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Perspective

The Future of Road Safety: Challenges and Opportunities

JOHNATHON P. EHSANI, JEFFREY P. MICHAEL, and ELLEN J. MACKENZIE

Johns Hopkins Bloomberg School of Public Health

Policy Points:

- Traditional approaches to addressing motor vehicle crashes are yielding diminishing returns. A comprehensive strategy known as the Safe Systems approach shows promise in both advancing safety and equity and reducing motor vehicle crashes.
- In addition, a range of emerging technologies, enabled by artificial intelligence, such as automated vehicles, impairment detection and telematics hold promise to advance road safety.
- Ultimately, the transportation system will need to evolve to provide the safe, efficient, and equitable movement of people and goods without reliance on private vehicle ownership, towards encouraging walking, bicycling and the use of public transportation.

Keywords: unintentional injury, road safety, Safe Systems.

As Elizabeth Milbank Anderson was establishing the foundation for the Milbank Memorial Fund in the beginning of the twentieth century, Henry Ford was refining the design of the Model T Ford, an invention which would revolutionize personal transportation in the United States.[1,2] In the century that has followed,

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the *Milbank Quarterly* has been at the forefront of brokering practical knowledge to decision makers about health policy for protecting and enhancing the health of populations. The relevance of the publication's mission to the prevention of motor vehicle crashes injuries, which is a leading cause of death and disability in the United States and globally, remains pressing.[3]

Injuries persist as a leading cause of death worldwide. Globally, intentional and unintentional injuries are responsible for approximately 4.4 million deaths annually, eclipsing the number of deaths caused by HIV, TB, and malaria combined.[4] Motor vehicle crashes are responsible for 1.35 million injury deaths each year worldwide and are the leading cause of death for those aged 5–29 years. Crash victims are overwhelmingly male, with three quarters (73%) of all road deaths occurring among young males under the age of 25 years .[5]

Crash deaths and injuries disproportionately burden low- and middle-income countries. More than 90% of road deaths occur in these nations, despite their accounting for about 60% of the world's vehicles.[6] More than half of global road deaths are among vulnerable road users, which include pedestrians, cyclists, and motorcyclists. An additional 20 to 50 million people suffer nonfatal injuries, with many incurring a lifelong disability as a result of their injury.[5]

The scale of the problem at a population level is vast, yet, road deaths present a paradox: each crash is experienced as an individual, isolated event. The systemic causes of crashes are often overlooked or ignored, and a narrative is constructed around the unique circumstances surrounding each crash. Victims and their families often suffer alone, and the actual scale of the burden is difficult to appreciate. Economic analyses estimate the cost of crashes to be equivalent to 3% of Gross Domestic Product for most countries,[5] but the true toll of the physical and psychological burden to individuals, families, communities, and society is unfathomable.

In the United States, road safety is also a pressing public health concern. In 2019, the population-based motor vehicle crash death rate in the United States (11.1 per 100,000 population) was the highest among 29 high-income countries.[7] Unlike almost every other high-income country which experienced a dramatic reduction in crashes during the pandemic, the United States experienced consecutive years of crash death increases in 2020 and 2021 despite reductions in the amount of driving due to the COVID-19 pandemic. In 2021, an estimated 42,915 people died in crashes on US roads.[8]

In the United States, traffic deaths disproportionately affect some population groups. An examination of national crash data between 2015 and 2019 revealed that the population-based rate of traffic deaths was more than twice as high among American Indians/Alaska Natives than for the overall population and that Black people were close to 20% more likely to die in a crash than the national average.[9] Other studies have found similar disparities across education and income groups.[10] Substantial urbanicity differences are also reported with rural areas experiencing mileage-adjusted fatality rates about 1.7 times those in urban areas.[11] Historically, the number of crash deaths in rural areas are higher than urban areas; however, between 2010 and 2019, motor vehicle crash fatalities in urban areas increased by 34%, while those in rural areas decreased by 10%. Consequently, in 2019, traffic fatalities in urban areas were higher than in rural areas.[12] Within urban areas, the metropolitan areas within the southern half of the country are overrepresented in crash deaths.[13]

The recent rise in crashes in the United States is undermining decades of progress. In 1999, the Centers for Disease Control and Prevention (CDC) highlighted the steady reduction of motor vehicle crashes as one of the defining public health achievements of the 20th century.[14] A decade later, the director of the CDC declared that motor vehicle crashes were a winnable battle.[15] While a considerable body of evidence for effective interventions has been accumulated—including safer infrastructure design, improvements in vehicle safety, enhancements in care for crash victims, effective laws coupled with enforcement, and increased public awareness—challenges still remain.

The purpose of this paper is to provide an analytic review of the history of road safety in the United States and provide a critical examination of shortcomings associated with conventional approaches. We then present a comprehensive strategy known as the Safe Systems approach which shows promise to advance both road safety and equity. We also discuss challenges and opportunities related to emerging issues such as vehicle automation.

Past Gains and Successes

In the United States, the public health burden of motor vehicle crashes was largely neglected until the 1960s and 1970s when Dr. William Had-

don, a public health physician and the first Administrator of the National Highway Traffic Safety Administration (NHTSA), the lead federal government agency charged with the prevention of crashes, led a concerted effort to address road safety using a public health approach. With Dr. Haddon's vision, the fledgling field of road safety was advanced through the introduction of new conceptual models, such as the Haddon Matrix which identified pre-crash, crash, and post-crash factors that could prevent injury and the loss of life,[16] and through rigorous epidemiology which quantified the burden of injuries to society.[17] A combination of improvements to vehicles, roads, road user behaviors, and post-crash care succeeded in reducing the motor vehicle fatality rate per mile traveled by nearly three-quarters over the next half-century.

Vehicle Safety Regulations

The vehicle safety regulations advanced by Dr. Haddon were an extremely effective public health intervention, as were later programs that improved safety practices of drivers and other road users. A 2015 NHTSA study that estimated the number of lives saved by regulated vehicle technologies shows how technology and behavior worked together to reduce fatalities. Safety technologies mandated by Federal Motor Vehicle Safety Standards between 1960 and 2012 saved more than 613,000 lives, with more than half of these savings—nearly 330,000 lives—resulting from the introduction of seat belts in the late 1960s.[18] A deliberate behavioral strategy was needed to achieve these seat belt benefits, as seat belt use was less than 20% nationwide before the mid-1980s. The availability of seat belts alone would have had limited effect if it were not for interventions that increased their use to the current 90% level.[19]

Airbags

Among the most effective improvements in vehicle safety in recent decades was the introduction of the air bag.[20] Air bags are inflatable gas-filled cushions designed to deploy almost instantaneously in the event of a crash. They prevent and minimize injuries by slowing the occupant's acceleration into hard surfaces, and by distributing crash forces across more surface area on the body. The federal government required

all new passenger vehicles to be equipped with driver and passenger-side air bags beginning with the 1999 model year. Since 2014, all new vehicles needed to comply with side-impact regulations, and have side airbags as standard equipment.[20] NHTSA estimates that as of 2017, 50,457 lives were saved by frontal airbags.[18]

Road User Behaviors: High-Visibility Law Enforcement

Through the 1970s, efforts to improve road user behavior relied primarily on awareness and education and achieved limited success. Two events changed this trend: the establishment of Mothers Against Drunk Driving (MADD) in 1980 and the nation's first seat belt law in 1985. The victim advocates who founded MADD quickly discovered that their army of volunteers was effective in lobbying for drunk driving laws and started a movement that resulted in the enactment of nearly 250 state laws in a little over a decade, including blood alcohol level laws, repeat offender laws, open container laws, and others. MADD was one of the first examples of grassroots victim advocacy and the organization was credited with making drunk driving one of the country's preeminent social issues in the 1980s.[21]

The first safety belt law—enacted in the State of New York in 1984—changed safety advice into a mandate and resulted in an unprecedented increase in buckling up. When safety advocates saw how much more effective these new laws were than prior public education campaigns, their focus shifted from public service announcements to influencing legislators to pass safety laws, state-by-state.

Within a few years, safety advocates found that when these new restraint use and alcohol impaired driving laws were combined with highly publicized enforcement campaigns, the results were dramatic. Sobriety checkpoints and seat belt checkpoints had been used successfully in a few other countries and inspired US safety organizations to follow suit. The combination of strong laws and aggressive law enforcement became known as "high-visibility law enforcement" and initially generated dramatic results, reducing drunk driving deaths by as much as 20% and increasing seat belt use as much as 20 percentage points in a few weeks.[22,23] The remarkable power of this new method was due to its effect as a general deterrent, affecting behavior in an entire commu-

nity rather than just among those who drove through a checkpoint. The *Click-It or Ticket* seat belt program launched in North Carolina in 1993 showed how high-visibility enforcement could be coordinated across an entire state, producing rapid statewide behavior change.[24]

National attention soon focused on this approach. Federal leadership, along with support from the automotive and insurance industries, further encouraged state and local adoption. In 2000, other states followed the North Carolina example, and in 2002, federal incentive funding was linked to state adoption of the *Click It or Ticket* program, and a coordinated nationwide campaign was launched. The same approach was later extended to other risky driving behaviors such as distracted driving.[25,26] However, in subsequent years, several indicators of state and local implementation began to show declines in high-visibility enforcement program activity due to competing demands on the financial and personnel resources of enforcement agencies, including increased focus on violent crime and other threats to communities.[27]

Child Passenger Safety

Groundbreaking epidemiological research by Susan Baker in the 1970's established that infants and young children were at elevated risk of death in a crash relative to other vehicle occupants.[28] This research coupled with national advocacy efforts led to widespread adoption of state child passenger safety legislation in the United States throughout the 1980s and 1990s.[29] Child restraint systems (CRS) are highly effective in reducing the risk of fatal crash injury among children. Between 1975 and 2017 CRS saved an estimated 11,606 lives.[18] While considerable advances have been made in child restraint use in personal vehicles,[30] motor vehicle crashes remain the leading cause of death for young children and the lack of restraint use has been identified as a key risk factor in fatal crashes involving children.[31]

Post-Crash Care

Since the early 1970s significant reductions in crash deaths were also made possible through advances in a population-based approach to trauma system development.[32,33] When fully operational, trauma systems ensure a continuum of care involving public access through 911

and effective communications systems, out-of-hospital emergency medical services (EMS), timely triage and transport to definitive acute hospital care, and transfer to inpatient and outpatient rehabilitation services.as needed.[34] Core to any trauma system is a network of hospital trauma centers that are prepared to treat injuries across the full spectrum of severity, including an optimal number of level I and II trauma centers that provide comprehensive trauma care to the most severely injured.[35]

Studies of potentially preventable deaths, population-based analyses of administrative data and large prospective cohort studies provide compelling evidence that the risk of dying of moderate to severe injuries is 25% lower for patients treated in level I/II trauma centers compared to non-designated centers.[36–38]

While most states now have enabling legislation that supports a regional approach to trauma care and designation of trauma centers, implementation has been uneven, leading to variations in geographic access to and quality of trauma center care, especially in rural parts of the country.[39,40] In addtition, emergency response times still remain a major determinant of crash survivability.[41] As summarized by the National Academies report, *where* you are injured may determine *whether* you survive.[33] They call for for a national trauma system grounded in sound learning health system principles applied across the continuum of turam care with the goal of achieving zero preventable deaths after injury and minimal trauma -realted disability.

Failures and Continuing Problems

During the 1990s, as new laws and high-visibility enforcement spread across the United States, there were unprecedented increases in seat belt use and reductions in drunk driving. However, concerns about racial profiling in enforcement were raised almost from the outset. These concerns led New Jersey, the second state to pass a seat belt use law, to enact a law that introduced a secondary enforcement provision. Whereas primary enforcement allows law enforcement officers to stop vehicles if a driver or passenger is observed not wearing a seat belt, secondary enforcement seat belt laws require officers to have some other reason for stopping a vehicle before citing a driver or passenger for not using a seat belt.[42] This secondary enforcement approach was subsequently adopted by 39 of the 49 states that enacted seat belt laws.[24] Primary enforcement

laws typically led to higher seat belt use rates than secondary laws. Profiling issues were raised again as many states attempted to upgrade the effectiveness of their seat belt laws by enacting amendments that would allow primary enforcement.[43]

Research evidence of racial bias in seat belt law enforcement is mixed, with some studies that examined the distribution of ticketing, population demographics and use rates finding no evidence of bias.[44,45] Other studies report disproportionate enforcement action according to driver race[46] and a perception by African Americans of increased likelihood of being ticketed for seat belt violations solely due to race.[47] These studies reflect a larger body of research that includes a range of viewpoints on the complex issue of racial profiling, with diverse conclusions drawn from differing sets of measures.

Inequities in Transportation Systems: Enforcement and Roadway Design

A broader view of traffic enforcement—and system design—shows more consistent patterns regarding equity. The Bureau of Justice Statistics reports that Black people are more likely than White or Hispanic individuals to experience a traffic stop.[48] Although most people who have been in a traffic stop report that the stop was legitimate and that police behaved properly, conflict escalates in a portion of stops. Among those who were stopped by police in 2018, more than 5% of Black people reported the threat or use of physical force in their most recent contact with police, about twice the rate reported by White people.[48]

Inequities in the built environment also lead to safety disparities. Communities of color experience higher crash death rates than predominately White areas, and low-income neighborhoods have fatality rates that are 3–4 times higher than those in wealthier areas.[49] These disparities especially affect vulnerable road users, such as people walking and biking, and are related to road designs that do not safely accommodate these road.[50] In many communities that have been traditionally underserved, the design of the road system encourages users to routinely take risks to reach their destinations.[51] For example, wide, high-speed roads that lack safe pedestrian crossing facilities invite walkers and bicyclists to take chances as they dodge traffic to get to the other side of the street.[52]

Potential Solutions: A Different Approach to Safety

An approach to achieving safety through system design known as the Safe System approach is being adopted by a growing number of nations around the world, reducing fatality rates by as much as one-half in some countries.[53] The Safe System approach was first implemented in Sweden and The Netherlands more than 25 years ago. The United States is in early stages of adoption with implementation of the Safe System approach in just a few jurisdictions. The Safe System approach is not a single type of intervention, but rather a comprehensive set of strategies that follow a common set of principles. In this paradigm shift, the focus for safety efforts shifts from, "how can *people* use the transportation system more safely?" to "how can the *system* be made safe for people to use?"

The Safe System approach can improve both safety and equity in the United States. The central goal of a Safe System is zero traffic deaths and serious injuries, and getting to zero requires a focus on equity. The goal is to eliminate roadway death and serious injury for *everyone*, including people of all ages, abilities, races, ethnicities, and income levels. Reaching this goal requires investment according to need. Communities that have previously suffered from under-investment will require more resources to reach zero traffic deaths than communities where safety improvements have already been made. Since Safe Systems cannot be implemented everywhere at one time, implementation can also be prioritized to areas most in need, closing gaps between the well-served and underserved and improving equity as implementation progresses.

The Safe System approach analyzes safety problems and diagnoses why they occur. For example, intersection crashes—which account for about one-quarter of traffic deaths and about half of injuries—are deadly because conventional intersection designs are susceptible to common and predictable human errors, such as distraction and inattention. When errors are made, they frequently lead to high speed head-on and side-impact collisions that produce crash forces beyond the limits of human injury tolerance. In a Safe System, the riskiest intersections are replaced by roundabouts that limit speed and change vehicle pathways so that common driver errors, such as failure to see a traffic signal, oncoming car, or crossing pedestrian, do not result in high-speed crashes. Round-

abouts are designed to require drivers to slow down and turn with the direction of traffic. Crashes may still happen in a roundabout, but because speeds are lower and deadly head-on and side-impact collisions are prevented, crash injuries are greatly reduced.

Roundabouts and other Safe System strategies are designed to be "self-enforcing," reducing the need for traffic stops. Safe System designs use physical design features such as narrowed lane widths, speed humps, tighter corner turning radii, and chicanes to lead people to drive at safe speeds, rather than relying solely on speed limits. Roads are designed so that the comfortable driving speed is also the safe speed. Separated bike lanes and intersections designed with clearly marked crosswalks, raised medians, and pedestrian refuge islands can slow traffic and ensure that people walking and bicycling are in drivers' field of view. With lower speeds, reaction times are increased so crashes are less likely and any crashes that do occur will be less severe. In the United States, more the 40% of crash deaths occur in rural areas. While intersection crashes are most prevalent in urban areas, other crash types such as roadway departures are more frequent in rural locations. Deaths and injuries from rural crashes can be prevented with Safe System improvements such as rumble strips and guardrails and improved emergency response.

The Safe System approach focuses on proactive prevention rather than reactive strategies for reducing crashes and can be applied to communities of various sizes and demographics. In urban areas, more focus will be on preventing injuries among vulnerable road users. In rural areas, greater attention will go to using road design to manage speed and prevent run-off -the-road crashes that result from distraction or inattention.

Implications for Social Policy

Prerequisites

Implementing Safe Systems on a large scale requires political leadership and public support, as well as technical guidance and funding. Local interest in Safe Systems is important because the great majority of the nation's 4 million miles of roads is locally owned and operated. Progress is being made in the United States each of these areas. Urban areas have led the way, motivated by their crash prevalence as well as strong local advocacy.[54]

Funding to support US Safe System implementation has been significantly boosted with provisions in the 2021 Bipartisan Infrastructure Law. The new "Safe Streets and Roads for All (SS4A)" grant program that is included in the law offers $1 billion to communities for each of the next five years for improvements to street design aligned with the principles of Safe Systems.[55] With this new law and increasing interest by road safety officials across the country, the Safe System approach has become a central policy objective of the US Department of Transportation. The new National Roadway Safety Strategy released by Transportation Secretary Pete Buttigieg in January 2022 is structured around the Safe System approach.

Potential Benefits

The current momentum toward US Safe System adoption has enormous potential in terms of lives saved and improved equity.[56] An analysis of trends in 53 countries indicates that those that have implemented a Safe Systems approach have reached the lowest fatality rates and the greatest reductions in fatality levels over the past 20 years.[53]

Globally, Safe Systems are being implemented in a variety of environments including cities in middle-income nations, such as Bogota and Mexico City.[53] Sweden, The Netherlands, and Australia—at least ten years ahead of the United States in implementation—have reduced traffic deaths by as much as half using the Safe System approach and are targeting further reductions in coming years. If the United States had experienced the same fatality rate per mile in 2017 as Sweden, more than 17,500 lives would have been saved in one year.[57]

When roads are built with Safe System principles, road users will find it easier to behave safely and there will be less need for behavioral correction through traffic enforcement. This reduction in traffic stops, the most common reason for contact between law enforcement and the public, will reduce sources of conflict which disproportionately involve people of color, and also decrease the burden of traffic fines which also have the greatest impact on low-income individuals.

Barriers

A substantial challenge faced by every nation that has implemented the Safe System approach, including the originators in Sweden and The

Netherlands, is overcoming institutional inertia that resists large scale change. Road design standards and practice guidelines are shaped to fit conventional methods and most funding streams incentivize traditional practices rather than a Safe System approach. An additional challenge is in identifying alternative revenue sources for the many small towns across the country that are dependent on traffic fines for basic municipal operating revenue. These jurisdictions will likely be reluctant to reduce traffic enforcement before alternative sources of revenue are identified.[58] Such inertia does not justify the status quo but will require dedicated effort to overcome.

A special challenge for the United States will be addressing past, present, and future inequities in transportation system investments. While there is potential to change biased and inequitable systems using the Safe System approach, there is also understandable skepticism among those who have been unfairly treated in the past. Implementation will require sensitivity to historical inequities and commitment to open planning processes that include meaningful community engagement.

Other barriers to change in road safety policy and practice include special interests which can be driven by economic motives, for example in cases where a policy may affect alcohol sales or the cost of new vehicles, or philosophical perspectives on the role of government as have been cited by some who oppose stronger seat belt laws. In some cases, such interests may succeed in reversing existing policies such as in the eight states where motorcycle helmet laws have been repealed or relaxed.

Looking Forward: Selected Challenges and Opportunities

Conventional safety strategies focus on changing human behavior—through education, laws, and enforcement—to adapt to an inherently dangerous roadway system. These strategies have been effective over prior decades in reducing traffic deaths and injury, but they hit a ceiling. The traffic fatality rate per mile traveled was the same in 2020 as in 2007. The Safe System approach offers a way to break through this ceiling and bring substantial further progress by redesigning the road transportation system—including roads and vehicles—to achieve safety while accommodating predictable human behavior.

The Safe Systems approach provides human-centered principles for redesigning the roadway system, rather than a specific new design. However, within this new approach several specific interventions are worthy of highlight because they are new, underutilized, and address challenging aspects of road transportation risk.

Driver Intoxication and In-Vehicle Impairment Detection Technology

Driver intoxication is associated with more than one-quarter of all motor vehicle fatalities each year. A broad range of legal and illicit drugs can impair driving functions, and while recent increases in the use of cannabis and opioids in the population are of concern, the prevalence of alcohol use and the strength of evidence regarding its involvement in serious crashes continue to make drunk driving prevention a high priority for research and policy development. Alcohol impaired driving has killed about one-half million people since record-keeping began in the 1980s and continues to pose a serious public health problem, claiming more than 10,000 lives each year.[59]

In-vehicle impairment detection technology has been in development since 2008 under a public-private partnership and is recognized by safety and health experts as a strategy with the potential to make substantial gains in reducing impaired driving deaths. Such technology could passively detect whether a driver is beyond the legal blood alcohol limit and prevent a drunk driver from operating the vehicle. Researchers predict that the technology will be ready for consumer use in 2024.[60] Other experts predict that driver monitoring and sensor systems being developed as part of automated driving systems could also accurately detect driver impairment.[61]

The Insurance Institute for Highway Safety (IIHS) estimates that if fitted on all new cars and fully implemented, impairment detection systems could save more 9,000 lives per year, reducing the drunk driving problem by more than 90%.[62] Reductions of this magnitude in drunk driving deaths are not matched by other interventions, prompting safety advocates to recommend that in-vehicle impairment detection systems be mandated for all vehicles when the technology is shown to be accurate and effective, and costs are similar to those of other safety equipment.[63]

Such a federal mandate was enacted in November 2021 as part of the Infrastructure Investment and Jobs Act of 2021, requiring the US Department of Transportation to establish a Federal Motor Vehicle Safety Standard within three years. Automakers will then have up to three years to comply and implement technology that detects and prevents drunk driving. This new in-vehicle technology mandate is consistent with Safe System principles in that the intervention is system-based rather than focusing on changing user behaviors, and offers a groundbreaking pathway to monitor driver performance, identify impairment, and intervene when appropriate. Public support for the congressional mandate is high and the majority of Americans are in favor of vehicle impairment prevention systems as standard features in all new cars.[64]

High-Risk Driving Addressed Through Driver Monitoring

Motor vehicle crashes persist as the leading cause of death among US teenagers, accounting for approximately one-third of all deaths among 16–19 year olds.[3] A lack of experience, rather than deliberate risk-taking, is the reason for most teenage drivers' crashes.[65] On the other end of the life course, older adults (65 years and older) are the fastest growing population group in the United States, projected to double to 95 million individuals by 2060.[66] Older adults have a traffic fatality rate per population that is nearly equal to that of the highest-risk age group—21-24 year olds—and are more than twice as likely to die once involved in a crash.[67] Demographic changes and increased longevity in this age group suggest that older driver crashes will increase dramatically in the coming decades.

In-vehicle and smartphone-based telematics hold considerable potential for use in shaping driver behaviors and preventing crashes among high-risk populations, such as teens and older drivers. Much like wearable sensors that allow individuals to track their physical activities, telematics can be used to monitor unsafe driving (e.g., speeding, hard acceleration/braking), provide real-time feedback to drivers, and incentivize safe driving. Behavioral theory suggests that personalized feedback in relation to a predetermined set of standards is essential to behavioral self-regulation.[68] Furthermore, studies of teen drivers suggest that behavior change requires drivers to face tangible consequences.[69]

Driver monitoring can be used to rebalance the structures of rewards and penalties for risky behaviors.[70] For instance, drivers tend to speed because the penalties (e.g., crashes, tickets) are uncertain and unlikely in the short-term, but rewards (e.g., thrill, time-savings) are certain and instant.[71] Telematics can address this imbalance by making penalties immediate and certain.[72] Further, insights from behavioral theory on how people respond to incentives (e.g., loss aversion and gain/loss asymmetry) can be exploited to make the interventions more effective.[73,74] Over time, incentive-based programs could evolve to encourage intrinsic motivation, a shift that would be aligned with the emerging literature on positive psychology and driving.[75]

Insurance companies already have large telematics programs, where insurance premiums are based on exposure to risk measured using telematics.[74] However, insurance companies primarily use telematics for collecting driving information for "ratemaking" and attracting low-risk drivers to their insurance pool, for example, they use telematics to find rather than make safer drivers.[76] Partnerships between telematics corporations and academic researchers are needed to advance the science of this field and demonstrate the effectiveness of telematics for large scale, population-based behavior change.

Realizing the Potential of Vehicle Automation Through Social Purpose

The development of vehicles with automated driving systems that do not require human drivers is rapidly advancing, with initial commercial deployments already occurring.[77] Despite the promise that highly automated (driverless or autonomous) vehicles (AVs) will improve access to mobility and reduce the number of traffic injuries and fatalities, public trust and confidence in this technology has wavered over the past years, partly due to media coverage about several serious crashes involving AVs.[78]

In the absence of specific federal safety standards for AVs, public confidence in AV technology—and interest in adopting this potentially life-saving technology—will come from other sources. These include the extent to which local city and state officials create a safe testing environment and the industry provides adequate safety assurance during testing. Part of the challenge in addressing public confidence is that

conventional approaches to regulatory safety assurance, such as barrier crash testing, are not adequate for assessing the risks inherent in self-driving technologies. New metrics are needed to demonstrate safety. For example, the notion that self-driving vehicles could be tested on public roadways until they demonstrate a certain benchmark of safety has been challenged by an analysis that suggests hundreds of millions or billions of miles of testing would be needed.[79]

One way to increase the robustness of public perception of the promise of AVs is to improve safety in the technology of the AVs and in the testing protocols. This could be facilitated through data sharing, and a graduated approach to on-road testing and deployments.[80] Encouragingly, the industry and regulators appear to be pursuing these approaches in recent years. Another approach to increasing trust and acceptance is to expand public perception of AV value beyond safety to include wider societal benefits. This would make public perception more resilient to safety incidents that will invariably occur.

Research is needed on the potential for AVs to provide mobility to those who lack transportation options to access critical health and wellness needs. Prioritizing deployment of AVs to serve such needs—for example, using AV shuttles that take advantage of the low per trip costs of driverless vehicles—could demonstrate social value by reducing mobility disparities and providing access to healthy foods, health care, economic opportunities, and recreation and exercise which influence quality of life.[81] Such research could be accompanied by examination of the physical infrastructure of underserved neighborhoods to ensure that AVs are adequately tested in these environments. Further research could assess how demonstrated social value affects public trust and acceptance of AVs.

Modal Shift

The 2030 Agenda for Sustainable Development adopted by United Nations member states in 2015 describes 17 essential goals for preserving our planet and people.[82] The subsequent Report for the 3rd Ministerial Conference on Road Safety pointed out how achievement of these goals, especially those related to health and climate action, could be facilitated by decreasing dependence on personal car use and shifting towards

modes of transportation that would advance both public health and climate goals, such as walking, bicycling and public transportation.[83]

Individuals in the United States are extraordinarily dependent on personal vehicles for mobility. This dependence is the result of more than 100 years of road system development shaped by economics, geography, land use policy, and other factors. Car dependence has come with both benefits—to mobility and opportunity—and costs to safety, health, and the environment.

Many of the changes that would be necessary to shift US dependence on personal cars, such as widespread availability of pedestrian- and bicycle-friendly infrastructure and efficient public transit, are high-cost and long-term aspirations, while others could be accomplished quickly with available resources. For example, the US Environmental Protection Agency estimates that if just one-half of personal car trips of one mile or less were replaced by walking or biking, the nation could save nearly $1 billion in driving costs and prevent about 2 million metric tons of carbon dioxide emissions per year.[84]

A deliberate program of research is needed to identify strategies for such modal shifts and assessing their health and climate impact. Such research could include modeling to identify where modal shifts could be most convenient for travelers and which types of shifts would yield the greatest benefits, as well as surveys to reveal the types of messages or incentives that would be most effective for motivating changes in modal choice.

Conclusion

Despite decades of progress, motor vehicle crashes persist as a leading cause of death in the United States and globally. The Safe Systems approach accounts for predictable human error and works to protect everyone on the road. Over the next decade, the United States and a number of other countries have the opportunity to reorient safety efforts towards the Safe Systems approach. In addition, a range of emerging technologies, enabled by artificial intelligence, such as automated vehicles, impairment detection, and telematics hold promise to advance road safety. To achieve sustainability, the transportation system will need to evolve to provide safe, efficient, and equitable movement of people and goods

with less dependence on private vehicle ownership, and more walking, bicycling, and use of public transportation.

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Address corrspondence to: Johnathon P. Ehsani, PhD, MPH, Associate Professor, Department of Health Policy and Management, Johns Hopkins Bloomberg School of Public Health, 624 N Broadway, Rm 555, Baltimore, MD 21205 (email: johnathon.ehsani@jhu.edu).