c; U.S. Census Bureau, 2016; Federal Highway Administration, 2016.

declined to 10.4 people killed per 100,000 population, and 1.1 per 100 million miles (Insurance Institute for Highway Safety [IIHS], 2017a). Even as population and driving climbed, deaths per population and deaths per miles driven all went down substantially between 1985 and 2011. However, the reverse is true for the past five years (2012 through 2016)—not only have deaths gone up, but they outpaced population growth. Five thousand more people died in 2016 than in 2011.

On one hand, the overall trend since Americans began taking to the roads in vast numbers a century ago is positive: As both the U.S. population and driving increased enormously, the number of people killed per population, and miles driven, steadily declined. This past progress can be attributed to a number of factors, including increased seat belt use, improvements in vehicle design, and stronger graduated driver's license programs for teen drivers.

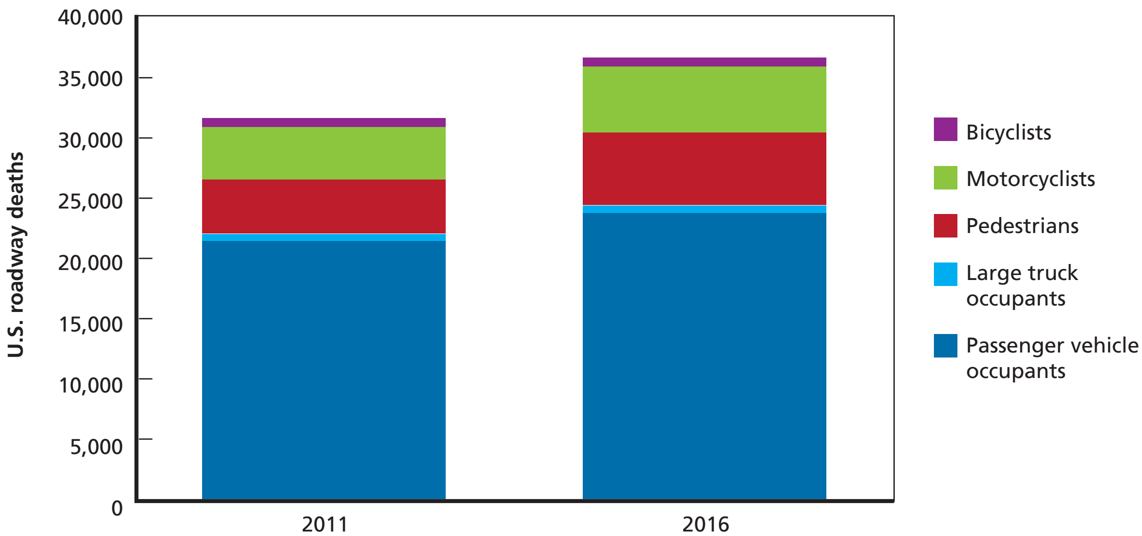
On the other hand, the recent reversal, after decades of progress, is troubling. There is no one single reason for it; roadway deaths have increased because of many causes and across demographic groups. Roadway deaths occur among all road users, although some groups are at greater risk than others. About two-thirds of those killed are drivers and passengers in cars and trucks; the others are motorcyclists, pedestrians, and bicyclists (NHTSA, 2017c). The largest increase in deaths of any road user type was among pedestrians; of those 5,000 more people who died in 2016 than in 2011, more than 1,500 were pedestrians (NHTSA, no date). As Figure 1.1 shows, increases have occurred across all road user types.

The United States could be doing much better in terms of traffic safety, based on comparisons with other high-income countries. In 2013, the U.S. roadway death rate was more than twice the average of other high-income countries, and almost all of those countries have seen greater improvement than the United States over the past two decades (Centers for Disease Control and Prevention [CDC], 2016). Even comparably large countries, such as Australia and Canada, have much lower fatality rates—5.0 and 5.2 roadway deaths per 100,000 population in 2015—and neither has experienced the type of uptick that the United States has since 2015 (Transport and Infrastructure Senior Officials' Committee [Australia], 2016; Transport Canada, 2015). These are less than half the U.S. rate of 10.9 deaths per 100,000 population.[6]

Besides the loss of life and injuries, motor vehicle crashes also have a large economic impact. One study estimates that crashes cost the U.S economy approximately $835 billion

6 For additional international comparisons, see Kahane, 2016.

Figure 1.1
Increases in Deaths by Road User Type, 2011 to 2016



SOURCES: NHTSA, 2017c (2016 data); NHTSA, no date (FARS 2011 data); U.S. Census Bureau, 2016; Federal Highway Administration, 2016.
RAND *RR2333-1.1*

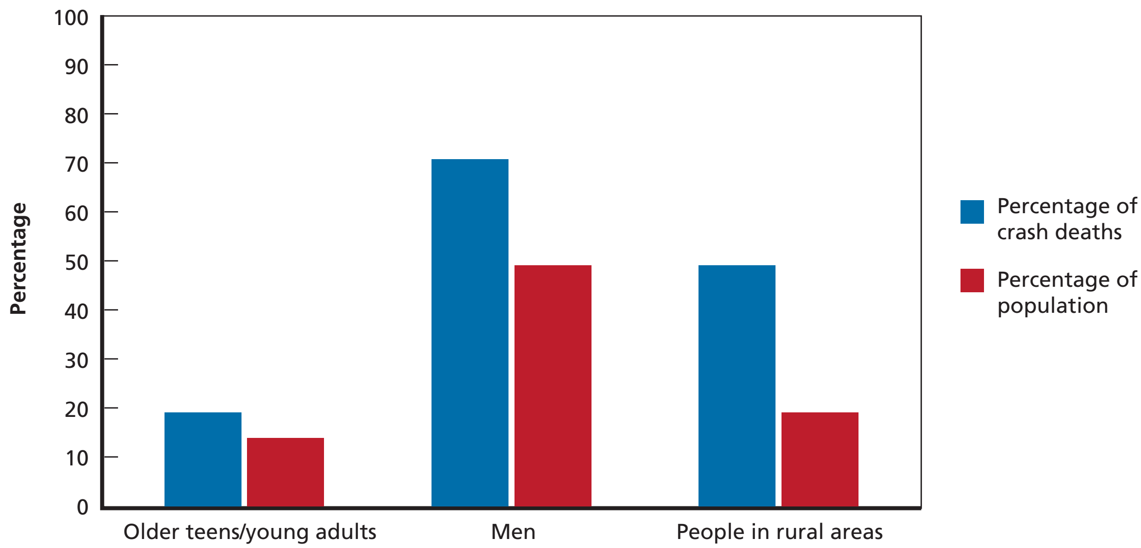
every year in medical care, emergency services, lost productivity, and other costs (Blincoe et al., 2015). Crashes are also a major cause of congestion, with 15,000 crashes occurring every day (Cambridge Systematics, 2011).

Who Dies in Crashes

Who is dying on U.S. roads, and why? While crashes occur in every state and affect every type of road user and demographic group, three groups are more frequently affected than others (Figure 1.2):

- **Young people** are affected disproportionately, as crashes are the leading cause of death for people age 15 to 24. Because so many victims are young, crashes are also a leading cause of years of life lost—that is, the number of years people would have lived had they not died of an illness or injury (U.S. Burden of Disease Collaborators, 2013). Crash risks for teen drivers are higher than for any other age group per mile driven; teen drivers ages 16 to 19 are almost three times more likely than drivers age 20 and up to be in a fatal crash, and the risks are highest at age 16 and 17 (IIHS, 2017b).
- **Men** die more frequently in crashes than women. Seventy-one percent of all motor vehicle crash deaths in 2016 were males. Males accounted for 71 percent of passenger vehicle driver deaths, 49 percent of passenger vehicle passenger deaths, 99 percent of large truck driver deaths, 70 percent of pedestrian deaths, 84 percent of bicyclist deaths, and 91 percent of motorcyclist deaths (IIHS, 2017a). Teenage males are particularly at risk. In 2016, the motor vehicle death rate for male drivers age 16 to 19 was nearly double that of their female counterparts (IIHS, 2017b).

Figure 1.2
Proportion of U.S. Roadway Deaths Relative to Proportion of Population



SOURCES: Older teen/young adult crashes: CDC, National Center for Injury Prevention and Control, no date (b); Men: IIHS, 2017a; People in rural areas: NHTSA, 2017b; Population: Howden and Meyer, 2011.
NOTE: Crash data for 2015; proportion of population from 2010 Census.
RAND *RR2333-1.2*

- **Rural road users** are disproportionately affected by motor vehicle crashes. In 2015, an estimated 19 percent of the U.S. population lived in rural areas, yet almost half of passenger-vehicle-occupant deaths occurred on rural roads. Per 100 million vehicle miles traveled, the rate of all traffic deaths on rural roads (1.8) is more than double the rate of all traffic deaths on urban roads (0.7) (NHTSA, 2017b).

In addition, **pedestrian** deaths have increased dramatically in recent years. Of the 5,000 more people who died in motor vehicle crashes in 2016 than in 2011, 1,500 were pedestrians (NHTSA, no date). In 2015, pedestrian deaths accounted for 15 percent of all traffic fatalities, a proportion that has been increasing over the past decade. In 2015, pedestrian deaths were largely male (70 percent) and urban (76 percent) and took place after dark (74 percent). The average age of pedestrians killed by vehicles was 47 (NHTSA, 2017a).

One irony of the recent uptick in roadway deaths is that our understanding of crashes and the research about what causes crashes and how they can be prevented continue to grow. The leading causes of roadway deaths have been studied for years. We can broadly classify the reasons that people die in car crashes in three ways:

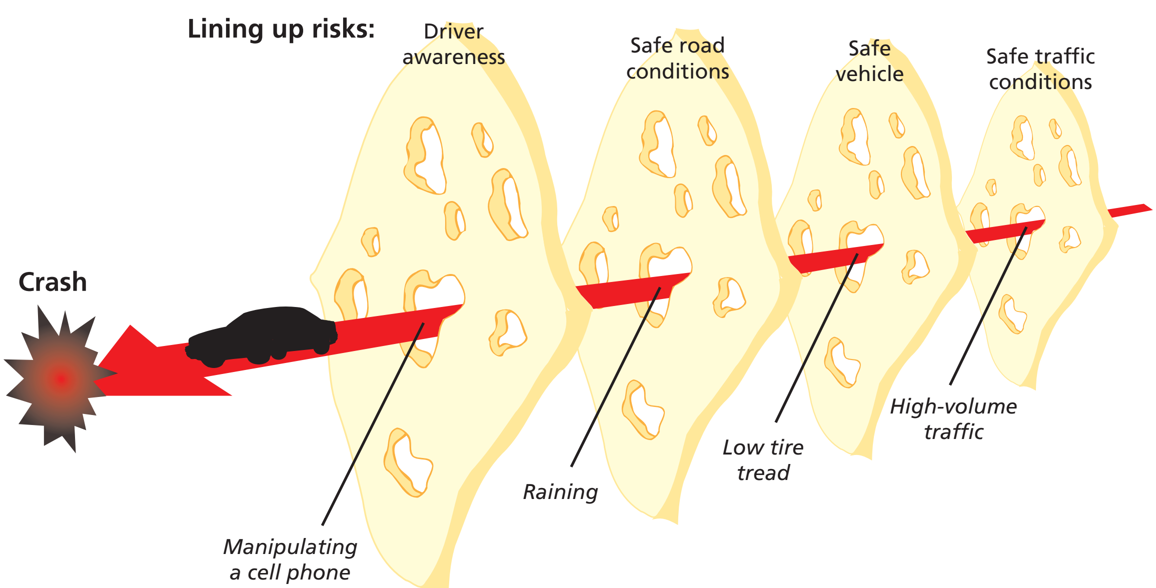
- **What causes the crash:** Crashes are caused by a variety of factors.[7] About 94 percent of serious crashes are due in part to frequent and predictable driver errors, such as speeding, or driving while impaired or distracted. Combined with current vehicle and road

7 Many crashes are considered to have more than one cause (e.g., a driver was both speeding and driving while intoxicated), so the numbers in this paragraph do not necessarily equal 100 percent. The fact that a crash was attributable in part to driver behavior does not negate other potential contributing causes, such as limited visibility, icy roads, or poorly maintained roads.

design, this leads to many serious and fatal crashes (NHTSA, 2015). Alcohol-impaired driving remains a serious problem, with just under one-third of all roadway deaths involving drivers with an alcohol level above the legal limit (NHTSA, 2017c). Speeding is a factor in just over one-quarter of fatal crashes (NHTSA, 2017c), while distracted driving and drowsy driving together account for as much as 25 percent (NHTSA, 2017c; Tefft, 2014). But driver behavior also interacts with other factors, such as whether the vehicle has automatic emergency braking and other advanced driver assistance systems (ADAS), or whether the road signs are confusing or the visibility is poor. Think of a piece of Swiss cheese—when all the "holes" in the system line up, a crash can result. This metaphor is illustrated in Figure 1.3.

- **Who survives the crash:** Most of the country's more than 6 million annual crashes are not fatal, and several factors contribute to the severity of outcomes. Nearly half of drivers and passengers killed in 2016 were not wearing seat belts (NHTSA, 2017c). Seat belts save about 14,000 lives each year, but 3,000 more people would have lived if they were using seat belts (NHTSA, 2016a). Fifteen percent of motorcyclists killed in crashes would have lived had they been wearing helmets (NHTSA, 2016a). Vehicle speed is a major factor in pedestrian deaths: A pedestrian hit by a car going 20 miles per hour is likely to survive, but if the car is going 40 miles per hour, the outcome will generally be fatal (Rosén and Sander, 2009). Vehicle safety technologies ranging from seat belts to air bags to improved door locks save about 27,000 lives per year (Kahane, 2015).
- **Who gets medical treatment:** About half of people who die in crashes survive the initial crash but later succumb to their injuries. In rural crashes, just over half of all fatalities occur sometime after emergency medical responders have arrived. In urban areas, that figure is 70 percent (NHTSA, no date). Up to 20 percent of roadway deaths among

Figure 1.3
Swiss Cheese Model of Crash Causation



SOURCES: Adapted from Seppa (2013) and Reason (2000).
RAND *RR2333-1.3*

victims who reach the hospital could be prevented if the victims received efficient and effective trauma care from the time of injury to acute care to rehabilitation and beyond (Berwick, Downey, and Cornett, 2016). Reaching a trauma center more quickly can also reduce the risk of a crash being fatal (Brown et al., 2017).

In addition to a wide body of knowledge about what causes crashes and roadway deaths, there is also considerable knowledge about how to prevent them. The substantial improvements in road safety that the United States has seen since 1985 can be attributed to the work of a wide range of safety experts: engineers and researchers across both the public and private sectors, public safety and public health professionals, emergency medical and trauma system developers, and government officials at the local, state, and federal levels. These groups have used systematic measurement, development, evaluation, and research to garner extensive evidence on which countermeasures and system design characteristics are most effective. At the same time, auto manufacturers have developed and introduced a wide variety of safety improvements to vehicle design and engineering. Improvements in safety have come about in four areas: roads, vehicles, drivers, and trauma medicine.

Since the 1980s, these countermeasures have resulted in significant decreases in fatalities. Laws (such as increasing the minimum drinking age from 18 to 21 years old and reducing the legal blood alcohol level to 0.08), enforcement, and awareness programs have cut the number of alcohol-impaired driving deaths by half (National Institute on Alcohol Abuse and Alcoholism, 2010; Hedlund, Ulmer, and Preusser, 2001). Similar approaches have increased seat belt use from less than 20 percent to 90 percent nationally (Williams, Wells, and Farmer, 2002; NHTSA, 2016b; Nichols and Ledingham, 2008).

Since 1985, more than 600,000 lives have been saved by vehicle safety technologies, such as electronic stability control and air bags, and changes to vehicle design, such as harder roofs (Kahane, 2015). Roadway improvements have shown similar benefits. For example, centerline rumble strips have been shown to reduce head-on, opposite-direction, and sideswipe fatal and injury crashes by up to 64 percent (Torbic et al., 2009). Colliding with guardrails and median cable barriers is safer than colliding with median concrete barriers (Zou et al., 2014).

Can Roadway Deaths Be Eliminated Altogether?

From 1985 to 2011, roadway deaths per population declined by more than 40 percent, and deaths per mile traveled declined by more than half. While that progress is significant, it still leaves the country with more than 37,000 preventable deaths—and several million injuries, many of them debilitating and permanent—every year. About 20 years ago, traffic safety experts started asking a bolder question—not "How else can traffic crashes be reduced?" but "Is it possible to eliminate roadway deaths altogether?"

In 1997, Sweden became the first country in the world to enact a policy called Vision Zero—a formal goal, adopted by the parliament, of reducing roadway deaths and serious injuries to zero.[8] One of the key elements of Vision Zero was a fundamental change in thinking about who was responsible for road safety. Previously, that responsibility was thought to rest primarily with road users—that is, that drivers should prevent crashes by driving more atten-

---

8 See Belin, Tillgren, and Vedung (2012) for a history of Vision Zero and the Safe System approach in Sweden.

Principles of a Safe System

The Safe System approach represents a paradigm shift from conventional safety approaches in three main ways.

First, rather than focusing on preventing human error, it instead *accommodates* human error. Since drivers are known to make mistakes that can lead to serious crashes—such as failing to notice a traffic light or falling asleep on a rural road and crossing the centerline—the Safe System is designed to accommodate such errors without resulting in serious injury. Implementing roundabouts rather than signalized intersections reduces speeds and prevents deadly side impacts. Providing additional separation between opposing traffic lanes, or including centerline rumble strips and median barriers on rural roads, vastly reduces the number of head-on collisions when a sleepy, distracted, or impaired driver drifts toward the oncoming lane. Slowing traffic on streets where pedestrians and bicyclists are present allows more reaction time and reduces injury levels when inevitable conflicts occur.

Second, the Safe System approach is characterized by shared responsibility. Rather than attributing serious crashes solely to a failure of the road user, the responsibility for serious crashes in a Safe System is shared among those who might have prevented the situation through improved roadway or vehicle design as well as improved road user behavior. In this way, everyone who could play a role in preventing future serious crashes is motivated to contribute to the solution.

And third, whereas conventional safety methods are primarily retrospective, the Safe System approach is prospective. In addition to analyzing past crashes and looking for ways they could have been prevented, the Safe System approach looks forward to identify where crashes might occur in the future and considers all ways that such crashes could be prevented. To identify future problems, the Safe System approach considers human injury tolerance and gives priority to systemwide changes that will prevent collisions that expose people to lethal crash forces.

tively. The shift in thinking was to make those people who design the transportation system—city planners, traffic engineers, and vehicle designers—responsible for preventing crashes. This approach, often referred to as the Safe System approach, assumes that drivers will still make mistakes but that the road system should be designed in such a way as to limit the possibility that human error results in a crash, or, if a crash occurs, limit its severity.

One step toward this goal is the *Toward Zero Deaths National Strategy*, released in 2014 by safety experts in transportation, safety, emergency medical services (EMS), and public health organizations, which recognized the need for a multidisciplinary approach and identified priority actions for safer roads and road users along with better medical care for crash victims (Toward Zero Deaths Steering Committee, 2014). The National Strategy emphasizes countermeasures with the strongest evidence of effectiveness and prescribes critical analytical and management functions to ensure their efficient deployment.

Building on this approach, a growing number of U.S. cities have adopted the Vision Zero approach. Linked by the Vision Zero Network, these cities are adopting a Safe System approach to decisionmaking, including a data-driven, multi-agency approach to roadway design, policy development, education, and enforcement. This approach particularly addresses the needs of vulnerable and high-risk road users who may have been overlooked in conventional safety efforts.

While Sweden has seen substantial progress from the Safe System approach—lowering its roadway death rate per 100,000 persons from 7 to 3 in a decade (Belin, 2016)—no city, state, or country has yet eliminated roadway deaths entirely. However, it is possible that we may reach a tipping point, with the rapid changes in vehicle technology now taking place, combined with changes in public attitudes about road safety.

In the near term, up to 10,000 lives could be saved if currently available ADAS, such as automatic emergency braking, lane departure warning, and blind spot detection systems, were deployed fleet-wide (Mosquet, Andersen, and Arora, 2015). Passive alcohol ignition interlock systems, such as the Driver Alcohol Detection System for Safety (DADSS), might save more than 7,000 lives annually if all cars were equipped (IIHS, 2011).

In the longer term, when vehicles with automated driving systems are fully developed and have worked their way into the fleet, self-driving systems may well have a tremendous impact on safety. The whole fleet will not convert overnight to being automated, since the average life of a car is more than 11 years (Bureau of Transportation Statistics, 2017, Table 1-11). But at some future point, automated driving is envisioned to provide substantial safety benefits, even if not every vehicle on the roads is automated.

Moreover, the increasing connectedness of vehicles, infrastructure, and vulnerable road users such as pedestrians, bicyclists, motorcyclists, and highway workers may further reduce serious crashes. As these technological improvements become more and more commonplace, and traffic fatalities are reduced accordingly, public acceptance of deaths on the roads will likely wane, as in the past with public acceptance of once common causes of death, such as air pollution and smoking. Widespread implementation of vehicle safety improvements in conjunction with broad acceptance of the Safe System approach and better use of existing countermeasures gives rise to a credible vision of roadway deaths declining to zero in 30 years.

The Road to Zero Coalition and Its Strategy

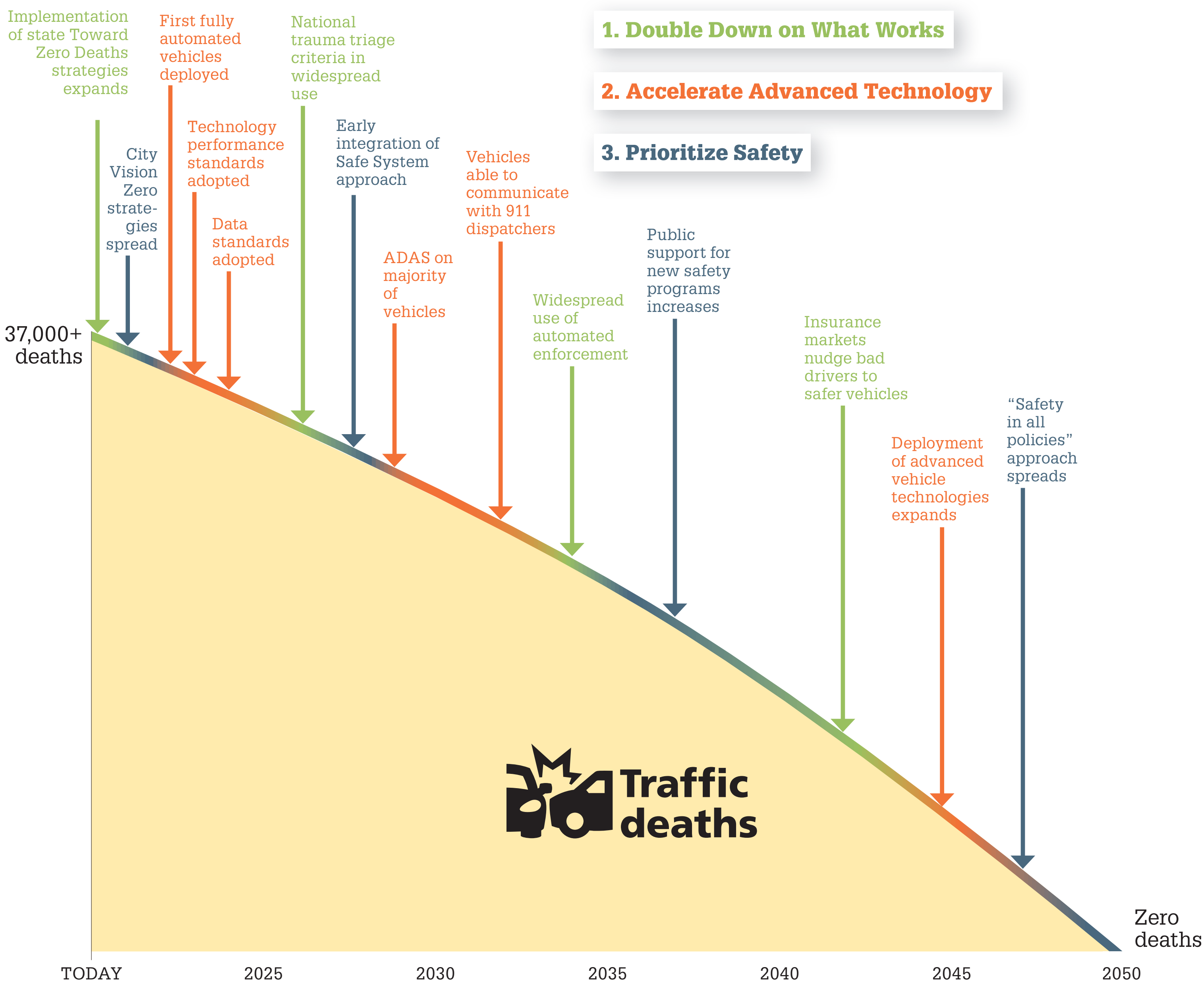
The Road to Zero Coalition was established by assembling a wide-ranging group of stakeholders to provide a major push to achieve zero roadway deaths. This is the largest and broadest coalition that has ever focused on roadway safety in the United States. The RTZ Coalition was launched in 2016 in reaction to sharp increases in roadway deaths and has brought together more than 650 professional associations, businesses and industry associations, safety groups, government agencies, and nonprofit organizations. With a clear, compelling, and unifying vision, the RTZ Coalition is a powerful force for change.

The National Safety Council commissioned the RAND Corporation to develop a process for the RTZ Coalition to develop an overall vision and strategy to reach zero deaths. The process included three intensive workshops that brought together disparate stakeholders to discuss vision, goals, obstacles, approaches, strategies, tactics, and ultimately a scenario of how zero deaths could be achieved by 2050 and what that future might look like. This report is the result of that process. While this report presents one of potentially many scenarios, it incorporates the perspectives and suggestions of a wide variety of road safety stakeholders.

To reach zero, the RTZ Coalition determined that three interrelated approaches are needed (Figure 1.4):

- **Double Down on What Works.** The United States has both an accumulated body of evidence-based countermeasures and a well-established network of experts who can deploy them. The RTZ Coalition envisions engaging political leaders and decisionmakers to sup-

Figure 1.4
Three Approaches Working Together to Reduce Roadway Deaths to Zero



RAND *RR2333-1.4*

port policies and identify new or shared resources for research, roadway design and construction, vehicle engineering, law enforcement, consumer education, and trauma care. Because motor vehicle crashes represent the single largest cause of workplace fatalities, the coalition will look to establish partnerships with businesses at the state and community levels as an important source of new energy for such change.

- **Accelerate Advanced Technology.** Existing and emerging technologies promise large advances in safety. ADAS—such as automatic emergency braking, adaptive cruise control, and lane-keeping—are already being introduced into the fleet. Each year, these technologies are offered on a greater number of new vehicles, and their safety performance improves. The rate of technology development, both in vehicle systems and overall connectivity, is expected to increase rapidly. To accelerate the deployment of these vehicle and infrastructure technologies and maximize their potential reach in a 30-year timeframe, the RTZ Coalition envisions new partnerships among manufacturers, technology providers, emergency medical and trauma systems, public safety/health groups, and the public sector to identify and prioritize safety applications and opportunities, to evaluate safety benefits, and to increase consumer interest and adoption through education and incentives.
- **Prioritize Safety.** The third approach focuses on methods to facilitate change. Key among these are creating a safety culture and adopting a Safe System approach. A pervasive safety culture is an essential ingredient for reaching zero roadway deaths and can be nurtured through awareness, education, and constant reinforcement. Safety needs to be among the highest priorities in decisions ranging from where to cross the street to where to devote federal funds. There are many opportunities to nurture a safety culture. For example, fostering development of community road safety action programs may prove effective in engaging citizens, corporations, and governments and changing social norms. Adopting the Safe System approach involves a fundamental shift from the common assumption that crashes generally happen because of people's behavior. Instead, a Safe System approach assumes that people will occasionally, but inevitably, make mistakes behind the wheel and that the overall transportation system should be designed to be forgiving so that these mistakes do not lead to fatal outcomes. The Safe System approach also involves commitment to analyze safety problems, identify changes that bring the best return on investment, and implement these improvements throughout the system to prevent further occurrences.

These three approaches are essential and interconnected; none of the three will work effectively independent of the others. They are complementary, mutually dependent, and synergistic. For example, a growing safety culture will foster safe behaviors, such as driving sober and within the speed limit, and create a strong market for advanced safety technologies (including automated vehicles [AVs]). As people become accustomed to the safety benefits of advanced technology and improved roads, they will become less tolerant of risky behavior and more supportive of the changes needed to build a Safe System. The effect of each change is intertwined with the others and mutually supportive—a "virtuous cycle."

The rest of this report is divided into three chapters:

- Chapter Two provides a vision of how driving and mobility could be different in 2050, including vignettes of how changes since 2018 play out in people's daily lives and how they prevent crashes, limit their severity, and enhance trauma care for those still injured in crashes.

- Chapter Three lays out a scenario of how we might get from today to 2050. In keeping with usual scenario practice, this is a "history" of how events unfolded from today through 2050, written from a future perspective.
- Chapter Four discusses specific actions that can be taken by stakeholders today to reach a future with zero deaths.
- Finally, Appendix A describes the process, involving three multi-day stakeholder workshops, through which the report was developed. Appendixes B, C, and D contain the agendas from the three workshops, and Appendix E lists the participants.

CHAPTER TWO

The Roads of 2050

This and the next chapter are written from a future standpoint, in 2050. We have footnoted events that have actually taken place.

Without much fanfare, the United States reached an amazing milestone this year: Not a single person was killed in a car crash.

Thirty-five years ago, most people would have had a hard time imagining this. In 2016, more than 100 people were killed every day in crashes.[1] This happened so often that it seldom made the news, unless it involved a celebrity, or a particularly tragic story, or was due to some bizarre fluke of circumstance. It was more like background noise, flaring up only on occasion and then dropping back quickly.

What changed?

It's not because Americans are fewer in number, or less mobile, or much better drivers. The U.S. population now stands at 400 million, having added over 80 million people in the past 35 years. More Americans are older—22 percent are over 65, as opposed to 15 percent 35 years ago—and almost 20 percent are immigrants (up from about 13 percent in 2014) (Colby and Ortman, 2015).[2]

Neither are Americans less mobile, at least overall. In fact, the demand for mobility has increased with population growth and improved access, especially for groups that previously had limited transportation options. Meanwhile, the increased availability of transportation options, including "mobility service" providers, has decreased individual dependence on private cars.

While the average household owns fewer vehicles than it used to, with the population increase and the vehicles in the "mobility service" fleets, 300 million vehicles are still on the road.

Are people driving any more safely? That's harder to say, but certainly people still get into crashes. Two things make crashes different, though: Fewer of them, occur, and, more importantly, they are not as severe as they used to be. Minor fender-benders, yes; fatal crashes, no.

1 Unless otherwise noted, all comparisons in Chapters Two and Three are to 2015 data.

2 Unless otherwise noted, future projections were developed by authors.

Smarter Cars, Fewer Crashes

So, if it's not major changes in the population or how we travel, how *did* this happen? Before we look at the history of this decline—which is due not to sheer good luck, but deliberate and sustained policy and technology changes, combined with on-the-ground efforts in cities and states that led to a change in social norms—let's look at how life behind the wheel in 2050 differs from when our parents or grandparents were driving.

The biggest change is the level of safety technology incorporated into the cars we buy today. While these go by a variety of diverse names in the industry—*driver-assist*, *connected vehicles*, *automated vehicles*, *semi-automated vehicles*, *on-off self-driving vehicles*—for our purposes we can divide these into two types: the cars that we drive, and the cars that drive us.

Cars That We Drive

Just over half of today's vehicles fall into the first category. They are not fully self-driving under any circumstances; drivers remain behind the wheel, and need to be alert and attentive. But the big difference from the previous generation of cars is the degree to which advanced driver assistance systems (ADAS) are in most cars.

Some forms of ADAS began entering the fleet as far back as the 1990s; today, it's impossible to buy a new car or truck without some ADAS features. Consumers have accepted these technologies and generally use them as intended (as opposed to ADAS in earlier models, which drivers occasionally turned off or misused). ADAS include a wide variety of technologies, and not every car is equipped with every one. But most cars now come standard with what once seemed like revolutionary technologies. These technologies include but are not limited to the following:

- **Intelligent speed adaption** manages vehicle speed, taking into account the presence of people and other vehicles, the design of the road, the surrounding road environment, traffic volume and flow, and the speed limit. Some systems incorporate incentives for drivers to maintain safe speeds, such as feedback that varies the resistance of the accelerator pedal. Other systems automatically adjust to the right speed for conditions, with the result that crash severity has been greatly reduced and most people can walk away from what once would have been a fatal crash. Systems have been developed for an emergency vehicle using lights and sirens to notify vehicles ahead of it so they can safely slow down and move over. Wake effect collisions—crashes that took place between vehicles near an emergency vehicle as drivers tried to avoid it—no longer occur. Speed is the best predictor of how bad a crash will be; reduce the speed, reduce the severity.
- **Automatic emergency braking** (AEB) means that your car senses the presence of an obstacle in front of you, and can respond more readily to changes in the roadway environment. AEB has reduced rear-end crashes, as well as many car-pedestrian and car-bicyclist collisions. The responsiveness varies between different makes and models, and the laws of physics mean that even though AEB can engage faster than a person can apply the brakes, certain crashes may be unavoidable. But the brakes engaging even a fraction of a second earlier can mean the difference between a crash and a safe stop. Other elements of brake systems have advanced as well: Passenger vehicles have emergency braking displays, and motorcycles have electronic stability control and anti-lock brakes. These brake systems can automatically slow the vehicle down and stop for red lights.

Near-miss in a city

Joe is cruising down a suburban arterial at about 8:30 p.m. He comes this way all the time, and it's a long stretch without a light, so he's going about 35 mph, idly thinking about the day, glancing at his phone when the road seems fairly empty. Suddenly, a woman appears in front of the car. She's crossing in the middle of the block, since this is one of the few streets remaining in the city where there are no formal crosswalks. But there is a grocery store on one side of the street and an apartment complex on the other side. The woman is tired from a long day of work and is just picking up a few odds and ends at the grocery store for dinner with her kids. It's three blocks out of her way each direction to cross at the nearest light, and there isn't a sidewalk for part of the way. And she isn't wearing anything reflective, since she's just on her way home and has crossed here before and nothing has ever happened. Although Joe doesn't see the pedestrian until it would have been too late, the car brakes in time. Happily, there isn't another vehicle directly behind—most cars give you a warning sound when you are following too closely. Joe texts city hall the next day to vent about the near-miss and learns that they are planning a crosswalk and traffic signal at that very spot. It's not the first near-miss there, and they appreciate him reporting the incident, since their planning efforts include collecting as much data on near-misses as possible to make sure they are making well-targeted investments.

DADSS prevents alcohol-impaired driving

Across town, Danny is a middle-aged man who doesn't want to admit he has a drinking problem—he's never lost a job, he's married, things are fine—and gets into his new car after stopping off for a few beers after work. He presses the ignition button like usual, but the darned thing won't turn over. He assumes something is wrong with the car and starts getting annoyed, but then he hears the tinny voice telling him that his blood alcohol concentration is 0.1, which is over the legal limit, and that the car will not engage for at least ten minutes, at which point he can try again. Cursing at the car, he texts his wife, Julie, knowing that after three (or maybe it was four?) beers, ten minutes isn't going to be enough. She's none too happy, but she gets a ride-hail to the bar and then drives him home. Julie is plenty annoyed in the heat of the moment, and they argue on the way home. But later she thinks about her uncle Bob, confined to a wheelchair starting in his forties after a serious crash in which he hit another car head-on, on a beautiful Tuesday afternoon. Nobody ever wanted to say it out loud—it was embarrassing to admit—but he was driving drunk. That could have been Danny, and she feels grateful for the sensor. He doesn't think he has a problem, so that's probably not the last time it'll come in handy.

- **Lane-departure warning and lane-keeping systems** help keep cars on the straight and narrow. The former alerts the driver when the vehicle is about to drift out of the lane, and the latter actually steers the car back to the lane. Most drivers have a strong preference for one or the other, especially those who have tried to avoid a bicyclist or a parked car with an open door by steering gently out of the lane, only to have the car unexpectedly swerve back. Car-buying guides tend to suggest lane-departure warnings for people who do more city driving, and lane-keeping for rural driving, for this very reason.

- Some technologies help drivers see things easily that used to be hard to see. **Blind-spot detection** tells drivers when something is approaching from behind. Almost nobody today remembers learning in drivers' ed how to swing your head around to check the blind spot. The main benefit has been to reduce highway crashes between passing vehicles. **Rearview cameras** allow drivers to see behind them, avoiding crashes due to hitting something behind the car (tragically, sometimes a small child). **Rear parking sensors** tell drivers when their back tires are too close to an object to park safely and can, if requested, park the car automatically. **Adaptive headlights** automatically change the intensity of headlights depending on visibility, making dark roads easier to navigate and improving visibility over hills and around curves.
- **DADSS** (Driver Alcohol Detection System for Safety) is less common, since it was introduced more recently, but is now standard on most new cars. DADSS accurately detects a driver's blood alcohol concentration through breath and/or touch systems and prevents a driver who triggers either from driving the car. It works only at illegal alcohol levels and has had a major impact on alcohol-impaired driving, since most alcohol-impaired crashes were caused by drivers over the legal limit. Since it's been on many new cars for 20 years, it is working its way into the fleet and is reaching the highest-risk drivers, even hard-core drunk drivers. Significant research has gone into developing technology that could detect drug impairment in much the same way as DADSS works for alcohol, but this has been trickier to develop due to the varying ways in which the effects of these drugs can be detected. Prototypes are being tested, but introduction of this technology in new cars is still some years in the future.

Overall, vehicle design and engineering prioritizes safety. This means that infotainment systems are integrated into the vehicle in a way that does not compromise driver attention. Head-up displays show routing information, speed, and other key pieces of information on the windshield so that the driver's eyes never have to leave the road. Many cars are now designed to prevent serious injuries to pedestrians if they are hit by those cars.

Not only are individual vehicles more sophisticated, they are more connected electronically than ever through an array of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P) technologies collectively known as V2X (vehicle-to-everything). "X" runs the gamut from other vehicles (through built-in or after-market technology) to emergency responders, pedestrians, and cyclists (via their digital devices, made possible by the ubiquity of what were previously called smart phones), to infrastructure sensors, traffic monitors, weather monitoring systems, etc. Using Dedicated Short-Range Communications (DSRC) protocol (or in the future LTE or 5G-based protocols in the 5.9 GHz band), this network of low-latency communication allows a constant automated flow of information among drivers, vehicles, and the outside world.[3] V2X technology translates this flow of information from the outside to inform and engage the vehicle's safety systems and warn drivers of hazards. V2X connectivity is working in tandem with automated driving systems, sharing information about vehicle speeds and directions and extending advanced safety benefits to the majority of vehicles on the road.

Increasing connectivity also brought with it high volumes of frequently updated data about vehicle operations. The automobile industry, mobility service providers, insurance com-

---

3 5G and 4G refer to the generation of the wireless technologies; LTE stands for *Long-Term Evolution*.

panies, and others partnered with the federal government to create data platforms that integrate many data sources and produce de-identified information that allows state and local transportation agencies, fleet operators, and others to monitor traffic operations and identify, predict, and mitigate risk. Highway system stakeholders meet regularly to ensure that risk information is disseminated and acted upon to prevent crashes.

Cars That Drive Us

The other part of the safety equation is the cars that drive us—highly automated vehicles (HAVs) that do not require you to drive yourself.[4] First introduced to regular car-buyers in the late 2020s, they have fulfilled some parts of the hype but not others. On the upside, getting older drivers into self-driving cars has been a major win-win. Seniors with declining vision or reflexes, who decades ago would have had to give up the benefits of driving, can continue to enjoy the conveniences of using cars without endangering themselves or others. One of the most painful parts of dealing with an aging parent used to be the conversation about "taking away the keys," which filled advice columns with anguished tales of stubborn seniors driving, some with failing eyesight and diminished abilities, because their adult children dreaded addressing the problem. Now those same children can sign them up for one of the many national or local "mobility service" programs, with which self-driving cars simply pick them up at home.

Groups such as AARP, the Centers for Medicare and Medicaid Services, and local area agencies on aging offer advice on choosing mobility services, having made a concerted push to bring these services to their clients (and in some cases even partnered with private firms to provide them directly). Some have assistants in the vehicles to help people in and out, while others are designed for more-able-bodied people who don't need such help. The option to have assistance has also made them valuable for some disabled people. Although mobility service programs are less prominent in rural areas, where reliance on owning a car remains high, they have made a big difference in urban and most suburban areas.

This has had other consequences as well, because it has facilitated "aging in place" for people who might otherwise have needed assisted living arrangements or depended on younger family members to drive them around. As self-driving cars improved in their abilities to handle bad weather, they became more common in northern cities (when first introduced, they were prevalent mainly in areas with more temperate weather, such as California and Florida).

Beyond older drivers, HAVs have spread to other road user groups. Among individuals with a disability or otherwise limited mobility, access to HAVs began in the late 2020s, as licensure laws changed to permit HAV user licenses to individuals unable to drive a vehicle themselves, and as the interiors of the vehicles were modified to accommodate universal design principles. Although these vehicles are geofenced, operate only under specific weather conditions, and are not accessible to all due to cost, they have been a boon to the disabled and those with mobility limitations. User evaluations showed reductions in missed medical appointments, increases in social engagement, and decreases in rates of depression among caregivers.

---

[4] We use the term *highly automated* to describe Level 4 on the Levels of Automation standards developed by the Society of Automotive Engineers. Level 4 means that the vehicle can drive in a limited area, on limited roads, or in limited modes. Level 5 means that the vehicle can drive itself on any road in any conditions (Auto Alliance, no date), and we refer to this as *fully automated*.

A senior citizen no longer has to drive

Jacqueline, who's in her mid-80s, was widowed two years ago. She has a driver's license, since her eyesight is still good—her state requires an in-person renewal every three years, but her license was issued before her husband Roger died. Her 40-something daughter, Emily, lives out of state so Jacqueline's determined to be independent, not to be a burden. But one day she goes for a drive—an easy one, no highways, roads she knows well, broad daylight—and it doesn't go the way she expects. She becomes distracted by a news item on the radio, loses focus and gets confused, and turns onto a major road with more traffic than she's used to. She panics and slows down, too much, leading to a volley of honking that doesn't help. After a few long minutes, she's able to gather herself, find a side street, and call Emily, distraught. It dawns on Emily that her mom's driving days are probably over, but she's still healthy enough to live on her own.

Emily calls the local Area Agency on Aging, and they recommend two mobility services. One provides unlimited rides for a fairly high flat fee each month (it's their senior plan, and they know from having been in business ten years that seniors don't really take that many trips), while the other charges by the trip length. Both have a fleet of automated vehicles, and both require that, to qualify for these plans, members have to be able to get into and out of the car on their own. They have different and more-expensive plans for seniors who need more assistance. Emily signs Jacqueline up for the flat fare plan, tying it to her credit card and requesting the usage records to make sure her mom is getting what she needs out of the service (and also not driving herself). Jacqueline is eager to try out the service, and a few days later she summons an auto-cab to take her to a hair appointment and home again. Soon she's encouraging her friends to sign up.

HAVs also became popular with younger people. Traditionally the riskiest of all drivers, teens and young adults began using HAVs for ridesharing more than people in their mid-20s and up. There was initial concern that young drivers might not learn how to drive because they were relying so heavily on HAVs, but due to limitations of AV technology, this was not borne out—people just got licenses later. Private ownership of HAVs among younger drivers is rare because of the high cost. In addition, similar to older drivers, use of HAVs is generally an urban phenomenon, with younger drivers in rural areas still owning and driving their own vehicle.

Another major application for self-driving vehicles is trucks and buses. Most trucks on the road today can be toggled between self-driving and human-driving. The trucking industry has been pleased, since drivers can crawl in the back and sleep during long-haul runs, eliminating the need to stop for breaks. Drivers still need to maneuver the trucks in some circumstances for deliveries and pick-ups, especially in congested cities, so the outskirts of many cities now have transfer zones where goods that arrived on automated long-haul trucks are transferred to local human-driven vehicles (much like the previous model of transferring goods from trains) or delivery drones. While trucks previously accounted for a disproportionate number of fatal crashes (back in 2015, they were 4 percent of vehicles but involved in 11 percent of fatal crashes[5]), serious truck crashes today are very rare.

5 Federal Motor Carrier Safety Administration, 2017, Crashes Table 1.

Similarly, intercity buses frequently drive themselves over long stretches of highway. Shuttle buses in predictable environments—office parks, college campuses, airports—drive themselves as well, as do some intracity buses on dedicated bus lanes. Other intracity buses and all school buses still have human drivers but are fully equipped with ADAS. Additionally, advances in material engineering around buses have reduced bus fires, previously a deadly and costly occurrence.

Finally, among the vehicles that should be the safest of all given their vulnerable human cargo, crashes involving ambulances are never fatal. New engineering standards for ambulances to make them more crashworthy for both patients and crew members were developed based on specialized crash tests. Ambulance crew members have restraint systems that allow them to perform patient care but survive a crash.

So, a key reason for the decline of fatalities is just how much safer the vehicles are, regardless of whether they drive themselves. Most consumers have noticed these changes, because people still largely get around by car. A more gradual and less-discussed shift is the changes in how roads are designed.

Roads That "Forgive" Mistakes

Roads are designed differently today than they once were. The types of changes you might notice depend on whether you live in a city or a small town. Over the course of several decades, engineers and urban planners began thinking differently about how roads work and for whom they are designed. The changes have been gradual, since you don't rebuild 4 million miles of road in a year or two, but over time new design ideas became commonplace, which in turn changed driving habits. The overarching idea in 2050 is that roads are "forgiving"—when drivers make a mistake, which they all will eventually, the consequences are relatively minor.

In cities, the main focus has been on reducing speed. The largest traffic safety problem in cities was the mingling of cars with people—people walking, bicycling, getting on and off buses and trains. For many years, the mindset was that those people were the problem—they were getting in the way of traffic.

Decades ago, that mindset starting changing in ways both large and small. Cities began to choke on their traffic—not to mention their air pollution—and looked for ways to encourage more residents and visitors to walk, bicycle, and use transit. Cars weren't going away, but cities sought ways to slow them down, after years of trying to speed them through.

If you live in a fairly large city, you may not even remember a time when speed limits were higher than the now-standard 25 miles per hour. Speed cameras equipped with V2X—alerting the driver in real-time to violations—have made enforcing these limits feasible throughout cities. But a larger difference is the way in which cities and their inner-ring suburbs have been slowing traffic through physical means.

Cities needed to do two things: calm traffic and provide more locations for pedestrians to cross roads safely. Road designers did this through a variety of means, including using road diets that either remove lanes or make them more narrow, adding more mid-block crosswalks, providing crossing systems that indicate when crosswalks are in use, and modifying travel lanes, on-street parking, and streetscapes to slow drivers' natural driving speed and make drivers, bicyclists, and pedestrians more visible to each other.

Another way cities have made progress is by continuing the work of right-sizing their major streets that was begun in the early 2000s. Cities have converted more streets from two lanes each way without turn lanes to one lane in each direction with turn lanes. They applied this principle—that streets are safer for vulnerable pedestrians and bicyclists when streets have fewer lanes, and motor vehicles operate at lower speeds—and converted additional streets to fewer lanes, with additional lanes operating only when truly necessary. This has left room for bus lanes, light rail, bikeways, and wider sidewalks, all of which have contributed to lower speed designs and provided better safety facilities for all transportation users.

Intersections have gotten makeovers, as well. Many cities have replaced four-way intersections with roundabouts, which have long been used in other countries. Roundabouts require drivers to slow down and pay closer attention to what is happening on the approach to the intersection, two key factors for avoiding crashes. And since traffic at roundabouts is all moving the same direction, counter-clockwise, they prevent the most-serious type of crashes at four-way intersections: angle crashes, or "T-bones," in which a driver going straight hits a driver who is turning left.

Four-way intersections are still around, of course, but they don't all look the same any more. At intersections with traffic lights, pedestrians and bicyclists often get their own traffic signal phase, allowing them to walk and bike when cars are stopped in all directions. At intersections without lights, raised crosswalks and hybrid beacons—lights that pedestrians can activate to let drivers know they are crossing the street—have effectively made walking a safer and more convenient option. Some cities have narrowed their turning radii, making it harder for cars to take right-hand turns without slowing down considerably. Far fewer pedestrians and bicyclists are hit at intersections now, and in these rare cases, they survive.

Some cities and even towns have even eliminated all car traffic from parts of their urban cores, ranging from one square block to large segments of the densest urban areas. Other cities and towns have designated car-free days in key neighborhoods. To ensure accessibility, public transit via low-speed automated buses and subways have increased in these areas.

Small towns and rural areas have used different strategies to reduce both crashes and crash severity. One type of serious crash was once head-on collisions on two-lane rural roads, where drivers might be traveling 50 or 60 miles per hour in poorly lit conditions. Most rural counties have incorporated durable high-friction treatments into their pavements to prevent skidding on curves and other risk areas. They have systematically improved roadsides, clearing potential obstacles and using signage designed to break on impact so that cars that collide with it are not seriously damaged. They also use more-consistent traffic control signs and markings so that drivers encounter similar uses regardless of location. Installing rumble strips along with a median between vehicles traveling in opposite directions has greatly reduced the number of head-on crashes. Some states have installed many additional miles of median barriers on their most dangerous roads, turning potential head-on crashes into relatively low-impact incidents that are far less lethal. Barriers installed in narrow medians have slightly decreased average speeds, reducing crash severity. In addition, many corridors now have alternate passing lanes to improve both safety and capacity.

Most towns in rural areas have added a gateway feature, such as a prominent welcome sign or crosswalk pavers of a different color, as a cue to drivers to slow down before they enter the city limits. And more small towns have also provided sidewalks and bicycle lanes in places where they previously didn't exist. This has made it safer for people who walk and bike, since they are not walking on the shoulder or bicycling in a lane with fast-moving traffic. As road-

A minor crash on a city roundabout

Andrea just got a promotion and moved to a new city, and her commute requires her to drive. She is still getting used to roundabouts, and there's one on her commute that would be hard to avoid. When she eases out into the roundabout, she misjudges the gap in traffic and sideswipes an oncoming delivery truck. Andrea sustains some bumps and bruises but is otherwise OK; the truck driver is uninjured. Unfortunately, her car needs thousands of dollars' worth of work, since the front fender area, driver door frame, and some electronic components are damaged. Her insurance premiums will probably go up, but they've been pretty affordable until now, since the car had several safety features. Andrea posts about the crash to social media, complaining about "stupid roundabouts," and most of her friends are sympathetic. Her college friend Josephine, however, posts a link to a story from eight years ago about what a dangerous intersection it was at the time. The story mentions a particularly bad crash that killed a woman when a truck driver, thinking he could make the light, barreled straight ahead and hit the woman's car directly on the passenger side. The son had been buckled in the back seat in an approved child seat, but he still ended up badly injured. "Maxine was my neighbor," said Josephine. "Stop whining about your premiums when that poor little boy grew up without a mother."

way and vehicle design have improved, average travel speeds have remained the same or even increased, but speeds in safety-critical areas, such as those with a high number of pedestrians, have been reduced.

Starting Trauma Care Quickly and More Efficiently

Even with all the changes in vehicles and roads, crashes still happen—2050 saw more than 1 million of them. Crashes are classified broadly into three types: fatal, injury, and property-damage-only (meaning, nobody was hurt but the car or whatever it hit was damaged). Injury crashes still happen, but they no longer become fatal crashes, in part because of advances in detecting crashes immediately, deploying emergency response resources proportionate to anticipated injury severity, and transporting crash survivors to appropriate trauma care efficiently and quickly.

The "efficiently" part means that emergency responders have a lot more information with which to work when they arrive. Most vehicles have advanced automatic crash notification (AACN) systems that communicate with 911 answering points, so the vehicle transmits information about itself and the crash. EMS responders now know when they arrive on the scene whether the crash involves a gasoline, hybrid, electric, or hydrogen vehicle, so they can avoid dangerous surprises, such as accidentally touching high-voltage components and getting an electric shock or being injured by an airbag that did not deploy during the crash.

EMS responders are also forearmed with the knowledge of the type of crash, including the force of the impact, what exactly the vehicle hit (another car, or a tree, or a person), and the number of people in the vehicle. Most people have also signed up with a medical records management service that provides access to important medical information, such as blood type, allergies, and existing medical conditions that might affect treatment. If that records service is registered with the vehicle, first responders can be prepared with the right care and can also re-transmit those data to the trauma center.

EMS systems have also widely adopted Centers for Disease Control and Prevention (CDC) field triage criteria and apply those algorithms based on information the vehicle transmitted, personal health information that the vehicle occupants chose in advance to share, and, when necessary, physical exams conducted by emergency responders. On many occasions, the first two of those three sets of data, coupled with an automatic injury severity prediction calculation, alert the 911 center to deploy different or additional resources (e.g., an EMS helicopter) to care for victims with a high degree of probability to need a trauma center rather than waste time by taking them to the closest hospital.

For mass casualty incidents, a universal triage system has been adopted nationwide. Even if EMS personnel cross county or state lines to provide mutual aid, the methodology used to "sort" patients based on injury severity does not vary among responders, so victims are provided with optimal care on scene and prioritized for access to hospitals and selective transportation to trauma centers. While most crashes involve one or two passenger vehicles, standardized triage systems have been useful in saving lives in incidents such as school and tour bus crashes, where a dozen or more people may be injured.

The "quickly" part means that incidents are detected as soon as they occur, emergency responders get to crash locations faster and with the right resources, and survivors of severe crashes reach trauma care centers quickly. In rural areas, sensors in the roadway detect sudden deceleration and roadway departures that indicate a crash and provide immediate location information to the appropriate 911 center. Drones are automatically dispatched to the alert location to provide a video feed to first responders to assess the situation. These drone fleets communicate securely to both 911 answering points and trauma centers. A drone dispatched to a crash can immediately transmit photos and precise location information. Passengers have apps that transmit medical information automatically. These capabilities have decreased the amount of time it takes to begin emergency response and allow the emergency response system to tailor or augment its response given the information that is available. This is especially important in rural locations, where the closest emergency response organization may have a travel time of 30, 45, or even 60 minutes to get to the scene.

Speaking of the 911 network, it too is much more sophisticated and integrated than it was a few decades ago. Reliability has been greatly improved, largely through technical redundancy and more-robust back-up systems. Widespread outages due to software failure are a thing of the past. Calls are routed correctly to the nearest answering point, and calls can be routed seamlessly between answering points if one cannot respond. The 911 system is integrated with the public safety radio and broadband networks to allow texts, photos, and video from 911 callers, as well as alert signals from crashed cars, personal health monitors, and other connected devices, to directly access the communications devices of appropriate response personnel. Radio communication equipment is required to meet interoperability standards developed by a consortium of emergency communications officials. The FirstNet Nationwide Public Safety Broadband Network assures interoperability by adhering to international standards for LTE devices and networks, and the EMS network is now accessible via private app-based communication channels and social media.[6] Callers can be instructed in first aid via these chan-

[6] The FirstNet system is already under development; see EMS1.com (2017).

nels, or via video chat services. Drones can bring emergency medications or defibrillators and other devices to a remote scene before EMS responders arrive. Telemedicine monitoring can assist those at the scene to assess the patient and use the medical devices dropped off by drone.

First responders can also be on the scene more rapidly. Those arriving in ground vehicles benefit from technology that changes traffic lights in their favor, and most other drivers and vehicles on the road receive wireless alerts about approaching ambulances before they hear the siren (a recent-model vehicle may also automatically respond via ADAS). Depending on traffic, other vehicles may even be rerouted via their in-vehicle GPS to other streets to reduce the volume of vehicles on the ambulance's route. Because vehicles are able to estimate crash severity and convey that information wirelessly, EMS responders arriving by air are notified quickly, without ground responders having to arrive beforehand to assess the scene. Safety checklist protocols around airborne EMS have improved, in part because of stricter oversight of providers, and no EMS helicopter has crashed in over a decade.

The Private Sector Joins the Safety Team

Another big helpful change is that the private sector has become more engaged in safety concerns. The broader coalition for traffic safety used to be largely public-sector entities: cities, counties, and states; public health officials; law enforcement and the court system; and transportation planners and engineers, supported by nonprofit safety advocacy groups. The lineup now includes private businesses of all sizes, the organizations that represent them, and, importantly, auto manufacturers, technology and software firms, and insurance companies.

Auto manufacturers began to focus more on safety technologies starting around the turn of the 21st century and have greatly stepped up their initiatives in recent decades. Some of this was spurred by government leadership and guidance, but the main factor is an increasing consumer focus on safety. As a result, the best-selling vehicles are the ones with the most-advanced safety features, and the advertising you see today emphasizes safety over speed and sleekness. Manufacturers also adhere to voluntary standards for in-vehicle communication and data privacy, both of which enable the vehicle-to-911 capabilities that have led to the improvements in trauma care. And the very term *auto manufacturers* is much broader than it used to be; it now includes firms that started on the technology side but have morphed over time into either building cars themselves or partnering with the legacy automakers.

Insurance firms have also changed their practices to do far more than give minor breaks in insurance costs to customers who drive less than average. Insurance firms now offer substantial discounts for individuals who use self-driving cars. Often, these price incentives discourage drivers from buying a car they can drive themselves. As a result of increased data sharing and changes in insurance regulations, insurance premiums are also highly stratified in terms of vehicle safety technologies, offering discounts to car owners with specific safety packages. Most of this change came about gradually and voluntarily on the part of the insurance industry, as claims data began to show convincingly that such technologies made a significant difference in crash rates and severity.

The public sector has also partnered with the private sector in another way: infrastructure investment. Public-private partnerships now take several forms, and many public entities insist on certain safety requirements before entering into such agreements. Social impact bonds have

A boardroom discussion

Kamal is the head of purchasing at MovingU, a successful mobility service in a major metro area that's planning to expand to several other areas over the next few years. The MovingU fleet has tens of thousands of vehicles, and the expansion will require purchasing several thousand more every year. Today he's meeting with LaDonna, a sales rep from one of the big automakers. LaDonna is under pressure to increase her company's sales to MovingU, which is seen as an important customer now that mobility services make up about half of all new car purchases. However, the sticking point is that MovingU has strict internal safety standards that they require their vehicles to meet—one of their main selling points to customers is that they will always be riding in a car guaranteed not to cause a crash. (They have been pretty successful at this—while they do have a few crashes per year, for the past five years the crash has always been caused by another vehicle.)

The vehicles they are discussing for MovingU's next purchase are fully automated, but they have been shown to be vulnerable to a type of hacking that can cause the car to exceed speed limits. It's not widespread, but "white hat" hackers—hackers who make a living testing security systems for vulnerabilities—have proven that it's possible. Kamal is concerned that any such incident would bring a huge round of negative publicity to MovingU at the time they're trying to win new customers. LaDonna is stressing that the vehicles fully conform to the industry's voluntary guidelines about vehicle security. Kamal responds that those guidelines have not yet been updated since that particular type of hack was discovered, and he is concerned that just meeting the voluntary guidelines is not sufficient. The meeting ends without a sale, and LaDonna reports to her boss that they are going to have to work with their security engineers to try to fix this particular vulnerability before she makes another sales call on MovingU.

also emerged to fund as-yet-untested safety improvements.[7] This type of bond brings private or philanthropic money to fund government programs—generally focused on prevention—and investors are repaid only if the program outcomes are achieved. Several roads with embedded sensors to aid safety have been constructed by private firms based on this model. In large rural states, the state Departments of Transportation (DOTs) have fostered cooperative programs with private companies to accelerate the deployment of better digital infrastructure.

The Car as Tool

In general, public attitudes about road safety and who is responsible for it have changed substantially. Historians have likened it to changes in social norms in the 1980s and 1990s regarding alcohol-impaired driving. It used to be something you might joke about, but now, due to sustained advocacy campaigns, driving under the influence of alcohol makes you a pariah in most circles. In the same way, some equally dangerous behaviors have become frowned on, particularly speeding. Car makers that used to brag about their "zero to sixty" acceleration and high performance now tout their safety features instead, given that they are far higher on

[7] Social impact bonds are already being used to fund projects; see Disley et al. (2015).

most consumers' lists of priorities. Alcohol-impaired driving is already effectively nonexistent due to these changes in attitudes and the effect of DADSS, and even glancing at your digital device will earn you a frown from your fifth-grader, who has been learning the importance of car safety at school since she was in kindergarten. Ongoing safety "action programs" help individuals join forces to try to change attitudes further, creating social media safety campaigns targeted toward, for example, wearing motorcycle helmets.

At the same time, vehicles have increasingly integrated the functions of personal electronics so that operations can be conducted via voice or integrated into the steering wheel controls, helping minimize instances in which drivers take their eyes off the road. Consumer awareness of the dangers of all types of distractions while driving has also improved.

Our behavior has changed, as well. For one thing, there are fewer drivers, period. The rate of getting a driver's license is lower than it used to be: Only 77 percent of Americans now have one, 10 percentage points lower than in 2015. Those Americans who don't drive have plenty of options. With all the safety improvements in cities, the rate of walking, cycling, and use of new transportation methods, such as electronic bicycles, or e-bikes, has climbed substantially—several cities now see 20 or even 30 percent of their trips made on foot or bicycle, which would have been unthinkable a generation ago, when rates were in the low single digits. Rail systems remain popular in larger cities, although many previous bus commuters are now using on-demand jitney services. Some of these changes have been led by immigrant groups who came come from countries where driving is less common and brought their habits with them. Assimilation no longer means buying a car.

For another, individual dependence on private cars has decreased because of several factors, including the aging population, higher rates of people in cities where one can live fairly easily without a car, and the explosion of mobility services. That's still a lot of cars on the road, but if 400 million Americans owned cars at the rate we did a generation ago, that would mean 25 million more cars in private hands and garages than we have today. It's still high by international standards, but the United States is no longer the outlier it once was. It's not unusual these days to find apartment buildings housing hundreds of people but just a handful of parking spaces, many of which are occupied by shared vehicles. Shared vehicles are popular, but they're still not for everybody—for example, they tend to be less popular among parents whose young children require car seats, or people who need to haul gear.

Finally, we collectively drive less, about 7,000 miles per capita per year, down from about 9,700 in 2015.[8] There are big differences between key groups. Vehicle owners drive somewhat less than they used to, as more people work from home or nearby shared workspaces, but there are still plenty of people racking up mileage. Owners of self-driving vehicles tend to put on more miles than people who drive themselves, but most vehicle owners still own conventional cars.

Of the now car-free households, or even those with one car, most belong to one or more mobility services. Mobility services let their members rent a variety of vehicles, both human-driven and self-driven, depending where you are going and what kind of vehicle you need. Few people rely on cars for all their transportation needs; in some cities, mobility service membership also pays for transit rides and bicycle shares. Some also allow carpoolers to share costs

8 Bureau of Transportation Statistics, 2017, Table 1-35.

easily, and various types of ride-hailing are included, as well. All the fees are charged automatically to your account.

Mobility services compete in part on their driving safety records, which were required to be made public as a condition of being able to access public transit networks. Most mobility services are based in individual cities, but a few offer membership privileges in multiple cities. Some of the most popular incorporate parental controls—for example, you can sign up your teenaged son, but limit him to self-driving vehicles. Or do the same for your aging parents.

The overarching difference is that people are much more likely than in past generations to see their car as a tool to get from point A to point B. Attitudes about car ownership and driving are more focused on convenience, comfort, efficiency, and safety rather than on power or speed. People still love cars, but they value different features than they did 30 years ago.

What Have We Gained?

Eliminating roadway deaths—along with all the changes that have led up to this moment—has improved our quality of life in very noticeable ways. Mobility services in particular have been a boon for all kinds of situations. Parents sign up their teens, many of whom think they won't need a car for years and don't care about getting a full license right now, just one that allows them to ride solo in HAVs. Adults sign up their aging parents. People going home after a night on the town just call an auto-cab via their mobility service—they probably took one to the bar in the first place, because it's just easy.

For the public sector, the financial effects are considerable. With fewer crashes to respond to, police and emergency responders can serve other community needs. States and insurance companies spend less on medical expenses, given that fewer crash victims need care and that long-term medical care is seldom needed after crashes. The federal government spends less on disability payments. The private sector has seen significant cost savings from reducing crashes among employees.

We don't often think about it, since the decline happened slowly. But not so long ago everybody knew somebody who had been killed in a car crash—maybe not a family member, but a girl you went to high school with, a guy you worked with, your parent's neighbor's son, your doctor's mom. They were everywhere, a steady drip-drip-drip of lives lost that you had stopped paying attention to until it happened to someone you knew, and you thought, "How awful, you never know what's going to happen." At some point, that number got smaller and smaller, and now it's zero. What an accomplishment.

CHAPTER THREE

How We Got Here

As with Chapter Two, this chapter is written from a future standpoint, in 2050. We have footnoted events that have actually taken place.

So how did we get crash fatalities to zero?

A lot of the progress was based on advances in vehicle technology that began about 50 years ago and have continued to evolve. Not only did the technologies themselves reduce certain types of crashes, but they had an even more profound impact: They changed peoples' expectations. People began to think that if cars could radically change the odds of being killed in a crash, maybe we shouldn't accept so many crashes. Combined with gradual but unmistakable changes in policies, funding, and attitudes, roadway deaths began to decline, slowly and then more quickly. The rest of this chapter looks at how we got here over the past three decades, step by gradual step.

The Early Years (Through the Mid-2020s)

While it didn't get the same attention as more high-profile causes of death, the mid-2010s saw something of a crisis in roadway deaths: After years of decline, they were going up. The causes were not necessarily clear: There were more miles being driven, but more people killed per mile; enforcement of existing state laws was challenging, and stronger laws were difficult to enact; and some states and demographic groups saw larger increases in deaths than others. People in the safety community agreed that they needed to attack the problem on multiple fronts.

Taking Local Action

That spurred some states to consider more seriously their own traffic safety laws and how to enforce them, especially as advocacy groups were able to gain traction by pointing to these increases in fatalities. Major change didn't happen overnight, but a few more states adopted motorcycle helmet laws, while others ramped up enforcement of alcohol-impaired driving. Utah was the first state to take another step toward battling alcohol-impaired driving: It adopted a blood alcohol concentration of 0.05, lower than the prevailing 0.08.[1] Safety advocates were delighted when studies showed that this change in the law lowered the number of alcohol-impaired driving crashes, which encouraged other states. States and communities also

[1] In 2017, all states had a legal limit of 0.08 blood alcohol concentration (BAC) for a driving while impaired charge. Utah's bill to reduce its legal BAC limit passed in 2017 and takes effect in December 2018 (Fell and Voas, 2017).

reconsidered the proven safety countermeasures identified in the *Toward Zero Deaths National Strategy* and redoubled their efforts on the programs and policies that best fit their needs.

As a result of efforts led by the National Academies of Sciences, Engineering, and Medicine calling for a national trauma care system, states were also more fully informed about the improvements to crash detection, injury severity prediction, 911 center capabilities and resource deployment, prehospital triage practices, policies to determine which trauma center victims should be directed to, and transport decisions by EMS personnel (i.e., ground versus air). Variations and gaps in state trauma systems were reduced based on evidence about what saves lives.

At the local level, cities were beginning to adopt their own Vision Zero policies, bringing together a variety of city agencies to tackle the problem from all angles. In New York, an early adopter, the effort included the city's departments of transportation, citywide administrative services, health and mental hygiene, education, and aging, as well as the police department, the district attorney's office, the Taxi and Limousine Commission, the Metropolitan Transportation Authority (which operates the subway and buses), and City Hall, including its office of operations and the community affairs unit.[2] Their mandate was for each department to incorporate safety outcomes into its own policies and share results and ideas with other departments. So they attacked a common problem with their own tools: The DOT funded projects to improve safety at dangerous intersections, prosecutors focused on keeping alcohol- and drug-impaired drivers off the streets, and city ambulance services considered how to help crash victims as quickly as possible.

Success was hardly overnight, but after about three to five years of such efforts, New York and other cities began seeing measurable results, especially in regard to pedestrian deaths. That helped create momentum within the city, gave city officials a concrete victory in a war many residents had assumed couldn't be fought, and served as an inspiration to other cities to adapt similar policies. By the mid 2020s, every city of more than 500,000 people was on board, and mayoral candidates started to include support for such policies in their platforms.

With these local successes, the city departments, buttressed by local advocacy groups, began pushing their states to allow them more leeway to institute yet more changes. For example, a few cities increased their use of speed cameras, given that speed reductions were a key part of their efforts. Other state advocacy efforts were more focused on local control of the street infrastructure, allowing the city to have local control of streets previously controlled by a state DOT and revamp them in ways that would slow traffic. Not all of these efforts were successful, but those that were received national attention through the networks that championed them as best practices, and a set of guidance for cities began to evolve based on the accumulating evidence about which initiatives worked the best.

A final element at the local level was involving police departments more effectively in traffic enforcement. As the number of crashes began to decline, police forces in those cities were able to shift some of their focus from crash sites to more-aggressive enforcement of speeding and alcohol-impaired driving laws. They also began working more closely with city departments and sharing data about places where speeding was a serious problem, to do more targeted enforcement in the short term and for the transportation agency to prioritize those areas

---

2 See New York City Vision Zero Task Force (2017) for an overview of that city's recent efforts and results.

for traffic calming measures. In a few cases, some cities were even able to increase enforcement budgets to target these areas.

Technology Ramp-Up

The advanced technologies so common today were making their way slowly but surely into the vehicle fleet decades ago. In 2015, about half the cars on the road had electronic stability control, but fewer than 5 percent had rear parking sensors, automatic emergency braking (AEB), or adaptive headlights.[3] Some technologies were still essentially limited to luxury models. Due to a combination of consumer pressure and the desire to show a good-faith effort, auto manufacturers reached a voluntary agreement that, by 2022, virtually all new cars would have forward collision warning and AEB.[4]

There were still concerns as these technologies rolled out that they differed slightly by make and model, both in how they were marketed and in their performance (for example, blind spot detection that varied in how far away a vehicle could be seen, and AEB whose stopping distance varied considerably). Some of the consumer-oriented websites for car buyers began calling attention to that inconsistency, and a consortium was developed to try to address it. The consortium did make progress, but some inconsistency remains.

Funding to invest in digital upgrades was one of the less challenging aspects, given that then-emerging technologies such as 5G and 4G LTE had widespread benefits beyond the transportation sector. A provision in the transportation reauthorization bill created specialized loans, tax relief, and other incentives to reward private firms for investing in these technologies, provided they could show that such investments could lead to fewer lives lost. For example, one state partnered with a private firm to demonstrate that upgraded digital networks would enable the real-time transmission of data from vehicles to 911 answering points, resulting in more-timely emergency response and lives saved.

Since some of the crashes that still took place involved looking at devices, the federal government launched a challenge with a hefty prize for the firm that could create a foolproof way to disable a driver's phone except to allow emergency calls. A number of technology providers responded, and several viable solutions were developed. Device suppliers began equipping products with new software, and, since it integrated well with onboard vehicle communications systems, most drivers found it acceptable. The late 2010s were also when the federal government started thinking seriously about the potential safety concerns of AVs, models of which were already being tested on some roads, albeit generally with human drivers to supervise. There were conflicting points of view among industry over what kind of and how much federal involvement was desirable. On the one hand, some opposed regulatory approaches as heavy-handed, not to mention unlikely to succeed given the rapidly changing nature of the technologies. On the other hand, some were concerned that a lack of federal regulation would leave a vacuum of regulations that each individual state would fill, creating a clunky patchwork of rules and regulations that might make a self-driving vehicle perfectly legal in one state and illegal when it crossed the state border.

In the late 2010s, a process to allow some exemptions from the Federal Motor Vehicle Safety Standards was developed specifically to spur AV technology while also encouraging

---

[3] Current and projected ADAS penetration in new vehicle sales and the entire fleet (passenger vehicles only) is from the Highway Data Loss Institute, 2016.

[4] This was announced in 2016 (Woodyard, 2016).

more uniformity at the state level. Around the same time, the federal government, specifically the National Highway Traffic Safety Administration (NHTSA), began issuing successive iterations of guidance about AVs, working toward voluntary self-assessment and ultimately issues of privacy and cybersecurity. Over subsequent years, this developed into a cooperative working relationship between NHTSA and the evolving group of automakers and technology developers.

One early output of this relationship was a set of technology performance measures, focused on the ability of cars to drive successfully regardless of weather or infrastructure conditions. Another was the ability of multiple firms to share some data under certain agreed-upon conditions about how well vehicles were learning to drive and where incidents were occurring. Progress toward commercialization would have been slowed considerably had each firm needed to get up to speed independently, and this pre-competitive cooperation led to a few firms merging once they realized that each had a niche competency that would complement the other.

Bringing in New Partners and Funding

Another way in which traffic safety evolved was that new groups began to be involved, brought in to the fold by existing advocacy groups. The early 2020s saw a concerted push to involve primary schools in teaching traffic safety lessons that include device use, a departure from waiting until drivers education in high school. With fewer teens getting licenses, a trend that started in the 2000s, some districts were receptive to bringing in traffic safety at earlier ages. In many cases, it was folded into a more general safety curriculum, encompassing lessons on social media safety and cybersecurity. Several safety advocacy groups developed model curriculums to make it easy to incorporate age-appropriate materials starting in grade school. The increase in safety awareness and interest by adolescents in many cases "rubbed off" on parents and helped change adult attitudes about safety as well.

Another major outreach effort involved the business community—not those directly involved with the auto industry or insurance, but more generally those with employees who drove for work-related reasons. Safety advocacy groups began making the point that car crashes were actually a measurable drag on the bottom line, since crashes were the leading cause of workplace deaths. They encouraged businesses with their own fleets to upgrade to safer vehicles when replacements were needed, or to sign up with car-sharing services with newer fleets. Some fleets were small, such as a news outlet with one or two vehicles available to cover stories around a big city, while others were sizable, such as a home improvement firm with dozens of small trucks to make service calls. This "business case for safety" was also broached with chambers of commerce across the country, focusing on the fact that car crashes are bad for business. Advocates suggested that more focus on safety overall would help bring in jobs and economic development as "smart cities" approaches were luring new businesses and entrepreneurs.

The successor to the FAST Act—the Fixing America's Surface Transportation Act, the federal transportation authorization bill from 2015—also helped alter the safety landscape.[5] One provision expanded the ability of states to move money between spending categories (e.g., requirements that some money was exclusively for highways), such that the number of activities that could be funded to further safety initiatives increased. States could use these funds to work directly with public health departments and law enforcement on data collection around

[5] Public Law 119-94.

safety initiatives. Not every state went this route immediately, but several did, with compelling results.

Safe System: A Change in Mindset

One of the important underlying principles during this period was a paradigm shift in thinking by the people who make transportation policy at all levels of government. The "Safe System" approach, imported from Sweden, flipped conventional thinking about safety on its head.[6] For decades, people had thought of drivers as the problem: They got drunk, they got tired, they texted while driving, they drove too fast. The best way to increase traffic safety, it was thought, was to pass laws and mount education campaigns to encourage drivers to pay attention behind the wheel.

The idea of Safe System was to shift the focus solely from the driver or pedestrian to encompass the system as a whole, including all vehicles and roadways. While safety advocates continued to encourage safe behaviors, they also realized that compliance would never be perfect. Even when doing their best, people will always make mistakes while driving or walking, sometimes because of neglect but other times because of honest mistakes—misjudging the speed of an oncoming car, losing control on a rainy road, turning their heads for just an instant to their passengers at exactly the wrong moment.

Instead, the Safe System approach places much more responsibility for preventing severe crashes on the system—on the roads and the vehicles. With regard to the roads, the goal was to design and build roads that minimized both the probability and impact of crashes. The main focus was on reducing speed in safety-critical locations, which accomplished two things at once: It reduced the chance of a crash taking place, since higher speeds mean that drivers need longer stopping distances, and it minimized the severity of a crash, since speed is a good predictor of whether a driver or a pedestrian will live, be seriously hurt, or die.

In a Safe System approach, roads are designed to prevent crashes and to reduce the severity of injuries if a crash does happen. Safety features are incorporated into the road design from the outset. Engineers can make roads that are easier to navigate. For example, roads can be built to slow the driver through a series of curves rather than present an abrupt turn after miles of relatively flat straight sections that encourage high speeds. The road can also encourage better driving habits, appropriate speeds, and driver attention. And roads can include features that are more forgiving in the event that a driver does make a mistake.

Another part of the Safe System approach is the vehicles themselves. They, too, should be forgiving of driver error, or prevent errors from happening in the first place. The ADAS technologies discussed previously are good examples of this: Even if the driver doesn't hit the brakes in time, AEB can take over and prevent a collision. Some automakers began taking this concept seriously even back in the 2010s,[7] and others followed suit. Cars can also be made more "crashworthy," meaning they are safer to the occupants because they tend to hold their shape when they hit something and protect occupants from absorbing lethal crash forces.

One of the most significant shifts in the Safe System approach that has occurred is the deliberate focus on post-crash care—since crashes and collisions with pedestrians and bicyclists have not been completely eliminated. A focus on safe systems has assured that the inci-

---

6 See Belin, Tillgren, and Vedung (2012) for a history of the Safe System approach and Vision Zero in Sweden.

7 See Volvo's 2020 pledge, described in Jackson (2016).

dent detection and emergency medical and trauma response capabilities have been maximized to avoid all preventable deaths.

Finally, the Safe System approach also emphasized overall review of the system, meaning that engineers and planners were continually monitoring where crashes continue to take place and recommending improvements. If a certain type of crossing signal seems to be linked with certain types of crashes, all of those signals should be replaced with something safer. If certain types of roads produce more than their share of crashes, all roads of that type should be modified to reduce that risk.

While this represents a paradigm shift, it obviously did not occur overnight. But the ways that experts think about traffic safety were beginning to change dramatically, and this helped to push along some of the broader changes that took place in the ensuing years.

Years of Rapid Change (Mid-2020s Through the 2030s)

These early efforts were followed by roughly 15 years of truly dizzying change in technologies, policies, and attitudes. The introduction of fully automated vehicles is credited with many of these changes; in addition to the effects of the technology itself, fully automated vehicles also spurred new ways of thinking and made new policies possible. With the building blocks in place, the country was poised for major changes in traffic safety.

Automated Vehicles Hit the Streets

HAVs became more common by the early 2020s, while fully automated vehicles were introduced primarily in commercial fleet operations. Concerns remained, however, about maintenance issues, data ownership and liability, and tracking of software versions and upgrades.

Several airports started using HAVs for parking and rental car shuttles, which were ideal environments—predictable routes covering the same terrain over and over. They didn't save much in costs, because the vehicles were expensive. Since some passengers complained that they still needed help with their luggage, the HAVs still required an employee on board. HAVs also started showing up on some warm-weather college campuses, where the environments were a bit less predictable but still finite and controllable.

Sales to the general public became more commonplace later in the 2020s. This was a few years later than some early enthusiasts predicted, held up by recurring problems navigating in bad weather and not-quite-accurate mapping software. But, the most problematic bugs were worked out, and several competing makes and models came out the same year.

In the first few years, the general public was somewhat leery about the new technology. The price tags of HAVs also made them prohibitively expensive, so luxury-car buyers were the primary market. There were also issues with software and sensor glitches that had to be addressed. Maintenance proved to be a challenge, and in many areas the infrastructure was not adequate for the vehicles to function at peak performance. For example, faded lane markings made it difficult for vehicles to remain in their lane on some roads, especially in snowy conditions.

The main change that the introduction of HAVs brought about was the delivery of "mobility services," provided by commercial entities. The idea had been brewing for a while to allow people to order and pay for transportation services across multiple modes from a single platform. The first mobility service was a type of public-private partnership that allowed private app developers access to real-time transit information along with ride-hailing, bike-sharing, and other modes (such as commuter ferries). The mid-sized southern city that pioneered this type of mobility service negotiated to have access to the ride-hailing and bike-sharing data as well, to help with planning efforts. What made this first mobility service popular with users was the convenience of having all of that information, ordering, and payment in one place, instead of needing multiple accounts

The metro area that pioneered this was able to bring together these disparate groups offering their individual services because they had a history of building alliances before AVs hit the market, especially between transit agencies and ride-hailing services.[8] Once the umbrella organization, formed and led by the metropolitan planning organization, brought the transit agency and a major ride-hailing firm on board, it was able to convince the bike-sharing provider to participate as well. It helped that the transit agency was willing to revamp its payment system to accommodate the new payment platform. Once these three services were all available through the same platform, membership and usage ramped up dramatically, providing the impetus to other metro areas to adopt similar platforms.

The metro area, tracking safety closely, found that HAVs represented a considerable increase in safety compared with the same trips made by mobility service members when they drove their own vehicles. Based on extensive member surveys and data collected from the mobility service fleet, the rate of crashes per miles driven by HAVs showed a distinct drop from those miles driven by humans, a fact that was widely reported and that helped make the case for wider use of HAVs over the next decade. Public exposure to these technologies in these vehicles also increased familiarity and confidence.

Investments in Data Infrastructure and Security

Increased automation and connectivity during this period enabled a major expansion in data analysis and utilization to improve safety of vehicles and roadways. Linked data sources and new predictive analytics identified opportunities to maintain return on investment in safety improvements even as crashes became increasingly rare events. However, along with these benefits came some challenges. One of the main hurdles these new technologies presented was dealing with the flood of data and their inherent vulnerabilities. How to protect sensitive customer data from cybertheft and maintain privacy? How to ensure that cars with no drivers were not sabotaged remotely by hackers, or by terrorists wanting to plunge them into a crowd? How to make sense of the torrent of data generated by both vehicles and users in ways that would make transportation more efficient? How to upgrade the digital infrastructure such that data could be used across organizations?

A more difficult challenge was in setting up mechanisms for data sharing. Both public and private organizations had been in the data collection business for years, but often on clunky legacy systems that were incapable of exporting data in formats that would be accessible to other organizations. Thefts of data from large organizations, both public and private, made the news seemingly every few months,[9] making the idea of sharing data across organizations even more problematic.

---

8 Such cooperation is already taking place; see McCutcheon (2016).

9 See Lord (2017) for a discussion of the frequency and increasing size of data breaches.

One key early step was establishing "safe harbor" rules for consumer protection. The U.S. Department of Justice, along with U.S. DOT and representatives of major industrial sectors that were the largest collectors of non-health data (which were already covered by other protections), convened a joint working group to look at this issue. Their main product was a "safe harbor" concept that protected consumers who were willing to share information that could be useful to government, industry, and research organizations.

Another issue addressed by this group was standardization of data formats to allow multiple organizations to use the same sets of data more easily. This was helpful, for example, in enabling emergency responders to receive critical information on crashes, potential injuries, and extraction situations in real time. Agreeing on the standard was difficult, given the huge variety of formats available and the possibility that future technology changes could render any standards obsolete. The working group agreed by the mid-2020s that the way forward was to adopt a set of somewhat flexible standards and revisit them periodically to reflect new technologies if needed. While not every member agreed on the specific standards, this was seen as a workable compromise, and it benefited from the promotion of open data that began to grow in the late 2010s.

The adoption of those standards led to new research and development efforts around making vehicle data transmissible to emergency service providers. The 911 system at the time was facing its own problems and anticipating a major upgrade,[10] and some members of the key working group began collaborating with the emergency services community to make this type of potentially life-saving data available to responders as soon as crashes took place.

Local Initiatives Continue to Advance

The local Vision Zero initiatives, incorporating the Safe System approach, continued to advance into the 2030s. By that point, a number of the cites who had been the first to adopt them were seeing unmistakable progress—decreases of 25 to 50 percent in pedestrian deaths from before the programs started, and smaller decreases in deaths for other types of crashes. While pedestrian deaths were never the largest category of crash fatalities nationally, their sizable increase in the late 2010s, combined with the fact that they were a substantial share of city crash fatalities, meant that serious progress was being made.

Buoyed by this success, some cities began taking more-aggressive measures. Some of these were consistent and spurred by best practices, such as reducing city speed limits to 25 miles per hour and creating "ped-scramble" traffic light phases that allow all pedestrians and bicyclists to cross while all the vehicles wait. These two measures also didn't incur much cost. The degree of infrastructure changes varied much more between cities, with some cities installing roundabouts at intersections that had been deemed more dangerous and making four-way intersections narrower, so that pedestrians wouldn't have to traverse six or eight lanes. Both of these slowed traffic and reduced crash severity. A few cities even experimented with AV-only zones, although these did not catch on at the time, given the dearth of privately owned AVs.

Other cities, especially those at lower densities, faced more obstacles in adopting these measures. Car owners and firms that make urban deliveries lodged some complaints with sympathetic city councils, claiming that the measures were discriminatory against drivers and that slower speeds made deliveries more expensive. However, some of these very auto-oriented cities

---

[10] See Federal Communications Commission (2014) for background on "sunny-day" outages and the transition to next-generation 911 services.

also faced opposing pressure from environmental and safety advocates, who strongly supported the slower speeds and redesigned intersections. The result was that even though all major cities were in theory in favor of Vision Zero, implementation moved at very different paces.

Around the same time, some largely rural states were also moving ahead with similar policies. Given the different environments, though, the focus was less on pedestrians and more on rural roads with high numbers of crashes. On the infrastructure side, state DOTs began paying more attention to improving the roadway, pavement, and roadside at curves to make roads more safe, rather than more comfortable for drivers to negotiate at high speeds. They added more space with rumble strips between the centerlines on undivided roads, and barrier and passing lanes where they were most needed. Median barriers were installed on most divided roads. These measures reduced or prevented many head-on crashes.

Intersections along high-speed, divided highways were retrofitted with "J-turns" to prevent severe angle and frontal crashes. Instead of crossing or turning left onto a four-lane divided highway, with wide medians and multiple lanes of high-speed traffic, J-turns require a right-turn followed by a U-turn, and have been proven to be safer than turning left directly.[11] Other initiatives that began spreading across states included more consistent crash reporting and data sharing between cities and states.

Making these infrastructure changes required additional funding, and states began turning to social impact bonds. This type of bond originated overseas and was first used to fund safety improvements in the late 2020s. A major foundation, coaxed by state safety activists, agreed to experiment with this approach in the state where it is headquartered to rebuild a road that had been the site of several major crashes. The deal the foundation made with the state was to provide up-front funding to reconstruct a 50-mile segment where one-third of the serious injuries and fatalities in this region had occurred. The reconstruction included specific safety features designed using the Safe System approach, such as embedded sensors that would communicate via V2X with vehicles in danger of leaving the road. The deal also spelled out a specific percentage reduction in serious injuries and fatalities along that segment over a five-year period, and the foundation would be repaid by the state DOT (including a small share of the cost savings) if that goal was reached. This gave the foundation an incentive to ensure that the changes made would be effective. Once this model had been shown to work, it spread to other states.

As both urban and rural approaches developed and spread, there were three spin-off effects. First, engineering curriculums began to adapt and incorporate Safe System thinking. With fatalities beginning to decline and cities continuing to encourage active transportation by building sidewalks and bicycling infrastructure, a change in mindset was occurring that emphasized safety across all modes. Newly minted traffic engineers, having absorbed Safe System thinking in college or graduate school, were enthusiastic about bringing their ideas to real projects. Technical guidance for planners and engineers was updated over time to reflect these changes.

Second, integrated data created a renewed push to improve data collection and analysis at both the systemwide and individual crash levels. Both cities and states used location information to pinpoint specific intersections and road segments with higher-than-average crash rates and compared them with other pertinent data on time of day, visibility, signage, and numbers

---

[11] The Minnesota DOT is using this technique to reduce crashes; see Minnesota Department of Transportation (no date).

of both vehicles and pedestrians. This allowed planners to identify the most-dangerous conditions and make needed adjustments, not just to those specific locations, but also to similar ones. Planners also reviewed the roadway network in light of the improved data to better understand problems in design that could be improved upon systemically with retrofits and new design protocols. Those jurisdictions with the resources to do so began to analyze specific crashes in depth, looking for additional insights.

And, finally, the declining rates of crashes meant that some state highway safety patrols and city police forces were able to improve the accuracy of crash reporting and redeploy some resources to other needs. They remain involved with Vision Zero efforts—most urban police forces have a liaison assigned to work with this group—but they can spend less officer time writing up crashes.

When Vehicles Got Even Smarter . . .

By the 2030s, ADAS technologies were much more widespread than even in the previous decade. Of the cars on the road, almost all had electronic stability control, rear-facing cameras, and blind spot monitors; over three-quarters had rear parking sensors, AEB, adaptive headlights, and lane-departure warning. All of these features were standard on new cars, and while prices had increased, they had done so slowly over time, not dramatically. Similar technologies began to be incorporated into motorcycles, in particular self-balancing control to prevent bikes from tipping over when moving slowly, and automated stability control that prevents loss of traction at higher speeds.[12] Economies of scale also allowed the price of these technologies to remain accessible to the average consumer.

Not yet standard on all vehicles, but increasing in prevalence, were design changes that contributed to pedestrian safety if the car hit a person. Car bodies have been engineered such that the hood raises a few inches on impact and has some "give," so that if a pedestrian's head hits the hood, those few extra inches reduce the chance that his head will hit the engine at high speed. The A-pillars—the part of the car frame that separates the windshields from the side windows—have also been modified to be softer to minimize head injuries. At the same time, front bumpers and hoods have been redesigned to reduce leg fractures and to scoop the pedestrian onto the hood rather than knocking her to the ground, where there is a chance of being run over. Sensors in the car automatically contribute to a new injury severity algorithm to predict the probability of severe injury in the struck pedestrian.

Another feature, first piloted around 2018, was the Driver Alcohol Detection System for Safety, or DADSS. The result of a public-private partnership between NHTSA and the industry group Automotive Coalition for Traffic Safety (ACTS),[13] DADSS had been under development for years. The technology can detect when a driver has a blood alcohol content above the legal limit based simply on his normal breath (unlike an old-style breathalyzer, that requires a driver to blow into it specifically) or in his hands. When DADSS finally became available for commercial use, auto manufacturers voluntarily agreed to offer it on nearly all models, given their role in its development. Even so, it takes about 25 years for automotive technologies to reach 95 percent of all vehicles, a figure that has remained fairly constant. However, within

[12] Such technology is already in development; see, for example, Adams (2017).

[13] See the DADSS website for further details: dadss.org.

about five years of the system's intensive rollout, alcohol-impaired driving deaths finally began to decline.

Cars changed so rapidly over a fairly short period of time that dealers began realizing that car buyers were a bit bewildered. Backed by congressional support, government stakeholders, consumer education groups, and the myriad of car-buying websites began a multi-pronged campaign to educate buyers (and even dealers, in some cases) about the safety records of these new technologies and how and why to use them.[14] Additionally, the government included crash avoidance information in a "star rating" system on the vehicle's window sticker, providing clear, easy-to-understand information about the safety effectiveness of technology installed on a given vehicle. The warning lights and sounds and vibrations still varied from model to model, and it was still a little too easy to turn the features off. But gradually, as most people had the experience of moving up from a car with relatively few safety features to one with all the latest ones, they came to accept and even depend on these technologies, and the problems of consumer confusion, lack of use, or misuse abated over time.

AVs made rapid progress during the 2030s, as well. One important issue was that the latest models were "all-weather," meaning they were able to perform well even in snow and rain, which had limited their usefulness in many areas during the winter months. Sales to the general public began to creep upward, but the price was still relatively high.

Mobility services, which had not even existed ten years prior, were now in pretty much every major metro area. Almost half of households had an account with the mobility service that served their area, even if it didn't substitute for car ownership. Once the novelty of AVs wore off, and the prices remained higher than for conventional cars, most people used them for the kinds of trips for which they might previously have used a ride-hailing service. Some cities began to pull back on fixed-route bus service and allow mobility services to directly provide jitney-type services that mostly run along established routes but allow for passengers to be picked up or dropped off within a few blocks.

For that reason, the mobility services were also one of the primary purchasers of AVs. Many made their pitches to potential customers on the grounds of convenience and safety, and they used their market power to exert a certain amount of pressure on AV manufacturers. Around this time, the mobility services themselves also began requiring certain levels of safety in their AV purchases via a set of safety standards that they agreed upon.

While this might have limited their sales to some extent, automakers were also perhaps relieved that the bulk of their vehicles were going into corporate hands, not private ones. That's because maintenance issues had remained difficult—AVs required considerably more upkeep than conventional vehicles, what with frequent software upgrades and sensors that didn't last as long as advertised. Poorly maintained vehicles had been responsible for several high-profile crashes, and one of the benefits offered by mobility service fleet ownership was that they had sufficient revenues to employ their own maintenance crews. That gave the mobility services leverage to demand increasingly safe vehicles, which they could then charge a premium for.

The other major customers for AVs were owners of long-haul truck and bus fleets. Similar to the mobility services, they were bulk purchasers, able to push for safety and maintain their fleets adequately. The trucking companies were eager to adopt AVs for cost savings, and most of their models could switch between self-driving and human driving, since humans were still

[14] For an early precursor of this campaign, see the website "My Car Does What?" at mycardoeswhat.org.

needed for refueling and loading. But now drivers could sleep during the long-haul portions of their routes. Some intercity bus providers went this route as well, although most still have a company employee on board for ticketing and luggage.

The insurance industry, too, was able to improve its bottom line by pushing for safer vehicles. Among people still driving their own vehicles, safety technologies had improved substantially, and claims were decreasing. Premiums began declining for people who drove safer vehicles, because there was evidence that they were making fewer claims. These vehicles were also generating a fair amount of data, and regulators allowed insurance companies more flexibility in using those data for risk-based pricing. Motorcycles lagged behind in adoption of advanced safety technology, but benefited from V2X technology and, since half of fatal motorcycle crashes had involved cars, from crash avoidance technologies in other vehicles, along with blind spot detection. Motorcyclists also benefited even more than other road users from improvements in trauma care.

. . . and Started Talking with Emergency Responders . . .

One of the biggest changes was based on the data-sharing work that had been underway for years. By the late 2020s, a luxury vehicle came out that could communicate directly with 911 answering points in a crash. (Previous luxury vehicles had communications with their own services, which could then turn around and call for help if needed; the change here was in eliminating the middleman.) Seeing the potential for this technology to save lives, traffic safety, EMS, and 911 advocacy groups and professional associations lobbied hard to persuade the regulators to make this a standard feature on all new models. By this point, the digital infrastructure work was far enough along that getting this onto all new models was not nearly as expensive as it might have been even a few years prior, and the auto industry agreed. In the early 2030s, all new vehicles had this capability. It was also important that interoperability of 911 equipment and the FirstNet system had advanced quite substantially, and more backups were built into the system overall, reducing the possibility of major outages.

This direct communication was a boon for rural areas, where emergency response times were slower simply because emergency response personnel and equipment were fewer and further between. Now, 911 dispatchers could receive a ream of information on a crash: the precise location, the type of vehicle, the type of crash, the condition of the vehicle, and the probable condition of the victim given the type of crash. Responders could be sent both more quickly and prepared with the knowledge of what to expect. As the digital infrastructure evolved, ambulances used V2X communication to send signals to both traffic lights and nearby vehicles to clear the route more smoothly.

As the capability became more widespread, the next major push was to share data with the receiving trauma centers. This did not happen as quickly as advocates hoped, because further work was needed to ensure that hospital data protocols were fully interoperable with vehicular data. This required broadening the data working group to medical organizations; working out appropriate protocols was a slow process, given the privacy and security concerns about linking external data transmissions into hospital systems with patient data. But, eventually, the protocols were agreed upon, and EMS responders on the scene of a crash could review the information already provided by the vehicle, add to or correct it, and transmit it to the trauma center.

Over time, this capability expanded to include real-time photos and video from crash sites. Emergency department (ED) doctors were able to provide more-direct feedback to EMS responders on the spot after reviewing photos and video via telemedicine links. ED training

A serious motorcycle crash, and how the victim is saved:

Trevor is on his motorcycle on his way home from hanging out with his friends in the rural town where they live. It's about 1 a.m., and Trevor is driving on a dark two-lane road and getting tired, when suddenly he loses control of the bike—he can't say what happened, just that it seems to have a mind of its own. It bounces off the newly installed median barrier—a huge blessing, since he might have hit the car coming from the opposite direction—and throws him onto the shoulder of the road.

Trevor doesn't remember anything after that, but it's true that the bike has a mind of its own. It activated an emergency message to the nearest 911 public safety answering point that a run-off-the-road, one-motorcycle crash had taken place at 38 miles per hour. The town's EMS crew scans the results of an injury severity prediction model that the victim has only a 30 percent probability of being seriously injured. Paramedics Evelyn and Sam arrive at the crash site in about 15 minutes, 3 minutes faster than they would have otherwise, thanks to an automatic routing system that uses signal preemption—changing traffic signals to green as the ambulance approaches—and a V2V signal to other cars on the road, alerting them of an ambulance nearby.

When they arrive, Trevor is conscious but has no serious external bleeding or obvious fractures. Evelyn's first gut feeling is that they can take him to the closest community hospital. Trevor complains of pain across his lower right chest and winces when she presses on his lowest two ribs. Evelyn suspects a rib fracture or two, but no other chest trauma is evident, and his vital signs are within normal limits. Sam docks the drone that took photos of the bike to send to the hospital so they can anticipate injuries, along with Trevor's vital signs, the ambulance location, and estimated time of arrival. Sam notes a medical alert bracelet on Trevor's wrist. With a Q-code reader, he accesses the young man's medical history and forwards it to the hospital, noting his allergies to certain painkillers.

They load Trevor into the ambulance on a cot with embedded ultrasound technology that automatically scans the patient. An alarm alerts them that blood is detected in the abdominal cavity and Sam pushes a button push for a video consult with Dr. Santos, a trauma surgeon, via the secure communications link. She evaluates the ultrasound images and determines that the lowest rib on Trevor's right side has lacerated his liver—not severely enough to cause his blood pressure to drop yet, but serious enough to need urgent surgery or Trevor would bleed out into his belly. Dr. Santos is at the closest trauma center, a 90-minute drive away, so she requests a helicopter, and Evelyn and Sam's ambulance is automatically directed to a safe landing zone along the route to the trauma center, so the roadway does not need to be closed for the helicopter to land.

The ambulance and helicopter meet at the assigned landing zone, and Trevor is transferred promptly. When the helicopter lands on the roof of the trauma center, the surgical team swings into action, led by Dr. Santos, who had reviewed the ultrasound and scene photos in advance and had advised her team to expect liver lacerations—she was right, and the operating suite was already prepared. Between the immediate crash notification, the fast extrication and transportation, and the medical technology and algorithms, Trevor is in the hospital for five days and then goes home with stitches, which will probably be out in a week.

started to include modules on predicting type and severity of injuries based on the vehicle type and type of crash.

Trauma care underwent several other changes during this period. First, EMS responders signed on to NHTSA and CDC field-triage criteria,[15] standardizing EMS transport protocols across the country using best practices. Advanced automatic crash notification (AACN) systems became standard in vehicles, allowing for the immediate transmission of crash occurrence and details to EMS dispatchers and the resources they have dispatched. Trauma systems were streamlined and a nationwide review led to better distribution of Level 1 and 2 trauma centers around the country to ensure quick access to appropriate clinical care.[16] Response times for all time-sensitive medical emergencies, not just trauma, have decreased. Due to a combination of legal and vehicular engineering changes, the crash rate of ambulances, especially when driving with lights and siren, is almost zero. EMS helicopter responders, convinced by evidence of fewer crashes, began using more safety checklist protocols to reduce their own crash rates.

In the late 2020s, a largely rural western state was the first to deploy drones on a widespread basis to spot and respond to crashes. Although new cars were able to transmit data about crashes, most of the cars that people owned in the state were too old to have such technology yet. Armed with better information about where crashes were likely to take place, the state used a fleet of fully automated drones to fly over hundreds of miles of major highways over increasingly greater durations, which now approach 24/7. During a yearlong pilot phase, although the number of crashes remained constant, the number of lives lost decreased by 10 percent due to improved EMS response. This had been a closely watched pilot, and after this success, other states began to deploy their own fleets.

. . . Attitudes Started to Change

At the beginning of this period, around the mid-2020s, roadway deaths were still relatively high, and the changes that were beginning to take place were still largely the province of government officials, safety advocates, and the technology and vehicle industries. But as roadway deaths began to fall, vehicles began to change rapidly, and mobility services became part of everyday life, some public attitudes about crashes began to change as well.

Part of this was that those elected officials who had been early champions of Vision Zero policies began talking more regularly about their successes, and over time this helped to reset the baseline. Individual car crashes had seldom made the news when they were plentiful, so people didn't think about them much—but as mayors talked regularly about how many fewer were happening, those that occurred got more attention. Some cities started posting construction-site-type signs on the roads leading in, saying "Welcome to our city, where we haven't had a fatal traffic crash in 27 days." That kind of publicity helped raise awareness of the previous levels of fatalities and started to make them seem less acceptable.

Schools and businesses also began to change the minds of their students and employees. Health and civics classes began discussing transportation and how it contributes to public health, and teaching young people about how land use policies and urban design affect the economy and the environment. Employers explained why they were making a point of buying

---

15 These were issued by the CDC in 2012; see Sasser et al. (2012).

16 While trauma center levels are set by states, broadly speaking, trauma centers categorized as Levels 1 and 2 can deliver the most-comprehensive care to trauma patients. In contrast, Level 5 trauma centers provide limited care. See American Trauma Society, no date.

safer vehicles, and those with large workforces shared information about how fewer of their own were killed in crashes. Other public-private groups worked on education campaigns as well, such as local civic and business organizations working with a city to develop messaging and posters for local businesses.

With this more heightened awareness of crashes, public attitudes toward traffic safety began shifting, and, overall, new regulations faced less opposition. States where motorcycle helmet laws had previously faced fervent opposition were able to debate them again, since motorcycle deaths were now an even larger proportion of roadway deaths and ongoing safety action campaigns had begun changing opinions about wearing helmets. Red light and speed cameras were introduced in places that had never had them—and safety advocacy groups, mindful of past experiences in which the cameras had been seen just as a means to generate revenue, often worked with the city or county to make sure the cameras were deployed in the places with the worst safety problems, serving as a kind of seal of approval to a skeptical public.

There had always been advocacy groups pushing for safer vehicles and better driver behavior, but as roadway deaths began a steady decline, these groups ramped up their efforts in some new directions. One key goal was to increase the stigma around speeding and distracted driving, as had been successfully done for alcohol-impaired driving. Stigmatizing speeding was especially difficult, because the crackdowns on speeding in both rural and urban areas had led to something of a backlash. Social media was full of complaints that posted speeds were too low and that AVs (which were programmed to keep to the posted speed limit) were taking the fun out of driving.

The Past Decade (2040–2050)

Over the past decade or so, we have seen continued progress on overcoming some of the thornier technological problems. With traffic safety efforts beginning to show real progress, a new generation of technology firms is eager to continue working on these problems, and advocates and officials have continued to build on past momentum.

Current Areas of Research

In-vehicle safety technologies have continued to improve, and all of the specific ADAS technologies mentioned above are on more than 90 percent of vehicles. Some people had thought that the pace at which these technologies diffused into the fleet might slow down if people kept their cars longer. This was not an unreasonable assumption, given that these vehicles crash less, but it turned out not to be true. The mindset around safety has, if anything, encouraged some people to buy new vehicles slightly more frequently, given that there is often a dramatic difference between a car manufactured ten years ago and one manufactured today. It also means that the used vehicles still on the road are safer as well.

One main focus of research is on driver attention and vigilance. As driving is increasingly automated, researchers are examining how the reduced cognitive demand affects performance and whether mind-wandering reduces the capacity for drivers to respond quickly during an emergency situation. Human factors experts are looking closely at the human-machine interface to ensure that vehicle and roadway design are supporting the maintenance of driver alertness.

Cybersecurity remains an area of concern. As data of all types accumulate, and the functions of AVs and roadways increase, the potential harm that could be caused by unauthorized access is greater than ever. Security measures are much more sophisticated than 30 years ago, but so are the methods used by hackers. No comprehensive solution has been found, but investment in security monitoring and defense has been multiplied, and an elaborate field of cybersecurity science, policy, and practice has evolved.

After years of steady growth, the spread of V2X technologies has reached a point where most vehicles on the road are sending and receiving information that helps them avoid crashes. Pathways for this communication vary by location, with rural areas relying less on infrastructure and more on vehicle-to-vehicle information flow. The federal government played an important role in defining interoperable protocols, but identifying the best common approaches was challenging given the range of constituents and the rapidly changing technologies. Once there was agreement on the protocols, adoption of the technology accelerated remarkably.

Another bright spot is the breakthrough in methods for testing drivers for drug impairment at the roadside. Researchers have identified a physiological measure that is strongly correlated with marijuana impairment and shows great promise as a practical and accurate test that courts will accept as evidence of impaired driving. As alcohol-impaired driving declined, prescription and illegal drugs remained a problem, and with more and more states legalizing recreational use of marijuana, safety experts began calling for more attention to drugged driving. A consortium of several states sponsored research into what would be a defensible legal limit for impairment due to tetrahydrocannabinol (THC), the active “ingredient” in marijuana. The goal was to establish both a measurement method and an acceptable impairment level, above which a driver would be assumed to be impaired, similar to the blood alcohol concentration limits used for alcohol. A series of research projects were needed, and they took nearly ten years, but once a practical and accurate measure was identified, work began to validate the measure with crash involvement and build a strong case for its acceptability as legal evidence.

In-vehicle based tests for drowsy driving have also been implemented. Sensors in the vehicle can actually monitor driver alertness level and temporarily restore alertness long enough for the driver to get to a safe spot to rest. Drivers can choose the type of alert they prefer, but the manufacturers are not allowed to make it possible to turn it off entirely. This function quickly became a standard feature, since nobody is in favor of drowsy driving.

Where We Are Now, in 2050

The pace of change has settled down a bit over the past decade, but what had gone before means that we live in a different world than our parents and grandparents did when it comes to transportation and safety. For the average person, the main difference from 30 years ago is the availability of mobility services, which continued to grow in membership to every three in four households. As their geographic spread increased, they had some profound changes for certain groups. The largest growth area has been for seniors, who became converts as people realized they could enjoy the advantages of getting around by car without actually having to drive. Elderly rural residents have especially benefited from new policies that make delivery of mobility services economically viable in low-density regions. In some states, the services have been extended into such areas by subsidies to service providers. A number of other states are working with mobility service providers to use a public utility model to support delivery of services in sparsely populated areas. People with disabilities also were avid supporters and early adopters, and the quality of life of many who previously had limited mobility has been enhanced immeasurably.

AVs have become an important part of the landscape, but have not fully replaced human driving. Even though pretty much all of new vehicles sold are AVs, given the slow pace of introduction and the length of time people keep their cars, there are still plenty of conventional vehicles on the road. In 2050, AVs constitute a little less than half of the total passenger cars, so we have been dealing with a mixed fleet for several decades. Since AVs remain expensive, most people's experience with them is through a mobility service, or perhaps a bus ride between cities. Maybe 20 percent or so of people rely on mobility services exclusively, and the percentage of American adults with drivers' licenses has fallen below 80 percent for the first time in decades. There remain environments where only AVs are allowed to operate, such as some college campuses, but most of them operate in mixed traffic.

Trauma care continues to improve, and Level 1 and 2 trauma centers are appropriately spaced and available. Trauma systems, which once consisted of a collection of hospitals that chose to be categorized as a trauma center, now include all hospitals, which work in concert to get the right care to patients. AACN is standard. The EMS system now accepts a range of notifications of emergencies, not just from vehicles but also from texts or social media. Another development over the past five years is that people now have the option to transmit their personal medical information from a wallet card or digital device. They can link it to their vehicle, so if they are in a crash and the vehicle self-reports to a 911 responder, it can provide medical information along with information about the crash itself. This information, in association with a range of medical innovations, continues to push the field of emergency medicine forward.

A new mentality has taken hold in public decisionmaking, called the "safety in all policies" approach. It has been building gradually over time, and it's modeled on the previous and now widely used "health in all policies" approach. Basically, both take as their starting point the idea that even unrelated policy issues should take account of health or safety. So, in building a new road we should ask the conventional questions: How much traffic will it serve? How much will it cost? How long will it last? Who will pay for it? But also questions about its effects on health and safety: Will it encourage or discourage people from walking and bicycling? Will it contribute to pollution? How can it be made as safe as possible?

One of the things that has really encouraged this way of thinking is the availability of funding across departments. After the loosening up of funding provisions in the federal transportation authorization bill 30 years ago, those measures have continued to evolve to bring more authority to the states to make decisions about ways to spend that funding. Under the most recent federal transportation bill, state DOTs can use most of the funding—if they so desire—to upgrade trauma centers, on the grounds that it will help save lives from traffic crashes. States also raise more of their own money for transportation, and here too some states use it for public health programs that promote traffic safety.

The work of keeping people safe on the road continues. Just because 2050 was the first year with no fatalities doesn't mean we are done; it means we have to keep pushing the technologies and revising the laws and encouraging people to behave more responsibly. But the fact that we've achieved zero roadway deaths in 2050 means it's possible and can happen again, hopefully indefinitely. Even one death is too many.

CHAPTER FOUR

The Road to Zero

The future described in Chapters Two and Three is not inevitable. The Road to Zero will be full of roadblocks and pitfalls that will need to be resolved in order to move forward. One such potential conflict is around bringing vehicles with advanced safety technologies to market. Safety advocates would like to see ADAS on all makes and models of vehicles as quickly as possible, but the business case for incorporating these technologies in affordable and widely available models depends on consumer demand at prices they are willing to pay. Another conflict is whether the public will accept some loss of freedom behind the wheel in exchange for a future with no fatalities.

While these outcomes will require strong and consistent effort by members of all of the constituents in the RTZ Coalition, the results of our meetings, discussions, and analyses, as described in previous chapters of this report, demonstrate what can be achieved. Never before has such a powerful combination of emerging technological opportunities and grassroots safety initiatives existed that, operating in synergy, can enable the country to reach the goal of zero traffic fatalities.

This chapter lays out specific actions that can be undertaken by different members of the traffic safety community, as well as "allies" who are not conventionally part of this conversation. The goal is to suggest actions, recommended by the Road to Zero stakeholders, to lay the groundwork for the scenario as described in the preceding chapters. Some are envisioned in the next five years or so; others will be required further in the future.

Federal Officials

In the scenario we have laid out, federal officials play several important roles, including continuing their work as conveners of some of the important conversations between stakeholders, facilitating public-private cooperation, and supporting research.

- Provide leadership that prioritizes achieving zero roadway fatalities by 2050.
- Promote and support best practices that reduce roadway fatalities, particularly those identified in the *Toward Zero Deaths National Strategy*.
- Encourage consistent adoption of safety policies and practices where essential for efficiency and interoperability.
- Encourage public-private partnerships at the state and city levels to address local safety problems.

- Work with industry to facilitate the development and safe deployment of advanced safety technologies, such as the public-private partnership that is developing the DADSS technology.
- Use incentives and standards as appropriate to accelerate effective safety technology into the market.
- Support new methods for achieving change, including promotion of a safety culture, support for the Safe System approach and Vision Zero principles, public-private partnerships, and innovative funding strategies, such as social impact bonds.
- Support efforts to achieve safety goals in rural areas.
- Explore opportunities to align safety and research and development funding with state and local needs and improve return on investment.
- Partner with industry and other stakeholders to develop platforms and systems to collect and analyze data that will generate the information needed to target safety interventions.
- Assess strategies for improving vehicle safety, including partnerships and incentives as well as regulation.
- Encourage consumer education to accelerate adoption of vehicle safety technologies.

State and Local Officials

An important element of the scenario is that states and local jurisdictions (cities and counties) serve as implementers of new ideas in traffic safety. They have the ability to pilot new ideas, and by using data to track existing crashes they can narrow in on approaches that work in their particular environment. Professional organizations and associations that represent states and local transportation officials can support and spread best practices.

- Provide leadership that prioritizes achieving zero roadway fatalities by 2050.
- Commit to adopting best practices in safety laws, programs, and other investments, particularly those identified in the *Toward Zero Deaths National Strategy*.
- Provide leadership and guidance for creating a safety culture and advancing Safe System and Vision Zero principles in government, industry, and communities.
- Enact and provide adequate resources for the enforcement of strong traffic safety laws.
- Coordinate efforts to ensure consistent state-to-state approaches to deploying automated vehicles in traffic.
- Work with business to identify priority safety needs, support new policies, and align resources.
- Incorporate Safe System principles to identify problems, allocate resources and develop policies, and adjust policies as necessary to accommodate important Safe System changes, such as adjustments in speed limits.
- Take advantage of evidence-based safety and trauma care methods, such as those identified in recent national reports.
- Consider consumer education and other incentives to accelerate adoption of advanced vehicle safety technologies.
- Take advantage of financial incentives provided at the federal level.
- Take more ownership of safety issues that can be addressed at the state level.

- Examine insurance laws to enhance data sharing and permit risk-based pricing where appropriate.

Auto Manufacturers and Technology Developers

The scenario envisions that major changes will continue to take place in automotive technology, driven by a combination of regulation, voluntary commitments, and market demand. This group will continue to evolve in membership as new firms emerge, firms push their engineering research in different directions, and (possibly) former competitors form alliances or merge.

- Work with stakeholders to identify priority safety needs and accelerate widespread adoption of the most promising life-saving technologies as quickly as possible.
- Work with governments and other stakeholders on adoption of the Safe System approach and promotion of a strong safety culture.
- Participate in efforts to improve data sharing, while enhancing privacy and cybersecurity for the common benefits of product development and research.
- Work with stakeholders to educate consumers about the safety benefits and the safe use of advanced technologies.
- Continue investing in emerging safety technology research.
- Address vulnerable road users in safety research and design.

Emergency Medicine and Trauma Academics, Practitioners, and Advocates

Although the scenario assumes that reaching zero deaths is feasible, it is not exclusively due to efforts to reduce the incidence of crashes. Trauma care can play a major role in ensuring that crash victims receive faster and more effective care, leading to fewer deaths and debilitating injuries.

- Prioritize investment in trauma system needs and identify methods with greatest return on investment, especially for rural areas.
- Work with local and state governments to prioritize trauma system investments and improve trauma care.
- Participate in forums about data and emergency communications.
- Adopt national trauma triage criteria for crash victims.
- Collaborate with government and business on adopting the Safe System approach and promoting a strong safety culture.

Safety Researchers and Advocates

Change at this scale requires both "insiders" who can make certain types of decisions (such as passing laws or changing policies) and "outsiders" who exert the pressure to make such decisions. Safety advocate groups working together can play a key role in education and in developing partnerships to bring together groups that will need to cooperate to make progress.

- Educate policymakers at the local, state, and federal levels about the potential of dramatic reductions in motor vehicle deaths and opportunities for change and, when appropriate, urge the adoption of strong laws and regulations.
- Educate consumers about the far-reaching effects of traffic crashes, injuries, and deaths, and about the potential for change.
- Educate professionals who are engaged in managing the transportation system about the need for a Safety Culture and the Safe System approach.
- Encourage adoption of the safety laws and programs and initiatives identified in the *Toward Zero Deaths National Strategy*.
- Coordinate with other advocacy groups and stakeholders on major safety campaigns.
- Develop partnerships with industry groups on issues of common interest.
- Continue research into evidence-based countermeasures that will reduce crashes and their severity.

Business Community and Fleet Owners

The scenario pictures important changes by businesses to both emphasize safety among their employees as well as use their power in the marketplace to push for safer vehicles. It also envisions a new type of business emerging that will purchase and maintain its own vehicles in large numbers.

- Work with local and state governments to utilize the full range of data sources to identify regional safety problems, select solutions, and create change.
- Adopt and enhance safety policies for employees and fleets.
- Adopt and maintain a strong safety culture.
- Demonstrate new technologies and increase consumer interest and acceptance through early adoption.

Insurance Companies

Insurance issues will play a key role as automated vehicles enter the consumer market. Insurers can provide incentives for purchasing vehicles with effective safety technology and use data to better understand driving patterns and the effectiveness of various ADAS technologies.

- Work with governments and industry to create a strong safety culture and support implementation of the Safe System approach.
- Participate in forums about data sharing and protecting consumer privacy.
- Educate consumers about the need for improved safety laws and programs as well as the benefits of advanced safety technologies.
- With better streams of data and regulatory flexibility, differentiate individual drivers and vehicles more precisely and tailor incentives accordingly.

Law Enforcement and Judicial System

In this scenario, law enforcement plays a key role in state and local efforts to reduce crash deaths, forming part of "Vision Zero" teams and sharing data about crashes.

- Enhance enforcement of existing and new safety laws.
- Participate with local leaders in supporting the safety initiatives identified in the *Toward Zero Deaths National Strategy* and in local Vision Zero efforts.
- Incorporate the latest standardized crash reporting protocols and share data as possible with other city, state, and federal agencies.

Achieving zero roadway deaths is an ambitious goal, and the future could develop in many different ways. This report delineates one possible route to zero, by consolidating the collective expertise of numerous engineers, researchers, safety planners, safety advocates, and many others. Until now, the combined potential of road safety efforts has not been sufficient to achieve zero roadway deaths. That situation is changing with the emergence of advanced vehicle technologies, married with political and societal will and our extensive, ever-growing understanding of strategies to enhance safety. 2050 is not too far down the road from today; getting there safely is within reach.

APPENDIX A

Scenario Development Methodology

The challenge of this project was to work with a broad-based coalition that grew to hundreds of member organizations not only to develop a concrete vision of a future with zero roadway deaths but also to provide a credible means for achieving it. Not only did the interests and perspectives of the constituent member organizations of the Road to Zero Coalition differ in important respects beyond the shared goal of eliminating roadway deaths, but the technological, political, economic, social, and cultural underpinnings of a future more than 30 years away are impossible to predict with any confidence. It is difficult for individuals to plan under these circumstances, much less a task force of organizations, most of which focus on immediate legislative and administrative agendas.

We constructed a methodology to meet this challenge, built principally around three techniques tailored to the specifics of this project: backcasting, assumption-based planning (ABP), and Three-Horizon Foresight (3HF.) [1] We will provide a brief overview of methods and then also briefly describe their implementation in this project.

Scenario Framework

The goal of the project was to develop a future scenario that lays out how a world with zero roadway deaths would operate. This would be paired with high-level "prerequisites"—policies and technologies—that would assist in achieving this goal over time.

The scenario method was shaped by the following operating principles:

- substantial input from a defined group of stakeholders (the Road to Zero Coalition)
- collaborative interaction in defining desirable futures and trade-offs (i.e., the initiatives, investments, policies, etc., not undertaken due to conflict with or scarcity of resources because of the chosen path, as well as the balance between goals that might come in conflict such as personal autonomy versus the desirability of having more effective automaticity in the driving and safety systems of vehicles)
- developing scenarios designed to illuminate alternative courses of actions, consequences, and bases for policy choices
- the desire to achieve one major future objective: "zero fatalities on our roadways."

[1] For more on each of these methods, see Popper, 2008, on backcasting; Dewar, 2002, on ABP; and Curry and Hodgson, 2008, on 3HF.

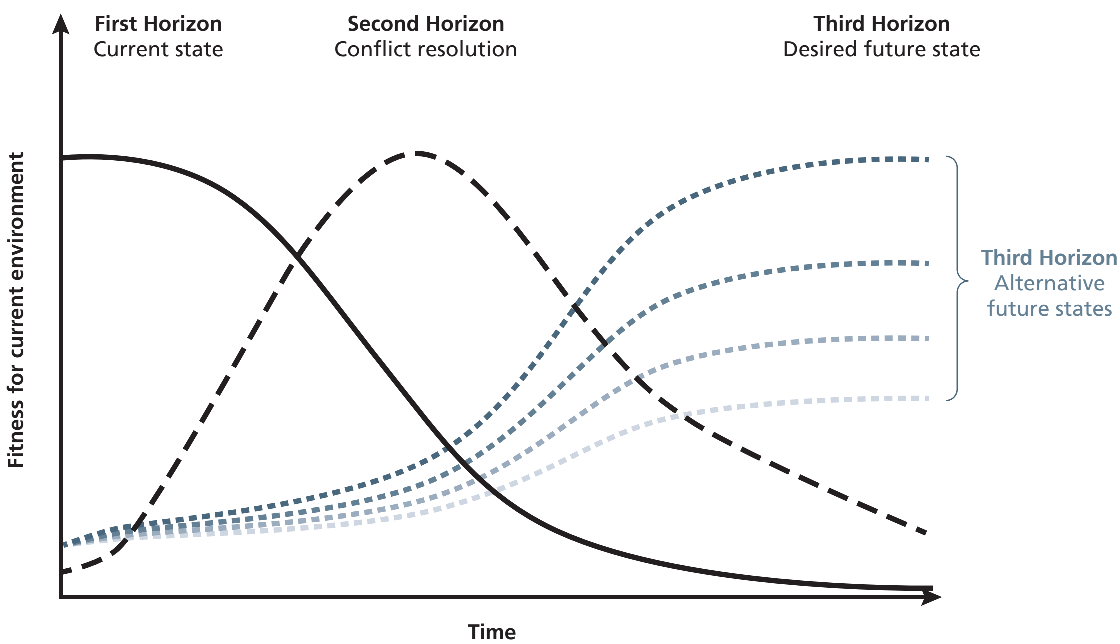
One difficulty with strategic plan development is that there is a natural tendency to focus on the strategy elements, as opposed to the overall vision. But the vision is the most important element of all: Without it, there is no purpose in having strategic elements. Further, the vision itself must be made both tangible and credible if the strategic path that eventually emerges is to be both compelling and motivating.

Three-Horizon Foresight provides a framework for defining a desired future vision collaboratively and connecting it with paths from the present. The underlying principle is that as the world changes, the systems and concepts well suited to current conditions may work increasingly less well in the future unless they also undergo change.

As trends unfold, the current state of the world (First Horizon) becomes transformed as the external environment changes, as shown by the solid line in Figure A.1.[2] The Third Horizon represents a long-term future state. Because of fundamental uncertainty and despite what we may intend, the systems supporting that Third Horizon state and the outcomes achieved may take several paths and forms, as portrayed in Figure A.1. This enables us to engage in active thinking about the course of transition between the First and Third Horizons.

The Second Horizon represents an intermediate state between the other two. It is shown in the graphic as yet another line that waxes and wanes over time because two processes are occurring. The first is the need to support efforts to achieve our goals during each incremen-

Figure A.1
Three-Horizon Foresight Provides a Framework for Visualizing Change over Time



SOURCE: Adapted from Curry and Hodgson, 2008.
RAND *RR2333-A.1*

---

2 Here is another way of thinking about the dynamics of change as conceived of in 3HF: Were the institutions, processes, and policies operating in the First Horizon to remain fixed even as external and internal conditions changed, those fixed policies would become ever less well suited to those changed conditions and therefore less able to sustain our ability to achieve societal objectives.

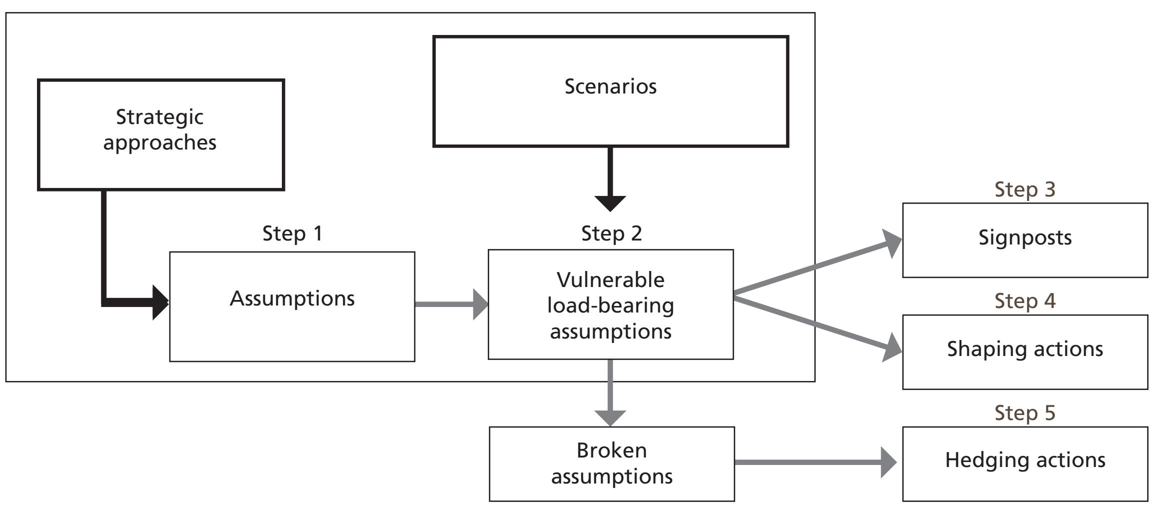
tal period of the transition. As with the system operating during the First Horizon, it too will be unable to retain its full fitness were it not to change as both goals and conditions change.[3] But the second process within the 3HF concept is to view the Second Horizon as a zone of conflict that is itself transitory from the perspective of arriving at the Third Horizon having achieved the desired state envisioned for that future. The Second Horizon therefore not only represents adaptation to current conditions but also a conscious effort to maneuver toward a desired future.

Consideration of the nature of that Second Horizon state becomes the central focus of 3HF. This construct supports the efforts of sometimes quite disparate groups of people to consider multiple paths to the Third Horizon. What conflicts can we envision between the status quo of the First Horizon and the radically changed state of the Third Horizon? How these conflicts play out could be resolved in many ways. The principle behind 3HF is that transition through the Second Horizon requires active management; the course of this transition will determine the likelihood that the desired Third Horizon vision can be attained.

Assumption-based planning facilitates discussion of alternative means for reaching envisioned outcomes. It focuses on exposing implicit assumptions connected to a desired strategic goal, in this case zero fatalities.

As shown in Figure A.2, ABP begins with examining strategic approaches in detail to identify their underlying assumptions, which may be explicit (directly stated) or implicit (unstated). Assumptions are then categorized based on whether they are vulnerable (that is, they may fail within the time horizon) and load-bearing (whether their failure would cause the strategy to fail, sometimes also called "key assumptions"). These are the important assump-

Figure A.2
Assumption-Based Planning Helps Groups Find Hidden Assumptions and Weigh Risks



SOURCE: Adapted from Dewar, 2002.
RAND *RR2333-A.2*

3 A more accurate—but vastly more confusing—representation of the curves associated with the First and Second Horizons would be a myriad of curves all slightly displaced, so that, over time, we could see supporting systems evolving with changing conditions and demands. These might be portrayed as being of different heights (that is, differing degrees of fitness) at different points along the time line if changes in internal and external conditions overwhelm our ability to change policies, institutions, and other structures swiftly enough to accommodate those changes.

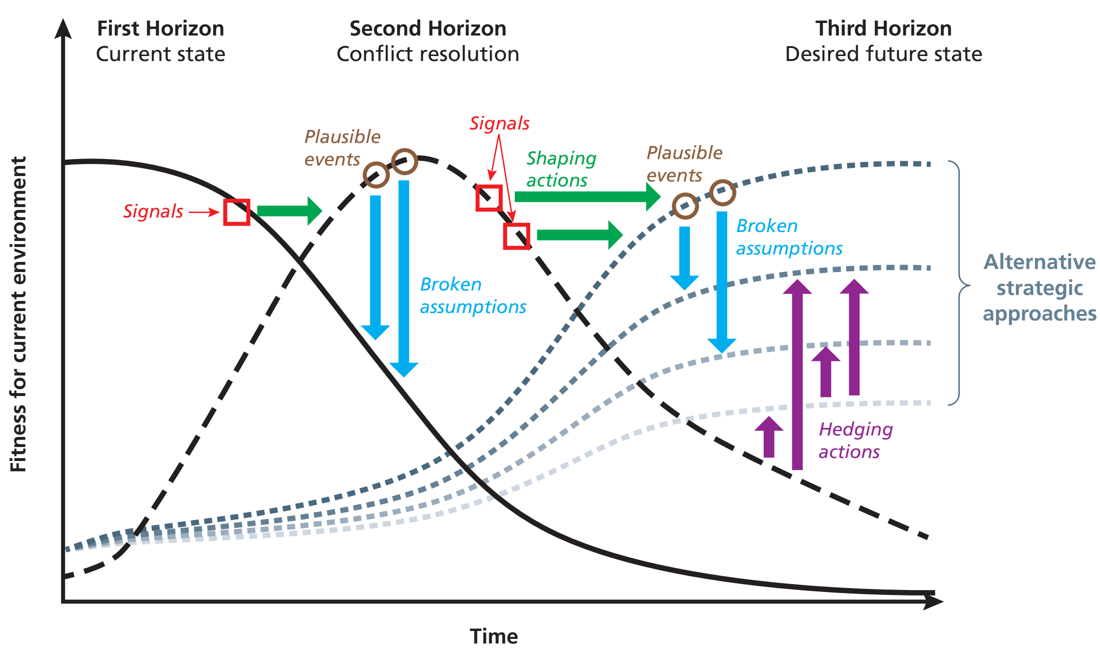
tions to watch over time for early signals of potential failure ("signposts" in the diagram above). ABP then identifies two types of responses to the potential failure of vulnerable and load-bearing assumptions. First, "hedging actions" help ensure against negative consequences when assumptions fail. Second, "shaping actions" help shape the future in a desirable way. In this way, ABP provides a framework to identify the assumptions that are at risk and how to respond to them effectively.

A principal value of ABP is that it is a useful means to support discussion of overall goals—once they have been made explicit—and coordinating that discussion with the policy design process. This suggests the value of combining these two methods, ABP and 3HF, into a framework for creating a coherent, integrated set of mapping, design, and implementation phases, as shown schematically in Figure A.3.

The RAND research team, together with workshop participants, used 3HF to develop a vision of the United States in 2050 with zero roadway deaths (the Third Horizon); its differences from the current transportation situation, with more than 37,000 roadway deaths in 2017 (the First Horizon); and plausible scenario pathways (the Second Horizon) between 2017 and 2050 that could lead to the zero roadway deaths vision. We used ABP to evaluate these scenario pathways by identifying their underlying assumptions and subjecting these to detailed critique based on the events assumed to occur and the basis for and various stakeholder actions underlying or responding to these events. These critiques allowed participants to explore the conditions, constraints, interactions, technology developments, policies, and overall environment that could support the RTZ goals.

We supplemented these two techniques at critical points during the process with other approaches, principally **backcasting**, in which, from the perspective of 2050 or other future times, the participants considered and described the various events and interactions that could

Figure A.3
Combining 3HF with ABP Weighs Both Future Visions and Alternative Strategic Pathways



RAND *RR2333-A.3*

have led to the assumed reductions in roadway deaths at these future times. During the workshops described below, such discussions were held both in smaller breakout groups and by the full group of participants.

Implementation of Framework

The RAND team met four times with different groups from the RTZ Coalition to facilitate this participatory foresight process.[4] These meetings began with as large a group as possible and then gradually decreased in size according to a protocol approved by the RTZ leadership.[5]

Preliminary Workshop: Matching Tools and Actions to Goals

The process began at the RTZ Coalition's December 15, 2016, meeting with about 150 participants. Focus groups led by RTZ Coalition steering group members proposed actions to reduce roadway deaths in the following areas within a template designed by RAND:[6]

- safer drivers and passengers
- protecting vulnerable users
- safer vehicles
- safer infrastructure
- enhanced emergency medical services
- improved safety management.

Dozens of different individual actions were proposed, discussed, and prioritized in the focus groups, and each focus group presented its best ideas to the full group of attendees. These discussions and the proposed actions themselves provided the basis for the subsequent series of three workshops with RTZ Coalition members that led to the zero roadway death vision presented in this report.

First Workshop: Developing Potential Courses of Action

The first ("framing") workshop was held January 26–27, 2017, with 60 invited attendees.[7] The first workshop agenda is shown in Appendix B. It employed two breakout sessions to identify individual potential actions to affect roadway deaths, their synergies and conflicts, and the role

---

[4] Participatory foresight is a process in which a group of participants selected to span a broad policy area and to balance expertise, experience, and perspectives comes together to jointly develop and analyze visions of the future. An excellent description of methods and examples can be found in Georgiou et al., 2008.

[5] A prerequisite for attending the last two in the series was a commitment to attend both. Therefore, these had a consistent set of participants.

[6] These categories were developed in the report, *Toward Zero Deaths: A National Strategy on Highway Safety* (Toward Zero Deaths Steering Committee, 2014), which was developed by a coalition of state and local transportation, safety, engineering, law enforcement, and EMS organizations. They were selected for use in the December exercise as a way to provide continuity with prior efforts that included many of the same organizations.

[7] All three workshops were held in Washington, D.C. Participation and invitations were coordinated through the RTZ Coalition Steering Committee, chaired by the National Safety Council. Attendees to all workshops were unpaid by the project team or the steering committee, and their expenses were covered by their home organizations. Participants were polled by the National Safety Council after each workshop for feedback, which we used to adjust the conduct of the successive workshops in the series.

of various stakeholders in implementing (or preventing the implementation of) these actions.[8] Participants were then led through a discussion of how these individual actions might be integrated into a set of broader courses of action (COAs) that could then be assessed, modified, and selected among as principal drivers along the road to zero. The results of the two breakout groups were briefed to the full group of attendees, and the following COAs emerged from the resulting discussion:[9]

- Use advanced data systems and analytics (archival and real-time)
- Employ a Safe System[10] approach
- Leverage innovation (in technology and process)
- Optimize things that work (interventions)
- Develop a strong safety culture.

Second Workshop: Envisioning a Credible Zero-Death Future

The second workshop was held March 13–15, 2017, with approximately 30 participants. The second workshop agenda is shown in Appendix C. This workshop focused on a detailed vision of the Third Horizon (i.e., 2050 at the end of the RTZ) and its contrast with the current time (First Horizon). The goal was to provide a solid footing to the emerging vision by developing a rich understanding of what systems and forces make it sustainable in the future. Breakout groups considered questions such as how policy, technological innovation, and societal conditions could work together coherently to enable the RTZ. They discussed societal conditions that sustain the current level of roadway deaths and considered actions, events, and trends that might effect a change in these conditions. This resulted in a vision of the world of 2050 with the following measurable outcomes deemed necessary to reach zero roadway deaths:

- All passengers are belted or otherwise restrained.
- No impaired drivers making critical decisions.
- No vehicle leaves the road.
- No crashes occur between vehicles occur at lethal force.
- No vehicle hits a vulnerable road user at lethal force.
- No post-event preventable deaths occur on the roadways and adjacent areas.

To achieve these outcomes, the workshop participants considered how the transportation system of 2050 could embody tangible safety improvements in its key system components: vehicle technologies, road design and technologies, road user behavior, emergency response and trauma care, and mobility alternatives.

Third Workshop: From Vision to Action: Mapping the Road to Zero

The third and final workshop was held across the three days of May 17–19, 2017, with largely the same attendees as at the second workshop. The third workshop agenda is shown in Appen-

---

8 This was one of several adjustments to the ideal 3HF paradigm to accommodate the needs of the project. In this case, this discussion was deemed to be important to provide a more seamless transition into the project's vision and scenario process from previous activities conducted in several prior forums.

9 Each of these COAs was accompanied with detailed actions, potential impact, assumptions, and trade-offs.

10 See the "Principles of a Safe System" text box in Chapter One.

dix D. This workshop was again organized around breakout groups. We assigned participants to specific groups to ensure multiple viewpoints in each group. We asked them to consider each of the five COAs listed above, and to focus the discussion on what must change to achieve the objectives of the COAs and how that could be accomplished, taking into account key stakeholders, their level of interest, the power that they wield, and their fears and concerns. The breakout groups considered critical steps and their timelines to achieve the changes envisioned in the COAs and developed 30-year narratives resulting in zero roadway deaths. These narratives were briefed to the full group of participants, discussed and debated, and then the full group of participants considered scenarios that integrated aspects of each of the breakout group narratives. This final discussion led to the description of the RTZ in terms of the three aspects around which the narrative of this report is based:

- Double Down on What Works
- Accelerate Advanced Technology
- Prioritize Safety.

APPENDIX B

Agenda for First Framing Workshop, January 26–27, 2017

Day 1

8:30–8:35 am	Workshop Introduction by Debbie Hersman
8:35–8:45 am	RAND describes workshop organization and objective
8:45–10:15 am	Keynote speakers (30 minutes each on potential effect on traffic fatalities, on a 30 year time frame, of Automated Vehicles, Infrastructure Connectivity, Enhanced Emergency Medical Response)
10:15–10:30 am	Break
10:30 am–12:15 pm	Two breakout sessions with identical agendas Topics are vehicles, infrastructure, and emergency medical response • Propose and discuss actions to reduce traffic fatalities • How will they be implemented? What are the obstacles they will face? • What will be the impact if successful? What do they enable, prevent? • What are the uncertainties and possible unintended consequences?
12:15–1:15 pm	Lunch on your own
1:15–3:00 pm	Continued breakout sessions with identical agendas Topics are drivers and passengers, vulnerable users, safety management (same topics as above bullets)
3:00–3:15 pm	Break

3:15–5:00 pm	Continued breakout sessions with identical agendas
	Integration of proposed actions from previous sessions
	• How do the proposed actions relate to each other?
	• Where are the synergies and conflicts?
	• What can/should different stakeholders do?
	  ○ How difficult?
	  ○ Why?
	• What are possible integrated courses of action (COAs)?
	• What are the tradeoffs and uncertainties for COAs?
	• Develop briefing for full group meeting on Day 2.
	• Decide on presenter of the group's results.

Day 2

8:30–10:20 am	Presentation of Day 1 results to full group of participants Each breakout group has 25 minutes to present, with 30 minutes for discussion
10:20–10:30 am	Break

10:30 am–Noon	Integrative discussion of breakout group findings
	• Areas of Consensus
	• Areas of Disagreement
	• Most Promising COAs
	    ○ Potential impact
	    ○ Trade-offs
	• Uncertainties

Noon–1:00 pm	Working Lunch
1:00–2:30 pm	Concluding Session: Characterizing the Road to Zero Discussion of Most Promising COAs • Stakeholder Roles • Potential Areas of Conflict • Strategies for Resolving Conflicts • Tradeoffs and Uncertainties

Workshop held at U.S. Department of Transportation, 1200 New Jersey Ave. SE, Washington, D.C.

APPENDIX C

Agenda for Second Workshop: Scenario Development, March 13–15, 2017

Day 1: Development of the Third Horizon (2047) Visions

9:00–9:30 am	Welcome by Debbie Hersman and Jeff Michael
9:30–10:00 am	RAND in-brief on Workshop Plan and Today's Assignment
10:00–10:30 am	Keynote address on Vision Zero (Matts Belin)
10:30–10:45 am	Break
10:45 am–Noon	Two breakout sessions with identical agendas

Technological components of the Third Horizon (2047) Vision

- What technological innovations in vehicle, infrastructure, and emergency medical response can be envisioned in 2047?
- How would these innovations affect the traffic fatality situation in 2047?
- How would societal conditions (e.g., economic, political, social, cultural) in 2047 support and sustain this situation?

Noon–1:00 pm	Lunch on your own
1:00–2:45 pm	Continued breakouts—Policy components of the Third Horizon (2047) Vision

- What new transportation system policies can be envisioned in 2047?
  - To leverage technological innovations
  - To modify user behavior
  - To affect system design and management
  - To promote Safe System approaches
  - To promote a safety culture
- How would these policies affect the traffic fatality situation in 2047?
- How would societal conditions (e.g., economic, political, social, cultural) in 2047 support and sustain these policies?

2:45–3:00 pm	Break
3:00–4:00 pm	Continued breakouts—Integrated view of the Third Horizon (2047) Vision

- How do policy, technological innovation, and societal conditions work together coherently to enable the Road to Zero?

4:00 pm	Adjourn Day 1

Day 2: Completion of Third Horizon (2047) Visions

9:00–9:30 am	RAND in-brief on Where We Are and Today's Assignment (Full Group)
9:30–10:30 am	Two breakout sessions with identical agendas Contrast between Third Horizon (2047) Vision and current (2017) First Horizon • What societal conditions (e.g., economic, political, social, cultural) in 2017 sustain the current traffic fatality situation? • What actions, events, trends might effect a change in these conditions?
10:30–10:45 am	Break
10:45 am–12:30 pm	Continued breakouts on contrast between Third Horizon (2047) Vision and current (2017) First Horizon • What societal conditions (e.g., economic, political, social, cultural) in 2017 sustain the current traffic fatality situation? • What actions, events, trends might effect a change in these conditions?
12:30–2:00 pm	Lunch on your own
2:00–4:00 pm	Final breakout sessions • Prepare summary of contrasts to present to Full Group ○ Technology/policy area ○ Societal conditions ○ Actions, events, trends for change
4:00 pm	Adjourn Day 2

Day 3: Integration of Third Horizon Visions (Full Group)

9:00–9:15 am	RAND in-brief on Where We Are and Today's Assignment

9:15–10:15 am	Breakout group presentations to full group of participants
	• Contrast between Third Horizon (2047) Vision and current (2017) First Horizon
	  ○ What societal conditions sustain the current situation?
	  ○ What actions, events, trends might effect change?
	Each breakout group has 15 minutes to present, with 15 minutes for discussion

10:15–11:45	Integrative discussion of breakout group reports
	• Similarities and differences in Third Horizon Visions
	• Contrast with current First Horizon
	  ○ Societal conditions
	  ○ Actions, events, trends for change

11:45–12:45 pm	Working Lunch

12:45–1:45 pm	Workshop summary and plans for final scenario workshop
	• Review Courses of Action (COAs) from January workshop
	  ○ Are they sufficiently broad?
	  ○ Do they reflect insights from the past 3 days?
	• Plan for next workshop

1:45–2:00 pm	Thank you and Goodbye (Debbie Hersman and Jeff Michael)
2:00 pm	Adjourn Day 3

Workshop held at RAND Corporation, 1200 S. Hayes Street, Arlington, Va.

APPENDIX D

Agenda for Third Workshop: Second Horizon, May 17–19, 2017

Day 1: Scenario Development

9:00–9:05 am — Welcome by Debbie Hersman

9:05–9:30 am — Discussion of RTZ Report Schedule, Jeff Michael, and Jane Terry

9:30–10:00 am — RAND In-brief on Workshop Plan and today's assignment

10:00 am–Noon — Five breakout groups, each working with an assigned Course of Action (COA)

- What must change to achieve the 2050 zero traffic fatality vision?
- Who are the principal stakeholders affected by or carrying out these changes?
  - What is their attitude toward the changes?
  - What is their level of interest?
  - What power do they wield?
  - What are their fears and concerns?

Noon–1:00 pm — Lunch on your own

1:00–2:45 pm — Continuation of the five COA breakout groups

- What are the critical steps that must occur in order to achieve the envisioned change by pursuing this COA?
  - How do they support each other?
- What are the key assumptions enabling this success?
- What are the core conflicts that must be resolved?
- How may these conflicts be resolved and what is the result?
- What critical events would benchmark change and when do they happen?

2:45–3:00 pm — Break

3:00–4:00 pm — Final session of the five COA breakout groups

- Using prior discussion, develop a 30-year narrative that details stakeholders and critical steps, explaining how the zero traffic fatality vision was achieved. Consider effects on vehicles, infrastructure, system design and management, users, and emergency medical response and trauma care.

4:00 pm — Adjourn Day 1

Day 2: Scenario Analysis

9:00–9:15 am	RAND In-brief on prior day's session and today's assignment
9:15–10:30 am	Presentation and discussion of the COA breakout group narratives • Breakout narrative presentation ○ Stakeholders ○ Critical steps ○ Assumptions • Initial group Q&A
10:30–10:45 am	Break
10:45 am–Noon	Continue presentation and discussion of the COA breakout group narratives 3–5 • Breakout narrative presentation ○ Stakeholders ○ Critical steps ○ Assumptions • Initial group Q&A
Noon–1:00 pm	Lunch on your own
1:00–2:30 pm	Analysis of critical events from COA breakout group narratives • Review of key assumptions • Plausibility and timing of the critical steps • Stakeholder actions/reactions • Alternative scenarios and outcomes
2:30–2:45 pm	Break
2:45–4:00 pm	Continue analysis of critical events from COA breakout group narratives • Review of key assumptions • Plausibility and timing of the critical steps • Stakeholder actions/reactions • Alternative scenarios and outcomes
4:00 pm	Adjourn Day 2

Day 3: Scenario Integration

9:00–9:15 am	RAND In-brief on prior day's session and today's assignment

9:15–10:15 am	Integration of the COA breakout group narratives
	• Early Second Horizon (2017–20??): *"Laying Groundwork"*
	  ○ Critical steps and stakeholder actions
	  ○ Core conflicts and how they are resolved
	  ○ Important signposts (e.g., events, situations, results that provide signals providing information on the actual path, toward or away from the Road to Zero scenario)
	  ○ Shaping and hedging actions (i.e., actions to shape the scenario path toward the Road to Zero or to hedge against events or situations that might block or detour path toward Road to Zero)

10:15–10:45 am	Break

10:45–11:45 am	Continue integration of the COA breakout group narratives
	• Middle Second Horizon (20??–20??) *"Heavy Lifting"*
	  ○ Critical steps and stakeholder actions
	  ○ Core conflicts and how they are resolved
	  ○ Important signposts
	  ○ Shaping and hedging actions

11:45–12:30 pm	Working Lunch

12:30–1:45 pm	Continue integration of the COA breakout group narratives
	• Late Second Horizon (20??–2050) *"Sustaining Accelerating Change"*
	  ○ Critical steps and stakeholder actions
	  ○ Core conflicts and how they are resolved
	  ○ Important signposts
	  ○ Shaping and hedging actions

1:45–2:30 pm	Discussion of next steps
	Thank you and goodbye (Debbie Hersman and Jeff Michael)
2:30 pm	Adjourn Day 3

Workshop held at Hall of the States Building, 444 North Capitol Street NW, Washington, D.C.

APPENDIX E

Participants in the Three Workshops

The people listed below participated in one or more of the three workshops.

Table E.1
Participants in the Three Worksops

Name	Organization
Debra Alvarez	AARP
Jackie Gillan	Advocates for Highway Safety
Allison Kennedy	Advocates for Highway Safety
Kristin Kingsley	Alliance of Auto Manufacturers
Rob Strassburger	Alliance of Auto Manufacturers
King Gee	American Association of State Highway and Transportation Officials
Ian Grossman	American Association of Motor Vehicle Administrators
Kelly Hardy	American Association of State Highway and Transportation Officials
Jill Ingrassia	American Automobile Association
Jennifer Ryan	American Automobile Association
Judge Earl Penrod	American Bar Association/NHTSA judicial fellow
Brandon Buchanan	American Bus Association
Andrea Eales	American Public Works Association
Bradley Sant	American Road and Transportation Builders Association
Roger Wentz	American Traffic Safety Services Association
Mike Cammisa	American Trucking Associations
Abigail Potter	American Trucking Associations
Marianne Karth	AnnaLeahMarie.com
Nathan George	Association of Pedestrian and Bicycle Professionals
Erin Sauber-Schatz	Centers for Disease Control and Prevention, National Center for Injury Prevention and Control
Stephanie Pratt	Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health
Adrienne Gildea	Commercial Vehicle Safety Alliance
Jack Gillis	Consumer Federation of America
Jackie McCarthy	CTIA
Jonathan Rogers	DC Department of Transportation

Name	Organization
Sandeep Punater	Delphi
Joel Feldman	End Distracted Driving
Beth Alicandri	Federal Highway Administration
Dana Gigliotti	Federal Highway Administration
Mike Griffith	Federal Highway Administration
Earl Hardy	Federal Motor Carriers Safety Administration
Quon Kwan	Federal Motor Carriers Safety Administration
Jeff Loftus	Federal Motor Carriers Safety Administration
Jack Van Steenburg	Federal Motor Carriers Safety Administration
Natalie Draisin	FIA Foundation
Brandy Nannini	Foundation for Advancing Alcohol Responsibility
John Bozzella	Global Automakers
Steve Gehring	Global Automakers
Paul Scullion	Global Automakers
Jonathan Adkins	Governors Highway Safety Association
Russ Martin	Governors Highway Safety Association
Ron Medford	Google/Waymo
Jeff Lindley	Institute of Transportation Engineers
Jeff Paniati	Institute of Transportation Engineers
Jessica Cicchino	Insurance Institute for Highway Safety
Catherine McCullough	Intelligent Car Coalition
Michael Fergus	International Association of Chiefs of Police
Domingo Herraiz	International Association of Chiefs of Police
Jennifer Rolfe	International Association of Chiefs of Police
Dr. Shannon Frattaroli	Johns Hopkins Center for Injury Research
Dr. Andrea Gielen	Johns Hopkins Center for Injury Research
Dr. Vanya Jones	Johns Hopkins Center for Injury Research
Janette Fennell	KidsAndCars.org
Lauren Belive	Lyft
John Leonard	Massachusetts Institute of Technology
Debbie Weir	Mothers Against Drunk Driving (MADD)
Gene Gurevich	Mobileye
Catherine Boland	Motor and Equipment Manufacturers Association
David Mendelsohn	Motor and Equipment Manufacturers Association
Tim Buche	Motorcycle Safety Foundation
Kathy Van Kleeck	Motorcycle Safety Foundation
Mark Neil	National Association of Attorneys General
Linda Bailey	National Association of City Transportation Officials

Name	Organization
Brian Roberts	National Association of County Engineers
Dia Gainor	National Association of State EMS Officials
Kim Brown	National District Attorneys Association
Kalyn Hill	National Governors Association
Ruth Esteban-Muir	National Highway Traffic Safety Administration
Robert Heilman	National Highway Traffic Safety Administration
Susan Kirinich	National Highway Traffic Safety Administration
Jeff Michael	National Highway Traffic Safety Administration
Essie Wagner	National Highway Traffic Safety Administration
Krista Mizenko	National Highway Traffic Safety Administration, Association of Schools and Programs of Public Health fellow
Ken Kolosh	National Safety Council
Susan Crotty	National Safety Council
Debbie Hersman	National Safety Council
Julian Hoffman	National Safety Council
Kelly Nantel	National Safety Council
Alex Taira	National Safety Council
Jane Terry	National Safety Council
Stephanie Shaw	National Transportation Safety Board
Marjory Blumenthal	RAND Corporation
Liisa Ecola	RAND Corporation
Laura Fraade-Blanar	RAND Corporation
Steven Popper	RAND Corporation
Rich Siberglitt	RAND Corporation
Peter Kissinger	Roadway Safety Foundation
Amitai Y. Bin-Nun	Securing America’s Future Energy
Dan Petterson	Skilled Motorcyclist Association—Responsible, Trained and Educated Riders (SMARTER)
Skip Yeakel	Society of Automotive Engineers
John Lannen	Truck Safety Coalition
Lindsay Elin	Uber
Ken Presley	Upper Merion Area Community Alliance for a Safer Tomorrow
David Harkey	University of North Carolina–Chapel Hill Highway Research Center
Leah Shahum	Vision Zero Network

References

Adams, Eric, "Honda's Self-Balancing Motorcycle Is Perfect for Noobs," *Wired*, January 6, 2017. As of March 9, 2018:
https://www.wired.com/2017/01/hondas-self-balancing-motorcycle-perfect-noobs/

American Trauma Society, "Trauma Center Levels Explained," webpage, no date. As of March 15, 2018:
http://www.amtrauma.org/?page=TraumaLevels

Auto Alliance, *Levels of Automation*, no date. As of February 5, 2018:
https://autoalliance.org/wp-content/uploads/2017/07/Automated-Vehicles-Levels-of-Automation.pdf

Belin, Matts-Åke, Vision Zero slides, 2016.

Belin, Matts-Åke, Per Tillgren, and Evert Vedung, "Vision Zero: A Road Safety Policy Innovation," *International Journal of Injury Control and Safety Promotion,* Vol. 19, No. 2, 2012, pp. 171–179.

Berwick, Donald, Autumn Downey, and Elizabeth Cornett, eds., *A National Trauma Care System: Integrating Military and Civilian Trauma Systems to Achieve Zero Preventable Deaths After Injury*, Washington, D.C.: National Academies Press, 2016.

Blincoe, Lawrence, Ted R. Miller, Eduard Zaloshnja, and Bruce A. Lawrence, *The Economic and Societal Impact of Motor Vehicle Crashes, 2010 (Revised),* Washington, D.C.: National Highway Traffic Safety Administration, DOT HS 812 013, May 2015.

Brown, Joshua B., Matthew R. Rosengart, Timothy R. Billiar, Andrew B. Peitzman, and Jason L. Sperry, "Distance Matters: Effect of Geographic Trauma System Resource Organization on Fatal Motor Vehicle Collisions," *Journal of Trauma and Acute Care Surgery*, Vol. 83, No. 1, 2017, pp. 111–118.

Bureau of Transportation Statistics, "National Transportation Statistics," 2017. As of November 7, 2017:
https://www.bts.gov/topics/national-transportation-statistics

Cambridge Systematics, Inc., *Crashes vs. Congestion: What's the Cost to Society?* American Automobile Association, November 2011. As of March 9, 2018:
http://newsroom.aaa.com/wp-content/uploads/2011/11/2011_AAA_CrashvCongUpd.pdf

Centers for Disease Control and Prevention, "Motor Vehicle Crash Deaths: How Is the US Doing?" *CDC Vital Signs*, July, 2016. As of March 9, 2018:
https://www.cdc.gov/vitalsigns/pdf/2016-07-vitalsigns.pdf

———, "Web-Based Injury Statistics Query and Reporting System," online data set, 2017. As of March 9, 2018:
https://www.cdc.gov/injury/wisqars/index.html

Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, "10 Leading Causes of Death by Age Group, United States—2015," Washington, D.C., no date (a). As of February 5, 2018:
https://www.cdc.gov/injury/wisqars/pdf/leading_causes_of_death_by_age_group_2015-a.pdf

———, "10 Leading Causes of Injury Deaths by Age Group Highlighting Unintentional Injury Deaths, United States—2015," Washington, D.C., no date (b). As of February 5, 2018:
https://www.cdc.gov/injury/wisqars/pdf/leading_causes_of_injury_deaths_highlighting_unintentional_injury_2015-a.pdf

———, "Ten Leading Causes of Death and Injury," Washington, D.C., 2017. As of March 9, 2018:
https://www.cdc.gov/injury/wisqars/LeadingCauses.html

Colby, Sandra L., and Jennifer M. Ortman, *Projections of the Size and Composition of the U.S. Population: 2014 to 2060*, Washington, D.C.: Census Bureau, P25-1143, March 2015. As of March 9, 2018: https://www.census.gov/content/dam/Census/library/publications/2015/demo/p25-1143.pdf

Curry, Andrew, and Anthony Hodgson, "Seeing in Multiple Horizons: Connecting Futures to Strategy," *Journal of Futures Studies*, Vol. 13, No. 1, 2008.

Dang, Jennifer N., *Statistical Analysis of Alcohol-Related Driving Trends, 1982–2005,* Washington, D.C.: National Highway Traffic Safety Administration, DOT-HS-810-942, May 2008.

Dewar, James A., *Assumption Based Planning*, Oxford University Press, 2002.

Disley, Emma, Chris Giacomantonio, Kristy Kruithof, and Megan Sim, *The Payment by Results Social Impact Bond Pilot at HMP Peterborough: Final Process Evaluation Report,* London: United Kingdom Ministry of Justice, 2015. As of March 9, 2018: https://www.gov.uk/government/publications/social-impact-bond-pilot-at-hmp-peterborough-final-report

Driver Alcohol Detection System for Safety, website. no date. As of March 24, 2018: https://www.dadss.org/

EMS1.com, "FirstNet, AT&T Advance Nationwide Broadband Network for Public Safety," June 20, 2017. As of February 5, 2018: https://www.ems1.com/ems-products/communications/articles/277451048-FirstNet-AT-T-advance-nationwide-broadband-network-for-public-safety/

Federal Communications Commission, *April 2014 Multistate 911 Outage Report: Cause and Impact*, Public Safety Docket No. 14-72; PSHSB Case File Nos. 14-CCR-0001-0007, Washington, D.C., October 2014. As of March 9, 2018: https://www.fcc.gov/document/april-2014-multistate-911-outage-report

Federal Highway Administration, "December 2016 Traffic Volume Trends," 2016. As of March 9, 2018: https://www.fhwa.dot.gov/policyinformation/travel_monitoring/16dectvt/

Federal Motor Carrier Safety Administration, *Large Truck and Bus Crash Facts 2015*, Washington, D.C., 2017. As of March 9, 2018: https://www.fmcsa.dot.gov/safety/data-and-statistics/large-truck-and-bus-crash-facts-2015#A4

Fell, James C., and Robert B. Voas, "Utah Is First State in the United States to Set a .05 BAC Limit for Driving," *Forensic Science Review*, Vol. 29, No. 1, January 2017, pp. 96–97.

Georgiou, Luc, Jennifer Cassingena Harper, Michael Keenan, Ian Miles, Rafael Popper, et al., eds., *The Handbook of Technology Foresight,* Cheltenham, UK: Edward Elgar, 2008.

Hedlund, J. H., R. G. Ulmer, and D. F. Preusser, *Determine Why There Are Fewer Young Alcohol-Impaired Drivers*, Washington, D.C.: National Highway Traffic Safety Administration, DOT HS 809 348, 2001. As of March 9, 2018: https://rosap.ntl.bts.gov/view/dot/1700

Highway Loss Data Institute, "Predicted Availability of Safety Features on Registered Vehicles—A 2016 Update," *HLDI Bulletin*, Vol. 33, No. 15, September 2016.

Howden, Lindsay M., and Julie A. Meyer, *Age and Sex Composition: 2010*, Washington, D.C.: U.S. Census Bureau, 2010 Census Briefs, C2010BR093, May 2011.

Insurance Institute for Highway Safety, "Alcohol-Detection Device Project Is Now in Development Phase," *Status Report,* Vol. 46, No. 10, November 11, 2011. As of March 9, 2018: http://www.iihs.org/iihs/sr/statusreport/article/46/10/4

———, "Motor Vehicle Crash Deaths per 100,000 People by Type, 1975–2016," December 2017a. As of March 9, 2018: http://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/overview-of-fatality-facts

———, "Teenagers: Driving Carries Extra Risk for Them," December 2017b. As of March 9, 2018: http://www.iihs.org/iihs/topics/t/teenagers/fatalityfacts/teenagers#Population-and-mileage-rates

Jackson, Molly, "Volvo's 2020 Pledge: No One Will Die in Our Cars," *Christian Science Monitor*, January 21, 2016.

Kahane, Charles J., *Lives Saved by Vehicle Safety Technologies and Associated Federal Motor Vehicle Safety Standards, 1960 to 2012: Passenger Cars and LTVs,* Washington, D.C.: National Highway Traffic Safety Administration, DOT HS 812 069, January 2015. As of March 9, 2018:
https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812069

———, *Comparison of 2013 VMT Fatality Rates in U.S. States and in High-Income Countries*, Washington, D.C.: National Highway Traffic Safety Administration, DOT HS 812 340, October 2016. As of March 9, 2018:
https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812340

Lord, Nate, "The History of Data Breaches," *Digital Guardian*, July 27, 2017. As of March 9, 2018:
https://digitalguardian.com/blog/history-data-breaches

McCutcheon, Chuck, "Connecting the Sectors: How Transit Is Looping in TNCs to Plan Integrated Transportation Networks," *Passenger Transport*, Vol. 74, No. 4, February 22, 2016, pp. 1, 6–8. As of March 9, 2018:
http://www.apta.com/passengertransport/PublishingImages/PT_02-22-16_Connecting%20the%20Sectors_Part%20II_in-depth_integrated%20mobility_McCutcheon.pdf

Minnesota Department of Transportation, "Reduced Conflict Intersections," webpage, no date. As of March 15, 2018: http://www.dot.state.mn.us/roadwork/rci/

Mosquet, Xavier, Michelle Andersen, and Aakash Arora, *A Roadmap to Safer Driving Through Advanced Driver Assistance Systems*, Motor & Equipment Manufacturers Association, 2015.

My Car Does What? website, no date. As of March 24, 2018:
https://mycardoeswhat.org/

National Highway Traffic Safety Administration, Fatality Analysis Reporting System (FARS) database, no date. As of March 9, 2018:
https://www-fars.nhtsa.dot.gov/Main/index.aspx

———, *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey*, Washington, D.C., DOT HS 812 115, February 2015. As of March 9, 2018:
https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115

———, *Lives Saved in 2015 by Restraint Use and Minimum Drinking Age Laws*, Washington, D.C., DOT HS 812 319, August 2016a. As of March 9, 2018:
https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812319

———, *Seat Belt Use in 2016: Overall Results*, Washington, D.C., DOT HS 812 351, November 2016b. As of March 9, 2018:
https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812351

———, *Pedestrians*, Washington, D.C., DOT HS 812 375, February 2017a. As of March 9, 2018:
https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812375

———, *Rural/Urban Comparison of Traffic Fatalities*, Washington, D.C., April 2017b. As of March 9, 2018:
https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812393

———, *2016 Fatal Motor Vehicle Crashes: Overview*, Washington, D.C., DOT HS 812 456, October 2017c. As of October 11, 2017:
https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812456

———, *Early Estimate of Motor Vehicle Traffic Fatalities for the First Quarter of 2017*, Washington, D.C., DOT HS 812 436, December 2017d. As of March 9, 2018:
https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812436

National Institute on Alcohol Abuse and Alcoholism, "Fact Sheet: Alcohol-Related Traffic Deaths," October 2010. As of March 9, 2018:
https://report.nih.gov/nihfactsheets/ViewFactSheet.aspx?csid=24

New York City Vision Zero Task Force, *Vision Zero Year Three Report,* February 2017. As of March 15, 2018:
http://www1.nyc.gov/assets/visionzero/downloads/pdf/vision-zero-year-3-report.pdf

Nichols, James L., and Katherine A. Ledingham, *The Impact of Legislation, Enforcement, and Sanctions on Safety Belt Use*, Washington, D.C.: Transportation Research Board, NCHRP Report 601, 2008.

Popper, Rafael, "Foresight Methodology," in Luc Georgiou et al., eds., *The Handbook of Technology Foresight*, Cheltenham, UK: Edward Elgar, 2008.

Public Law 119-94, Fixing America's Surface Transportation (FAST) Act, December 4, 2015.

Reason, James, "Human Error: Models and Management," *The BMJ*, Vol. 320, No. 7237, 2000, pp. 768–770. As of March 9, 2018:
http://www.bmj.com/content/bmj/320/7237/768.full.pdf

Rosén, Erik, and Ulrich Sander, "Pedestrian Fatality Risk as a Function of Car Impact Speed," *Accident Analysis and Prevention,* Vol. 41, No. 3, 2009, pp. 536–542.

Sasser, Scott M., Richard C. Hunt, Mark Faul, David Sugerman, William S. Pearson, Theresa Dulski, Marlena M. Wald, Gregory J. Jurkovich, Craig D. Newgard, E. Brooke Lerner, Arthur Cooper, Stewart C. Wang, Mark C. Henry, Jeffrey P. Salomone, and Robert L. Galli, "Guidelines for Field Triage of Injured Patients: Recommendations of the National Expert Panel on Field Triage, 2011," *Morbidity and Mortality Weekly Report*, Vol. 61, No. 1, January 13, 2012.

Seppa, Nathan, "Impactful Distraction," *Science News,* Vol. 184, No. 4, August 24, 2013.

Tefft, Brian C., *Prevalence of Motor Vehicle Crashes Involving Drowsy Drivers, United States, 2009–2013,* AAA Foundation for Traffic Safety, November 2014. As of March 9, 2018:
https://aaafoundation.org/wp-content/uploads/2017/12/PrevalenceofMVCDrowsyDriversReport.pdf

Torbic, D. J., J. M. Hutton, C. D. Bokenkroger, K. M. Bauer, D. W. Harwood, D. K. Gilmore, J. M. Dunn, J. J. Ronchetto, E. T. Donnell, H. J. Sommer III, P. Garvey, B. Persaud, and C. Lyon, *Guidance for the Design and Application of Shoulder and Centerline Rumble Strips,* Washington, D.C.: National Academy of Sciences, NCHRP Report 641, 2009.

Toward Zero Deaths Steering Committee, *Toward Zero Deaths: A National Strategy on Highway Safety*, 2014. As of March 9, 2018:
http://www.towardzerodeaths.org/wp-content/uploads/TZD_Strategy_12_1_2014.pdf

Transport and Infrastructure Senior Officials' Committee (Australia), *National Road Safety Strategy 2011–2020: Implementation Status Report*, Canberra, November 2016.

Transport Canada, "Canadian Motor Vehicle Traffic Collision Statistics: 2015," 2017. As of March 9, 2018:
https://www.tc.gc.ca/media/documents/roadsafety/Canadian_Motor_Vehicle_Traffic_Collision_Statistics_2015-EN.pdf

U.S. Burden of Disease Collaborators, "The State of U.S. Health, 1990–2010: Burden of Diseases, Injuries, and Risk Factors," *JAMA*, Vol. 310, No. 6, 2013, pp. 591–606.

U.S. Census Bureau, *Census Bureau Projects U.S. and World Populations on New Year's Day*, Release Number: CB16-TPS.158, Washington, D.C., December 28, 2016. As of March 9, 2018:
https://www.census.gov/newsroom/press-releases/2016/cb16-tps158.html

Williams, A. F., J. K. Wells, and C. M. Farmer, "Effectiveness of Ford's Belt Reminder System in Increasing Seat Belt Use," *Injury Prevention*, Vol. 8, No. 4, 2002, pp. 293–296.

Woodyard, Chris, "Automatic Emergency Braking Coming to 99% of Cars by 2022," *USA Today*, March 17, 2016.

World Health Organization, "Road Traffic Deaths, Data by Country," 2017. As of March 9, 2018:
http://apps.who.int/gho/data/node.main.A997

Zou, Y., A. P. Tarko, E. Chen, and M. Romero, "Effectiveness of Cable Barriers, Guardrails, and Concrete Barrier Walls in Reducing the Risk of Injury," *Accident Analysis and Prevention,* Vol. 72, November 2014, pp. 55–65.