NCHRP Research Report 1135

National Cooperative Highway Research Program

A Guide to Applying the Safe System Approach to Transportation Planning, Design, and Operations

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A Guide to Applying the Safe System Approach to Transportation Planning, Design, and Operations

Seth LaJeunesse
Daniel Gelinne
Wesley Kumfer
Katherine Harmon
Laura Sandt
Jonathon Weisenfeld
The University of North Carolina Highway Safety Research Center
University of North Carolina at Chapel Hill
Chapel Hill, NC

Tabitha Combs
Department of City and Regional Planning,
University of North Carolina at Chapel Hill
Chapel Hill, NC

Kendra Schenk
Jeremy VanVleet
Burgess & Niple
Columbus, OH

Nick Falbo
Narayan Donaldson
Mobycon
Ottawa, ON, Canada

Timothy E. Barnett
Brundidge, AL

Alan Dellapenna
Wake Forest, NC

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Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

NATIONAL ACADEMIES *Sciences Engineering Medicine*

TRB TRANSPORTATION RESEARCH BOARD

2025

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed, and implementable research is the most effective way to solve many problems facing state department of transportation (DOT) administrators and engineers. Often, highway problems are of local or regional interest and can best be studied by state DOTs individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration (FHWA), United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments, by committees of AASHTO, and by the FHWA. Topics of the highest merit are selected by the AASHTO Special Committee on Research and Innovation (R&I), and each year R&I's recommendations are proposed to the AASHTO Board of Directors, the FHWA, and the National Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and oversight of research contracts are the responsibilities of NCHRP.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

NCHRP RESEARCH REPORT 1135

Project 17-101
ISSN 2572-3766 (Print)
ISSN 2572-3774 (Online)
ISBN 978-0-309-99350-0
Library of Congress Control Number 2025941355

NOTICE

The research report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the National Academies of Sciences, Engineering, and Medicine.

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Published research reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from

National Academies Press
500 Fifth Street, NW, Keck 360
Washington, DC 20001

(800) 624-6242

and can be ordered through the Internet by going to

https://nap.nationalacademies.org

Printed in the United States of America

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CRP STAFF FOR NCHRP RESEARCH REPORT 1135

Monique R. Evans, *Director, Cooperative Research Programs*
Waseem Dekelbab, *Deputy Director, Cooperative Research Programs, and Manager, National Cooperative Highway Research Program*
David M. Jared, *Senior Program Officer*
Dajaih Bias-Johnson, *Senior Program Assistant*
Natalie Barnes, *Director of Publications*
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AUTHOR ACKNOWLEDGMENTS

The authors acknowledge the respondents to the research team's practitioner survey and the focus group participants. The insights provided by the survey respondents and focus group participants rendered the guidance provided herein far more practical and useful than had they not contributed to this effort.

FOREWORD

By David M. Jared
Staff Officer
Transportation Research Board

NCHRP Research Report 1135: A Guide to Applying the Safe System Approach to Transportation Planning, Design, and Operations presents information for applying the Safe System approach among state departments of transportation (DOTs) and other transportation agencies. Based on extensive stakeholder outreach, including practitioner focus groups, the guide covers six domains of practice in transportation safety that users can draw from based on their organizational interests, competencies, and safety-oriented goals. This guide should be of particular use to state DOTs and any other transportation agency seeking to provide resources for transportation planners, designers, and operations managers to implement Safe System principles and make the systems under their jurisdictions safer.

The Safe System approach is a holistic approach that provides a framework for making the national transportation system safer. It is based on building and reinforcing multiple layers of protection to prevent crashes from happening and minimize the harm caused when crashes occur. This safety approach differs from conventional ones because it focuses on human vulnerability and creates a system with many redundancies to protect all transportation users. Despite increased interest in the Safe System approach, few guidelines exist for transportation planners, designers, and operations managers for implementing a safe system. To fully implement a Safe System approach, infrastructure design, vehicle design, policies and law, recognition of shared safety responsibility, road-user behavior, and public culture—all of which will require some degree of change—must be addressed. Research was needed to begin providing resources for transportation planners, designers, and operations managers to consult during safety problem identification, project development, and countermeasure selection.

Under NCHRP Project 17-101, “Applying the Safe System Approach to Transportation Planning, Design, and Operations in the United States,” the University of North Carolina at Chapel Hill was asked to develop materials that would enable a range of professionals and organizations to adopt and implement the Safe System approach in their work. Using extensive outreach to a variety of safety stakeholders, the research team identified strategies, practices, and policies for implementing the Safe System approach in the United States then modularized them using six domains of practice integral to implementation. The resultant guide provides safety teams with the foregoing resources and a Safe System Strategy Implementation Self-Assessment designed to offer insight into teams’ progress in implementing Safe System–aligned strategies across domains of practice.

In addition to *NCHRP Research Report 1135*, the following three deliverables can be found on the National Academies Press website (nap.nationalacademies.org) by searching for *NCHRP Research Report 1135: A Guide to Applying the Safe System Approach to Transportation Planning, Design, and Operations*:

- A conduct of research report summarizing the entire effort, available as *NCHRP Web-Only Document 413: Applying the Safe System Approach to Transportation Planning, Design, and Operations*
- A plan that identifies mechanisms and channels for communicating and implementing this research
- A PowerPoint presentation introducing *NCHRP Research Report 1135*

CONTENTS

SUMMARY

A Guide to Applying the Safe System Approach to Transportation Planning, Design, and Operations

This guide supplies a framework for transportation agencies and their partners in policymaking, planning, road design, law enforcement, injury prevention, and post-crash response, among others, to begin implementing Safe System–aligned practices and policies. These guidelines aim to accomplish the following:

- Provide a unifying definition of a safe system
- Describe organizational principles designed to foster a Safe System
- Articulate implementation of a Safe System by defining aligned safety strategies and practices
- Explain the roles of six interrelated practice domains (e.g., planning, design, policy) in creating a Safe System
- Present Safe System strategies that orient teams toward longer-term safety visions
- Illustrate safety practices drawn from domestic and international literature on Safe System interventions and policies
- Offer step-by-step guidance on how to effectively implement Safe System–aligned practices

This guide was developed as part of NCHRP Project 17-101, "Applying the Safe System Approach to Transportation Planning, Design, and Operations in the United States." A conduct of research report, available as *NCHRP Web-Only Document 413: Applying the Safe System Approach to Transportation Planning, Design, and Operations*, complements this guide and offers greater detail on the research methods and results and discusses how the research informed the creation of the guidelines. This complementary report can be found on the National Academies Press website (nap.nationalacademies.org).

Intended Audience

These guidelines are primarily intended to assist state departments of transportation (DOTs) personnel and contractors, including managers and staff in safety offices, in implementing a Safe System. However, given the complex nature of transitioning to a Safe System, the guidelines are also germane to safety-minded policymakers; regional and local transportation engineering and planning managers and staff; regional and local land-use planners' public works managers; traffic safety–focused law enforcement leads; state- and county-level public health professionals; emergency medical services managers; and transportation and injury prevention researchers. The introductory chapter, with its focus on Safe System–aligned organizational principles, is intended for safety team leads operating at all levels of government.

How to Read This Guide

The chapters that follow the introduction of and background on the Safe System in Chapter 1 provide guidance related to six distinct yet interrelated domains of practice in transportation safety. Reading all chapters ideally will provide the reader with a holistic sense of how agencies

and partners might begin to implement a Safe System in the United States. However, it is possible that not all chapters will be of interest or relevance to all readers. In these cases, readers are invited to visit the chapters and Safe System domains that align with their interests, skills, and safety-oriented goals.

Chapters 2 through 7 are uniformly organized. They each describe the role of the domain in fostering a Safe System. Each description is followed by an explanation of the need for a paradigm shift within each domain. Next, domain-specific Safe System strategies are presented. These strategies point to longer-term foci for safety practices and policies (e.g., clearly define the functionality of roads). An examination of domain-specific practices drawn from the domestic and international literature on Safe System interventions and policies follows. These practices have been appraised by transportation and public health professionals from around the United States in terms of the practices' ability to improve safety and their feasibility to implement.

Following is a list of the specific domains addressed in Chapters 2 through 7 and the contents in the appendices:

- Chapter 2 explores Safe System policy, with a focus on creating and maintaining effective and adaptive policy.
- Chapter 3 covers Safe System planning and provides a more network-level and longer-term view of a Safe System transition.
- Chapter 4 is about Safe System design and its role in accommodating inevitable road-user mistakes.
- Chapter 5 offers guidance on adaptive Safe System–aligned operations and maintenance practices.
- Chapter 6 provides strategies and examples of Safe System law enforcement strategy and practice.
- Chapter 7 addresses Safe System post-crash response and illustrates ways in which road trauma management can feed into safety policy and investment discussions.
- Appendices A through F provide data on how different safety professionals appraised various safety practices across domains (e.g., policy, design, law enforcement) in terms of ability to improve safety and social, political, and budgetary feasibility to implement.
- Appendix G provides safety teams with a Safe System Strategy Implementation Self-Assessment tool designed to offer insight into teams' phase of implementing Safe System–aligned strategies across domains of practice.

CHAPTER 1

Background of the Safe System

Since the introduction of the private automobile in the United States, traffic safety has undergone at least four distinct yet interrelated paradigms. These paradigms shaped how travel speed was perceived (e.g., as inherently dangerous or safe with the right road or vehicle designs), which parties were considered responsible or innocent in the event of a collision, the role of road and vehicle design in safety, and the inevitability or preventability of serious crashes. According to Norton (2015), the concept of traffic safety emerged in the early 1900s with the introduction of the motor vehicle and a focus on the safety of child pedestrians and the role of vehicle speed in safety outcomes. This period, which ushered in a Safety First paradigm, coincided with the establishment of the National Safety Council (NSC) in 1913 (NSC 2024b). In the 1920s and ’30s, Safety First campaigning gave way to a Control paradigm, which empowered a growing class of professional traffic engineers [e.g., ITE, formed in 1930; (ITE 2024)] and law enforcement who provided expert engineering (highway-focused), education, and enforcement to prevent serious crashes. The Control paradigm was later superseded by a Crashworthiness paradigm in the 1960s and ’70s, which maintained a focus on the safety of vehicles [e.g., Ralph Nader published his book *Unsafe at Any Speed* in 1965; Nader (1965)]. Traffic deaths exceeded 40,000 for the first time in 1962, then 50,000 in 1966 (NSC 2024a). During the Crashworthiness paradigm, advocates and organizations called for improved vehicle design to protect vehicle occupants (e.g., seatbelts became ubiquitous, and airbags were introduced in the 1970s). The 1980s ushered in a Responsibility paradigm, which centered safety discussion on the role of responsible drivers and appears to be the prevailing paradigm of today. Alternatively, the Safe System, with its emphasis on proactively addressing safety, instituting system redundancies, and managing travel speeds, might represent a new paradigm, one in which the United States has witnessed growing interest and investment.

Indeed, for the past decade local, state, and federal commitment to advancing the safety of the U.S. transportation system and realizing a future without serious and fatal injury has been increasing (Shi et al. 2023; Evenson et al. 2023). Organizations and agencies have adapted road safety philosophies from abroad to propose a Safe System approach (FHWA 2019a). Most typically, a Safe System is thought to be shaped by pragmatic principles (e.g., redundancy is crucial, safety is proactive) and ethical ones (e.g., death and serious injury are unacceptable) and comprises the following safety elements: safe road users, safe vehicles, safe speeds, safe roads, post-crash care (Vision Zero Network 2023; FHWA 2019a).

Today, in the transportation industry, the term “safety” typically refers to the probability of harm while traveling (e.g., a higher level of safety indicates a lower level of harm). Another general definition presents it as an absolute value, meaning freedom from harm or not involving any risk of severe injury (Sakashita, Job, and Belin 2022).

These guidelines were developed with the understanding that transitioning to a Safe System would initially favor probabilistic definitions of safety given the current state of the practice

[e.g., use of crash modification factor (CMF) studies that indicate likely reductions in crashes after the installation of an engineering countermeasure]. Ideally, over time, safety professionals and partners will keep the "Ultimate Safe System" concept in mind and increasingly institute strategies and practices that reliably protect road users from harm: "In road transport, the Ultimate Safe System is one in which road users cannot be killed or seriously injured regardless of their behavior or the behavior of other road users" (Soames Job, Truong, and Sakashita 2022).

This Ultimate Safe System definition aligns with the Netherland's Sustainable Safety Vision, which is organized around three facts about humans: People are vulnerable. People can be reckless and make mistakes. People do not always follow rules (Shi et al. 2023).

1.1 Safe System Principles

In 2022 the U.S. Department of Transportation (DOT) adopted the Safe System approach as the core of the National Roadway Safety Strategy (U.S. DOT 2022). This strategy (1) recognizes the status quo is unacceptable, (2) asserts that fatal and serious crashes are preventable, and (3) incorporates the following Safe System approach principles:

- **Death and serious injuries are unacceptable.** Ideally all crashes would be avoided, but given that achieving that goal is unrealistic, the Safe System approach prioritizes the elimination of crashes that result in death and serious injuries. No one should experience either when using the transportation system. This principle also presupposes a more absolute definition of safety, rather than a probabilistic one—that is, given the inherent vulnerability of humans, they need to be free from harm, from any risk of serious injury, or otherwise protected from danger (Sakashita, Job, and Belin 2022).

  This moral principle needs to be the primary objective of transportation design. There should also be mission statements at high levels (e.g., state DOT level) to underpin changes to design standards and guidelines, thereby ensuring decisions are rooted in the fundamental safety of road users.
- **Humans make mistakes.** People will inevitably make mistakes and decisions that can lead or contribute to crashes, but the transportation system can be designed and operated to accommodate certain types and degrees of human mistakes and avoid death and serious injuries when crashes occur.

  This principle recognizes that human beings are prone to behaviors and conditions that produce risk on the road, for example, inattention, impairment, risk-seeking, impatience, and errors in judgment and observation. Managing these conditions requires a two-pronged approach:
  1. Limit the number of mistakes humans make by maintaining an appropriate level of task saturation. Task saturation should be high enough that road users remain alert, but not so high they become overwhelmed and likely to miss key pieces of information (Calvert and van Arem 2020).
  2. Ensure redundant systems are in place to mitigate the mistakes that road users inevitably make (Williamson 2021).
- **Humans are vulnerable.** People have physical limits for tolerating crash forces before death or serious injury occurs; therefore, it is critical to design and operate a human-centric transportation system and seek to manage flows of kinetic energy to protect the known vulnerabilities of human beings (Jurewicz et al. 2016).

  This principle implies that vulnerable road users (e.g., cyclists, pedestrians, motorcyclists) should be separated from the greater kinetic energy generated by fast or heavy flows of motor vehicle traffic. The same logic applies to occupants of smaller vehicles.

- **Safety is proactive.** Proactive methodologies and tools should be used to identify and address safety issues in the transportation system, rather than waiting for crashes to occur and reacting afterward.

  This principle indicates any death or serious injury by the transportation system should trigger a response aimed at understanding how to systematically prevent its repetition, followed by whatever investment of resources and implementation of changes are required to make this happen. Whenever streets or roads are reconstructed, layouts should be modified to reflect Safe System best practices. Safety features such as neighborhood traffic calming should be implemented proactively, not only as a response to collision hotspots or neighbors' complaints. Continual study of designs should lead to improvements in design standards, as should research from other parties such as universities.
- **Responsibility is shared.** Preventing serious and fatal road injury is possible and requires involvement from government at all levels, health and education sectors, private industries, and civic organizations. All are vital to preventing fatalities and serious injuries on roadways (WHO 2023).
- **Redundancy is crucial.** Reducing risks requires all parts of the transportation safety system to be strengthened, so if one part fails, the other parts still protect people. This principle focuses on the elements of the system that provide reliable protection for road users when other elements of the system fail, which requires designing robust backup systems, such as cable-wire barriers to catch drivers who leave the road when their vehicle's lane-keeping technology fails (Alluri et al. 2016).

Applying Safe System Principles

The following sections outline applications of the Safe System principles in planning, design, operations, and safety practices that collectively have the potential to transition the United States toward a truly Safe System (Figure 1).

Following is an example of a Safe System principle and corresponding strategy and practices:

Principle: Humans are vulnerable.
Strategy: Design around human tolerances to crash forces.
Practices: Installing permanent barrier-protected bike lanes on arterial roads; Installing cable barriers on the edges and in the medians of rural roads.

Safe System elements (e.g., safe roads, safe speeds, safe road users) are the results of the activation and advancement of Safe System principles, strategies, and practices.

Figure 1. Conceptual arrangement of Safe System principles, strategies, and practices.

Safe System Pillars (Elements/Outcomes)

Safe vehicles ensure drivers will not crash into people or objects with human-intolerable force by providing intelligent speed assistance depending on the operating context. They are designed to enhance visibility of vulnerable road users with direct vision, lane keeping, and automated emergency braking, among other safety features.

Safe speeds are aligned with known human tolerances to closing/impact speed forces, varying speeds by the road and land-use contexts, as well as road-user mix.

Safe roads are self-explaining and enforcing, automatically cueing drivers to engage in context-appropriate, desired behaviors, and they are designed with energy-absorbing protections (e.g., breakaway poles, see Vardaki, Papadimitriou, and Kopelias 2014). They have sufficient task saturation to keep drivers alert, but not overwhelmed (Calvert and van Arem 2020). Furthermore, they are based on likely interactions of vehicles and users of different speeds, directions, and masses (Johansson 2009).

Post-crash care is well resourced, equipped with crash predictive capabilities, inclusive of Next Generation 911 (NG911) functionality, better able to access level 1 and 2 trauma centers across the country, and part of safety planning to improve crash scene management and prevent secondary crashes and injuries (Liu 2022).

Safe road users are the desired result of a Safe System. They value safety, endorse safety regulations, understand and appreciate the reasons for safety policies and investments, and elect policymakers partly on evident safety-oriented values and interests.

1.2 Organizational Principles

A Safe System provides professionals with clear principles from which to operate. "Death and serious injury is unacceptable" is the first and ethical principle of the Safe System. It is followed by the principles about the psychological and physiological realities of human road users, "humans make mistakes" and "humans are vulnerable." Next are the practical principles "safety is proactive" and "redundancy is crucial." The final principle, "responsibility is shared," is interpreted for the purposes of this guide as an interorganizational principle and framed as "system operator responsibility" (see the "System Operator Responsibility" section for more information). To activate the Safe System principles, the following guidelines offer organizational principles around organizational change management, system operator responsibility, learning and innovating, communications and messaging, and participation in decision-making.

Change Management

The first organizational principle is rooted in the concept and practice of change management. This practice starts with authentic leadership and the central notion that change is necessary and possible.

- Change leaders begin change management by communicating to managers and employees the need and urgency for change, articulating why the organization cannot stay in its current state and that a better place from which to operate exists (Luecke 2003).
- Leaders and managers, in partnership, invite groups within the organization to define and commit to realizing expressed change goals. They jointly identify existing problems with the organization's approach to road safety and develop solutions (Al-Haddad and Kotnour 2015).
- Next, leaders encourage the group to focus on realizing the change goals and appropriately engaging all the people who own the change in carrying out the necessary work to realize

change. More explicitly, leaders create space for groups to share their perspectives on the status quo and where they would like to end up, find belonging with those who share common cause, and make clearer everyone's value in the change-making process (Errida and Lotfi 2021).
- Leaders also manage the space for the group by establishing and enforcing (1) team-working norms (e.g., trust and communication norms), (2) quality improvement tools for testing out new safety policies and practices via demonstration projects, and (3) task-management tools for tracking progress over time and sustaining momentum (Phillips and Klein 2023).

System Operator Responsibility

Under this second organizational principle, professionals involved in designing, operating, and maintaining roads and vehicles, as well as those providing injury surveillance and coordinating post-crash care and trauma response, are collectively responsible for maximizing the safety of vehicle and road designs and operations (Shi et al. 2023). In short, system operators should be held accountable for delivering the road-using public a Safe System (Soames Job, Truong, and Sakashita 2022).

Learning and Innovating

As social and political norms shift and technologies become more commonplace, Safe System professionals and researchers will need to remain nimble in their work. They will need to examine the questions they are asking and expand them; for example, "does this countermeasure work?" becomes "does this countermeasure work, why does it work, and in what contexts does it work?" Adopting a habit of continual learning and innovating supports the complex system within which society operates (Adams et al. 2016). It would benefit road safety professionals and researchers to develop a holistic understanding of their community's road trauma patterns and injury contributors, as well as timely feedback on the safety risks and performance of implemented countermeasures. Iterating, learning, and innovating in this way can help safety analysts account for demographic shifts, and simultaneously implemented policies, in their safety impact assessment, something deterministic CMFs cannot do (Noland 2013).

Communications and Messaging

Avoid individualism. Placing blame on victims of road trauma harms the victims and those close to the victims and fails to inspire calls for altering the system in community-benefiting ways. Instead, whenever possible, reference the context in which road users operate and in which serious crashes occur.

Frame the Safe System as a viable solution to road trauma. Though it is common to learn many people die on U.S. roads each year, such bad news, when presented without information on solutions, can incite cynicism rather than motivation to improve the situation. Instead, introduce solutions to road trauma early and often and in ways that remind policymakers and the public how serious traffic injury and death can be prevented. Following are a few tips (adapted from Frameworks Institute 2022):

- Help people visualize how one or more safety interventions work [e.g., "Replacing traffic lights with roundabouts can reduce deadly traffic injuries by 90% by lowering the speed of vehicles entering the intersection and changing the angles at which any crashes may occur, avoiding deadly side-impacts" (Michael et al. 2023)].
- Emphasize solutions that involve different people coming together to reduce road trauma (e.g., "Law enforcement officers informed the city's transportation engineers that pedestrians were often crossing between intersections in places without marked crosswalks and being struck. After observing conditions, the planning and engineering teams designed and installed a raised crossing in a location where most pedestrians were already crossing, thereby greatly reducing midblock pedestrian crashes").

- Talk about preventing road trauma as doable and within reach (e.g., "By lowering our posted speed limits, adding road elements to encourage slower speeds, and providing more physical barriers between people driving cars and those riding bicycles, we are seeing a major drop in people being injured on our roads. We look forward to making many more safety improvements in the months and years ahead").
- After a crash, reference the human toll of road trauma (e.g., "This and every death affects the victim's family, friends, and broader community").
- Place crashes in time- and place-based context (e.g., "This is the fifth deadly run-off-road crash on Old Greensboro Rd in the past few years").
- Note how road injuries are preventable through proven means and how improving safety benefits everyone [e.g., "Road improvements such as rumble strips can prevent run-off-road crashes, which can result in disabling injuries. All of us who use rural roads would benefit from a backup system for when something goes wrong" (Michael et al. 2023)].

Participation in Decision-Making

Safe transportation access starts with representation in decision-making (Karner and Marcantonio 2018; McCullough and van Stokkum 2021). If a safe transportation system is to be built, there should be broad representation of community members in decision-making (Bello-Bravo, Medendorp, and Pittendrigh 2022).

Participation in decision-making can ensure that what is counted as useful data, information, or knowledge in the realm of traffic safety includes the first-person perspectives of people who have lived experience—also recognized as "lived expertise"—contending with often unsafe and unreliable transportation systems (Lowe, Barajas, and Coren 2023). Safety analysts should not rely solely on police-documented crash data to discern injury hot spots or to allocate scarce resources. Instead, analysts should also aim to incorporate community members' perspectives into their problem identification and countermeasure selection procedures.

The ability to participate in decision-making and offer one's lived expertise to addressing safety problems holds promise for increasing community members' trust in the legal system (Bottoms and Tankebe 2020) and improving the distribution of high-quality infrastructure and transportation services (Pereira, Schwanen, and Banister 2017).

1.3 Safe System Strategies and Practices

Bridging Safe System Principles, Strategies, and Practices

In the following chapters, this guide proposes several domain-specific Safe System strategies for professionals to consider adopting, adapting, and implementing in their work. These Safe System strategies provide a conceptual and practical bridge between Safe System principles and practices, being neither lofty nor "on-the-ground." Instead, these strategies offer longer-term orientations toward key safety practices.

An example design strategy is to base design on known human tolerances to crash forces. An example policy strategy is to advance adaptive safety policies rather than inflexible ones. An example planning strategy is to replace forecasting with backcasting. Each of these strategies channels one or more Safe System principles (e.g., humans are vulnerable, safety is proactive, and redundancy is crucial) and brings the principles closer to actual safety practice.

A Safe System practice, on the other hand, is something that is usually or regularly done, often as a habit, tradition, or custom. In this guide, a safety practice can also mean an intervention or program that (1) significantly enhances understanding of contributing factors or outcomes

associated with traffic injuries, (2) reduces the likelihood or severity of road-user exposure to human-intolerable kinetic energy transfer, and (3) can be applied routinely or over a wide area (e.g., from corridor to district to village/town/city to county to region to state).

Achieving Zero Deaths

Placed together, Safe System principles lead to strategies, which lead to practices. An example follows: Safety is proactive (principle), leads to a base design on known human tolerances to crash forces (design strategy), leads to installing cable barriers on the edges and in the medians of rural roads (design practice).

The guidance offered in the following chapters is organized around Safe System strategy and practice domains. A truly Safe System, one in which achieving zero deaths and serious injuries on the nation's roadways, can be realized only when all domains are applied in concert with one another (Figure 2).

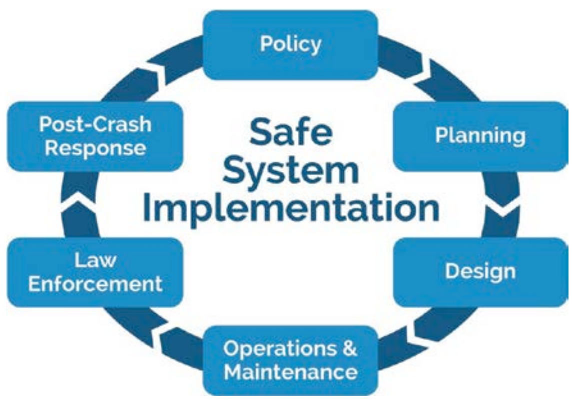


Figure 2. Safe System implementation via domains of strategy and practice.

CHAPTER 2

Safe System Policy

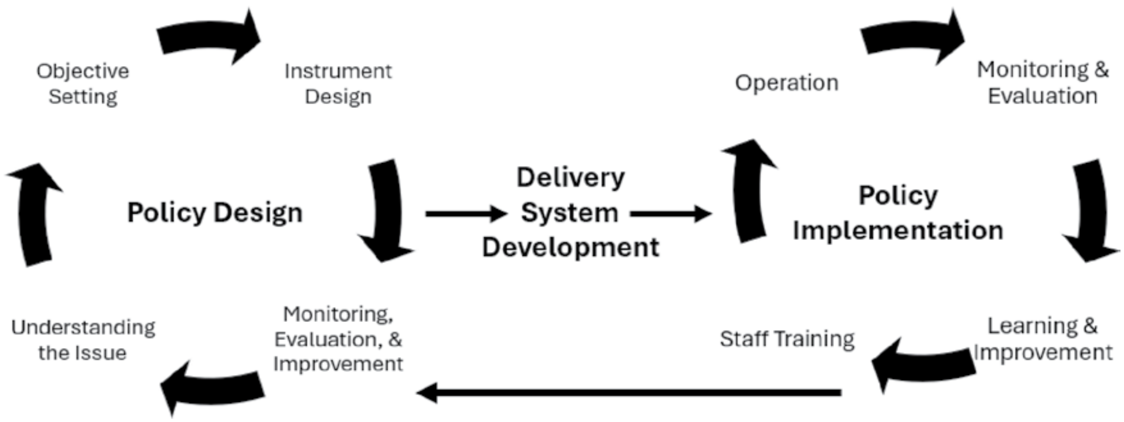
Safety policy plays a critical role in fostering a Safe System. Policies establish the rules that govern what is allowed by law or by custom. They provide legal and regulatory legitimacy for changes in safety procedures and practices. Moreover, Safe System policies impact safety work at local, regional, and state levels of government. For example, municipal policies might require the provision of a minimum number of parking spaces per square feet of various development types, which can induce motor vehicle traffic and render municipal commercial areas less safe for road users (Dumbaugh and Rae 2009). On the other hand, state laws that govern local municipalities might prohibit the use of speed safety cameras, a proven safety countermeasure, especially when equitably implemented in communities (Ralph et al. 2022). Pedestrian safety is shaped by federal regulations around the pedestrian detection and collision avoidance capabilities of motor vehicles sold in the United States (Mallory et al. 2023).

As Swanson and Bhadwal (2009) observed, and as shown in Figure 3, all policies proceed through a design phase and an implementation phase. As an illustration of these phases, consider posted speed limits. The federal government can define how speed limits may be set, and local or state lawmakers define the penalties for drivers who exceed the posted speed limit by a certain amount. Police officers are then tasked with implementing the policy by choosing which speeding drivers to stop and deciding how precisely to implement the policy (e.g., determining whether the speeding infraction was worthy of a warning or a speeding ticket). Together with additional speed-related infractions, the local government and its police department will decide whether speeding is a pressing issue and thus worthy of high or low enforcement priority.

Currently, transportation safety policies tend to focus on providing protection for vehicle occupants and are organized around active measures, ones that rely on individual road users to adopt safe behaviors such as requiring people to wear seat belts or motorcycle helmets. However, policies could also advance population-level harm-reduction practices (Ederer et al. 2023) such as requiring location-based speed limiters in all commercial and private vehicles and in vehicle designs like adequate direct vision for large vehicles to minimize serious crashes with vulnerable road users. Before introducing novel safety policies, policymakers could enhance policy compliance by sharing the reasoning underlying a policy and outlining its potential benefits (see Communications and Messaging in Chapter 1).

By not solely relying on individuals to adopt safe technologies and behaviors and instead providing technology, equipment, and infrastructure that offer reliable protections to road users, Safe System policies can vastly improve population-level safety and related health and environmental concerns (De Nazelle et al. 2011). For example, barrier-protected bicycle lanes provide reliable protection for people riding bicycles and can temper drivers' speeds by perceptually narrowing the travel lane (Schlossberg 2022).

Population-impacting safety policies are necessary and possible. For example, the state of California updated its traffic impact assessments to focus on land-use arrangements that could



Source: Adapted from *Creating Adaptive Policies: A Guide for Policymaking in an Uncertain World* (Swanson and Bhadwal 2009).

Figure 3. Illustration of policy design and implementation.

significantly reduce vehicle miles traveled (VMT) rather than concentrating on managing drivers' delay using level of service (LOS) metrics (Lee and Handy 2018). Moreover, as the Parking Reform Network is demonstrating, several states and thousands of municipalities across the United States are modifying their land-use ordinances to allow for greater flexibility in providing car parking (Parking Reform Network 2024). Further, NHTSA is updating its New Car Assessment Program (NCAP) to consider the implications of vehicle mass, height, and design on the safety for vulnerable road users (NHTSA 2023b).

Unfortunately, as established by the U.S. Congress, some federal-aid funding programs disallow funding to be used to maintain safety infrastructure. The inability to rely on federal funds to maintain infrastructure may result in states disallowing the installation of certain countermeasures (e.g., rectangular rapid flashing beacons, sidewalks, cable-median barriers) on state-owned roadways (Jane Gibson and Marshall 2022).

Additionally, state agencies and governments regularly aim to provide high degrees of motor vehicle mobility throughout a corridor, yet state and local agencies often permit dense concentrations of driveways that provide high degrees of access to land developments. However, in a Safe System, roads and streets do not provide mobility and access within the same corridor (Corben 2022). Not only that, state and local agencies tend to employ vehicular LOS as performance measures for intersections and segments, but a Safe System calls for using survivable operating speed measures to assess facilities' performance (Kumfer et al. 2023).

2.1 Key Policy-Related Strategies

An array of policies could influence Safe System work at the local, regional, and state levels. For example, a community might have a local policy that establishes default 20 miles per hour (mph) posted speed limits on local streets unless otherwise specified. Examples of types of policies to review at the local, regional, and state levels include those outlined in Table 1.

Table 1 presents examples of specific policies to review and discern their alignment with creating a safe transportation system.

To apply the principles of a Safe System in the context of policymaking, the following three policy strategies can encourage practices that contribute to a Safe System:

1. Advance adaptive safety policies.
   No matter the level of legal authority or the strength of the policy guidance, in an ever-changing environment, ideal policies are adaptive rather than inflexible—that is, policies should have

Table 1. Types and examples of safety policies.

Types of Policies	Examples
Policies That Possess Legal Authority	
Laws (state statutes or local ordinances)	Speed limits for certain road classification types, graduated driver licensing, red-light-running cameras, speed safety cameras
Codes	Building codes regarding whether sustainable modes of transportation are required to be considered, street design types (eliminate cul-de-sacs), providing street grids, disallowing gated communities, parking maximums/parking unbundled from residential and office uses, fire codes that require unobstructed street width
Regulations	Posted speed limit setting
Policies That Guide Choices	
Rules	The National Car Assessment Program
Standards	Standards and design models for how a road should be designed, *Manual on Uniform Traffic Control Devices*
Agreements or guidance documents	Agreement around reducing or eliminating deaths and serious traffic-related injuries

Source: Adapted from *Guide to Developing a Vision Zero Plan* (LaJeunesse et al. 2020). Collaborative Sciences Center for Road Safety. https://www.roadsafety.unc.edu/research/projects/2018r17.

the ability to change in response to disruptions and alterations in funding, available technology, extreme weather events, demographic shifts, changes in travel patterns, and more (Markolf et al. 2019; Marsden and Docherty 2013). Further, those tasked with implementing policies should adopt an explicit learning orientation and gather feedback on policy performance and adjusting policies accordingly (Sterman 1994; Reiman et al. 2015).

Some changes and disruptions can be anticipated, such as the need to routinely maintain bridge and street infrastructure. Other changes will be unanticipated; therefore, implementing redundancies that can back up failing parts of the system must be required.

Methods to proactively respond to anticipated and unanticipated conditions include the following:

- Enable automatic policy adjustments that are triggered by anticipated events (e.g., experimenting with quick-build curb extensions during foreseen diminished capital funding).
- Schedule regular policy reviews even when the policy is performing as intended so that policies can meaningfully respond to emerging issues (e.g., rising use of drugs while driving) and adjust to changing conditions that could not have been anticipated.
- Diversify implemented policies, which makes it easier to contend with changes, by spreading risk across the system (Berkes, Colding, and Folke, 2003) (e.g., simultaneously updating rezoning and Complete Street policies, both of which shape streets' relationships with surrounding land uses, such as the size of building setbacks and the type of bicycle infrastructure appropriate for specific road classifications).
- Decentralize decision-making, which involves granting the authority and responsibility for decision-making to the lowest effective unit of governance, such as setting local speed limits. This often enhances the ability of a policy to perform successfully when confronted with unanticipated events (Swanson and Bhadwal 2009).

2. Build up Safe System–consistent practices and break down inconsistent practices.

Safe System policies should be designed to break down Safe System–inconsistent practices while building up consistent practices. Too often, policymakers and professionals ramp up the

addition of safety measures (e.g., installing separated bicycle lanes along a corridor with a high rate of injuries) without altering policies and practices that increase the risk of severe road-user conflicts (e.g., traffic impact assessments resulting in the addition of turning lanes and widening of driveways, which renders crossing the road more difficult and dangerous). An example of this build-up–break-down approach to Safe System policymaking is allocating revenues generated from speed safety and red-light-running cameras to addressing network gaps in safety infrastructure, especially in areas that have not been involved in decision-making to date. In this case, the unsafe behaviors of speeding and red-light running are actively discouraged, while investment in safe, traffic-calming infrastructure is elevated.

3. Provide reliable and protective system redundancies.

   Safe System policies promote a transition away from layering interventions to providing more reliable, protective redundancies in the system. The popular Swiss cheese model of hazard mitigation shows layers of hole-ridden Swiss cheese illustrating how the layering of different Safe System elements (e.g., safe road users, safe roads, safe speeds) creates system redundancies. However, simply layering safe road users, safe roads, and safe speed elements of a Safe System on top of one another does not guarantee protection for road users. For example, installing new advisory speed plaques can be argued to address the safe road users, safe roads, and safe speeds elements of a Safe System, but signs and plaques alone do not provide reliable protection to road users under a Safe System (Williamson 2021; Soames Job, Truong, and Sakashita 2022).

   Consider a policy that (1) requires location-based speed limiters in private vehicles—e.g., Washington, DC's "Strengthening Traffic Enforcement, Education, and Responsibility (STEER) Amendment Act of 2023," which will pilot test the installation of intelligent speed assist (ISA) in the cars of drivers convicted of criminal aggravated or reckless driving (District of Columbia 2024)—and (2) includes raised pedestrian crossings at transit stop locations. This speed limiter and raised crossing policy combination integrates a reliably protective vehicle technology (i.e., speed governance) with an engineering countermeasure designed to calm car traffic in the realm of crossing pedestrians (i.e., raised pedestrian crossings at transit stop locations). Another example of providing reliably protective system redundancies is pairing automated vehicle lane-keeping technology with longitudinal rumble strips and cable-wire barriers on the edges of rural roads. Furthermore, maintenance of safety infrastructure can be argued to support system redundancy (Große 2023). Road users are protected to the extent diverse system elements are functioning as intended and remain in healthy operating condition.

2.2 Study-Identified Policy Practices

Stemming from policy strategies are more specific safety practices. The example practices outlined in Table 2 align with the strategies of Safe System policies in that they are intended to be adaptive rather than inflexible, to be paired with a scaling down of Safe System–inconsistent policy, and to create conditions within which system redundancies can be implemented and maintained.

The research team identified 19 Safe System–aligned policies from the literature review phase of the research and presented them to safety practitioners via an online survey. Survey participants were asked to rate the safety impact and the financial, social, and political feasibility of each practice, based on their professional experience and institutional knowledge. Participants' responses on the perceived impact and feasibility of the 19 policy practices can be found in Appendix A.

Table 2. Safe System policy practices.

Example Policy	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Updating NHTSA's New Car Assessment Program (NCAP) to include pedestrian detection and collision avoidance safety tests	Reduces chances of severe vehicle-pedestrian crashes via detection and crash avoidance technology	–	☑	☑	–	High
Requiring alcohol ignition interlocks installed for all drivers convicted of driving under the influence (DUI)	Prevents repeat offenders from operating a vehicle under the influence and reduces other road users' exposure to impaired drivers	☑	☑	–	–	Medium
Promoting the installation of technology in private automobiles that records drivers' distraction, drowsiness, and other forms of incapacitation	Reduces drivers' impairment levels by monitoring their degree of alertness and reduces other road users' exposure to impaired drivers	☑	☑	–	–	Low
Establishing maximums in vehicle size (in terms of width, length, height, weight) permitted in areas with high pedestrian activity	Reduces pedestrians' exposure to harmful kinetic energy levels and vehicle profile heights	☑	☑	☑	–	Medium
Installing seat belt interlocks in vehicles	Secures vehicle occupants to their seats, allowing the vehicle's crush zone to absorb the kinetic energy transferred in a crash	–	–	☑	–	High
Installing speed governors/ limiters in all municipal or state fleet vehicles	Prevents drivers of municipal fleet vehicles from traveling at unsafe speeds and conveys lower operating speed norms	–	☑	☑	–	Medium
Requiring location-based speed limiters in all commercial and private vehicles in areas with high pedestrian activity	Reduces vehicle operating speeds in locations pedestrians are likely to be present	–	☑	☑	–	Low

Table 2. (Continued).

Example Policy	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Developing policies requiring forward- and near-side-facing sensors on heavy vehicles to detect pedestrians and cyclists	Reduces chances of vehicle-pedestrian crashes by sensing pedestrians and cyclist in heavy vehicles' blind spots	–	✓	–	–	Low
Setting posted speed limits based on harm minimization principles, road function, and severe crash types rather than reliance on operating speed data	When reliably enforced and designed to slow vehicles, reduces injury likelihood and severity by lowering vehicle operating speeds	–	✓	✓	–	Low
Instituting or enforcing a statewide primary enforcement seat-belt-use law	Increases the odds vehicle occupants will be secured to their seats, allowing the vehicle's crush zone to absorb the kinetic energy transferred in a crash	–	–	✓	–	Medium
Implementing speed safety cameras (automated speed enforcement) that use revenues to improve safety	Deters drivers from operating their vehicles at unsafe speeds while building up safety programming	–	✓	✓	–	High
Instituting or enforcing a statewide universal motorcycle helmet law, which would require all motorcyclists to wear U.S. DOT–compliant helmets, regardless of the rider's age or experience	Absorbs initial crash impact and spreads the transferred kinetic energy around the helmet	–	–	✓	–	Medium
Implementing red-light camera enforcement that uses revenues to fund safety infrastructure	Deters drivers from running red lights while building up safety infrastructure	–	✓	–	–	High

(continued on next page)

Table 2. (Continued).

Example Policy	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Extending graduated driver licensing requirements to include all novice drivers regardless of age	Requires novice drivers to develop safe driving skills via supervised practice	–	☑	–	–	High
Establishing a default speed limit of 20 mph or lower in every business or residential district	When reliably enforced and designed to slow vehicles, can reduce vehicle operating speeds in locations pedestrians are likely to be present	–	☑	☑	–	Medium
Instituting immediate administrative license revocation or suspension (ALR/ALS) for alcohol- and drug-impaired-driving offenses	Deters impaired driving by swiftly removing driving privileges in the event of an infraction	☑	☑	–	–	High
Lowering the blood alcohol concentration (BAC) limit for driving from 0.08 to 0.05	By pairing this policy with public education and reliable enforcement procedures, the policy can lower serious crash risks by reducing the degree of alcohol impairment among the driving population	–	☑	–	–	Low
Installing leading pedestrian intervals with right-turn-on-red restrictions in areas with high pedestrian activity	Reduces right turn vehicle-pedestrian crashes by separating these road users in time	☑	☑	–	–	Low
Instituting a driver license renewal program that requires passing an on-road driving test every 5–10 years	Enhances the likelihood that drivers possess safe levels of visual acuity, perceptual decision-making, and reaction times	–	☑	–	–	High

Note: – = Not applicable.

[1] IRA = injury risk assessment, PCC = professional and community coordination, CD = crash diagnoses.

[2] Costs correspond to the total financial cost associated with a policy or practice, including labor, equipment, and infrastructure (Low ≤ $100k, Medium = $100k–$1 million, and High ≥ $1 million in total or per year).

In keeping with Safe System principles and policy strategies, the team determined whether each planning practice would reduce road users' exposure to severe crash types (e.g., run-off-road, head-on, intersection, pedestrian, bicyclist, or motorcyclist crashes) and the likelihood road users would be involved in one or more of these crash types.

- Exposure reflects the number of people with the potential to be involved in serious crash types.
- Likelihood reflects the probability road users will be involved in a crash.
- Severity reflects the chances a crash will result in a fatality or serious injury to the road users involved.
- Improves injury risk assessment, professional and community coordination, or crash diagnoses reflects a practice's ability to estimate road-user injury risks associated with land use, policy, or engineering interventions; to improve coordination among professionals in different sectors and with the public; or to uncover contributing factors to serious crash events.

Table 2 provides example policies and their change mechanisms (i.e., the steps or processes responsible for improving road users' safety).

Implementing Safe System Policies

Safe System policies are adaptive, replace Safe System–inconsistent policies, and provide reliable protection to road users through system redundancy. These policies are useful only to the extent they are implemented and maintained.

To begin implementing Safe System–aligned law enforcement practices, consider the following steps and substeps:

1. Identify at least one significant safety problem. Identification and prioritization of a safety problem might be based on the following:
   - Severity and magnitude of the safety problem
   - Disproportionate harm caused by the problem and endured by some community members
   - Importance of addressing the problem to community representatives
   - Availability of resources to address the problem
2. Ask the following two questions once a safety problem has been identified and prioritized:
   - To what extent does a proposed practice to address the identified problem align with Safe System–aligned policy strategies?
     - Advance adaptive safety policies
     - Build up Safe System–consistent practices and break down inconsistent practices
     - Provide reliable and protective system redundancies
   - To what extent does a proposed practice reduce the following?
     - Users' exposure to serious crashes
     - Likelihood of serious crashes
     - Severity of crashes when they occur
     - Improvements to injury risk assessment, professional and community coordination, or crash diagnoses

For example, in step 1, if a safety team identifies and prioritizes addressing pedestrian injury near schools, they might pursue establishing maximums in vehicle size (in terms of width, length, height, and weight) permitted in areas with high pedestrian activity given the disproportionate harm endured by some community members.

In step 2, a safety team might conclude that a maximum vehicle size policy aligns with the Safe System strategy to provide reliable and protective system redundancies, especially if coupled with robust speed enforcement. The team might also conclude that a maximum vehicle size policy can reduce the severity of crashes when they inevitably occur.

At this point, a team should reflect on whether a selected safety practice (1) aligns with one or more Safe System strategies; (2) can significantly reduce the likelihood of users' exposure to severe crash forces or enhance injury risk assessment, professional and community coordination, or crash diagnoses; and (3) is feasible given available resources to institute the practice. If the team concludes that all three criteria are satisfied, the practice should be considered for implementation, and the safety team could follow the steps outlined in Table 3. However, if one or more of these three criteria are not satisfied, teams are recommended to start over from step 1 until all three criteria are satisfied.

For illustrative purposes, consider a safety team looking to establish vehicle size maximums (in terms of width, length, height, weight) in areas with high pedestrian activity. Table 3 provides recommended steps to implement this safety practice along with elements to consider within each step.

Table 3. Policy practice implementation steps and example elements.

Step	Example Step Elements
Determine the policy's intended goals, the factors that contribute to policy performance and interactions among factors, what key factors might look like in the future, and success indicators.	• The goals of this policy are to protect people from unsafe interactions with larger vehicles in places replete with pedestrians. • The factors that contribute to policy performance include, at least, the dimensions of maximums in vehicle width, length, height, and weight; the means of measuring these vehicle dimensions; and how reliably enforceable this policy is. • Key factors in the future will likely involve the potential for favoring more privileged populations with these protections over protecting less advantaged populations if only reacting to requests from the public, waxing and waning of public interest in enforcing the vehicle size policy, or applying the policy in different geographic areas over time, and more. • Success indicators might include decreasing pedestrian fatalities and serious injuries involving larger vehicles inside the policy-applied areas versus outside the policy-applied areas, community member reports of feeling safer in the policy-applied areas versus outside the policy-applied areas, and more people walking for all purposes in the policy-applied areas versus outside the policy-applied areas over time.
Enable innovation of policies to meaningfully respond to foreseen and unforeseen opportunities.	• Meaningfully responding to foreseen and unforeseen opportunities might include policy adjustments to triggered anticipated events (e.g., expansion of the vehicle size-limiting zone based on anticipated development on the edge of downtown); yearly review to assess whether the policy is associated with reductions in serious and fatal pedestrian injury in the policy zone; coupling the vehicle size-limiting zone policy with speed safety camera installation in the zone toward spreading serious crash risk across reductions in vehicle size and vehicle operating speeds; and granting authority to the local municipality to institute and adjust the policy based upon local knowledge of anticipated and unanticipated events.
Monitor indicators of performance in relation to policy objectives, key factor indicators and thresholds for adjusting the policy, and interested party feedback on the policy.	• Indicators of policy performance would likely involve collecting data before and during policy implementation on serious and fatal injury in vehicle size-limiting zone, public feedback on the policy, delivery industry feedback on the policy, pedestrian volumes in the zone, and more. • Key factor indicators and thresholds for adjusting the policy might include rising serious and fatal-injury-involving crashes with larger vehicles within or outside the vehicle size-limiting zone, growing negative public or industry feedback on the policy, a reduction in pedestrian volumes in the zone, planned land developments near the policy zone that could shift pedestrian movement to outside the zone, and more.

Table 3. (Continued).

Step	Example Step Elements
Improve learning of policy performance to make necessary adjustments to shore up policy performance.	• Learning about policy performance requires consistent measurement of policy performance indicators such as the number of serious and fatal injuries inside and outside the vehicle size-limiting zone, public and delivery industry perspectives of the policy, pedestrian volumes inside and outside the policy zone, additional health metrics of interest (e.g., air quality, noise), and more. • Making necessary policy adjustments to shore up policy performance requires local agencies and partners to reflect on results of the measured performance indicators and decide to update policy parameters (e.g., adjusting the boundaries of the policy zone, increasing enforcement of the policy, changing which heavy vehicle operators are permitted in the zone).

Conclusion

The shift toward Safe System policy is possible and necessary for the United States to realize zero deaths and serious injuries on the nation's roadways. Policymakers and partners can design and implement adaptive safety policies. They can also put forth policies that simultaneously build up Safe System–consistent practices while breaking down inconsistent practices. In addition, policymakers can advance policies that provide reliable and protective system redundancies for all road users. Indeed, policy provides the foundation from which to foster and maintain a truly Safe System. Chapter 3 focuses on Safe System–aligned planning.

CHAPTER 3

Safe System Planning

Planning is the process of creating a vision, goals, and proposed actions for a community in the short, medium, and long term. Planning is a critical forum for creating safer transportation systems at the local, regional, state, and federal levels.

Making planning decisions based on Safe System principles would allow future land use and transportation network decisions to actively improve safety for all road users and prevent some of the conflicts that might otherwise need to be mitigated through other measures such as design or enforcement.

Traditional planning in the 20th and early 21st centuries focused on using traffic generation models to predict the future needs of drivers (Lana et al. 2018). These models were typically built on the assumption that vehicle demand would always increase and that municipalities should treat this increase in VMT as though vehicular traffic were water overflowing a network of too-small pipes by building larger pipes (or in this case, roads) (Downs 2000).

This assumption has been used to justify directing immense energy and public funds toward adding extra vehicle capacity into the road network. However, because of the well-established principle of induced demand (Lee, Klein, and Camus 1999; Hymel 2019), this planning approach has led to increased traffic and a vicious cycle of expanding roadways and intersections to serve increasing volumes of vehicles. Increasingly wide roads and fast-moving traffic have come at an enormous financial expense and led to increased crash potential for all road users but especially people walking, rolling, and using transit (Schmitt 2020).

A paradigm shift is needed to embed safety as a primary objective of long-range transportation plans and to program funding for safety-oriented projects in transportation improvement plans. Federal adoption of the Safe System approach is explicitly aimed at changing these processes to embed safety at all levels of the planning process (Evenson et al. 2023).

The Safe System approach, which has roots in Sweden and the Netherlands, prioritizes human health and safety above all other transportation goals and aims to reduce the frequency and severity of collisions through layers of systemic decisions that insulate users from injurious human errors (Tingvall and Haworth 1999). Vision Zero gained popularity in the United States in 2014 when New York City became the first U.S. city to adopt a goal of zero traffic fatalities and serious injuries (City of New York 2014). Since then, nearly 90 U.S. cities have adopted Vision Zero programs (Evenson et al. 2023). There is an immense appetite for this planning shift, as evidenced by the spread of Vision Zero plans across the United States and the increase in safety-focused federal transportation grants, as well as other measurable results. For example, in 2024 Hoboken, New Jersey, celebrated its seventh consecutive year without a single road death (Brey 2024).

3.1 Key Planning Strategies

The most effective method of managing traffic conflicts is to prevent them from occurring in the first place. Safe System planning encompasses a wide variety of approaches for reducing fatalities and serious injury, from reducing the use of transportation modes that tend to increase the frequency and severity of crashes to planning urban areas so that most motor traffic is kept away from the areas where people live, work, and play.

To apply the principles of a Safe System in the context of planning, the following planning strategies can encourage practices that contribute to a Safe System:

- Start from a collective vision for a Safe System.
- Integrate planning vertically and horizontally.
- Clearly define the functionality of roads.
- Separate motor vehicle networks from active transportation networks.

Start from a Collective Vision for a Safe System

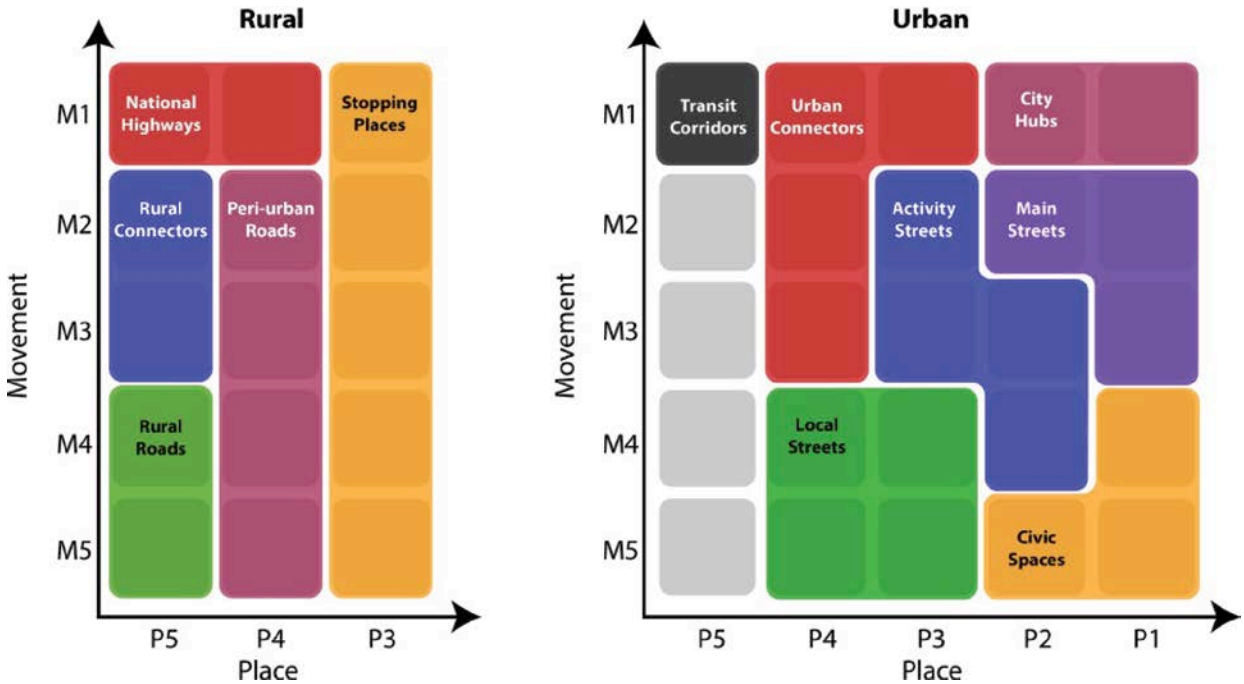
A vision-led planning process can effectively guide the way toward fostering a Safe System. Vision-led planning, also called a decide-and-provide approach, identifies transportation system needs and investments based on their alignment with a collective vision for the future. Rather than predicting and accommodating future travel demand, it instead orients investments toward the foundational goals and aims of the community and transportation system itself. The process defines what the future of the system should be and then implements policies and makes choices that can help bring about these intended changes (Lyons et al. 2015; International Transport Forum 2021).

A consequence of a Safe System vision is a general reduction in the public's dependence on the automobile (Corben, Peiris, and Mishra 2022). It is common practice to evaluate road safety using metrics such as the fatality rate per 100 VMT. While this is a valuable statistic that can facilitate comparisons between infrastructure types, the goal of a Safe System is not merely to reduce the fatalities per vehicle mile, but to reduce fatalities overall. In addition to reducing the fatalities per vehicle mile, it is also helpful to reduce the total number of VMT. To support this strategy, planners support mode shift toward modes with lower fatality and serious injury outcomes such as trains and buses (Ibrahim et al. 2023).

Integrate Planning Vertically and Horizontally

Ensuring vertical integration across regional and local jurisdictions operating at different levels of government helps embed Safe System decision-making along all scales of the U.S. transportation system, from policy to network planning and implementation of street design projects (Tayarani et al. 2018; Bax, Leroy, and Hagenzieker 2014). This coordination could result in something akin to Australia's and New Zealand's "Movement and Place" framework (Chiarenza, Sharplin, and McGill 2023), which outlines the types of movement and place-making privileged in designated areas throughout rural and urban transportation networks (Figure 4).

At more local levels of government, horizontal integration requires transportation planners and urban designers to coordinate their site plan reviews, corridor audits, and street standard policies with local land-use planners and coding officials and developers. The horizontal alignment of the transportation and land-use planning disciplines has the potential to harmonize the transportation and land-use systems in ways that vastly improve the safety of road users (Heanue 1998; Combs and McDonald 2021), for example, by systematically rendering roads "self-explaining," with a clear priority for mobility or access purposes (Dumbaugh, Saha, and



Source: Chiarenza, Sharplin, and McGill 2023.

Figure 4. Illustration of the Movement and Place framework.

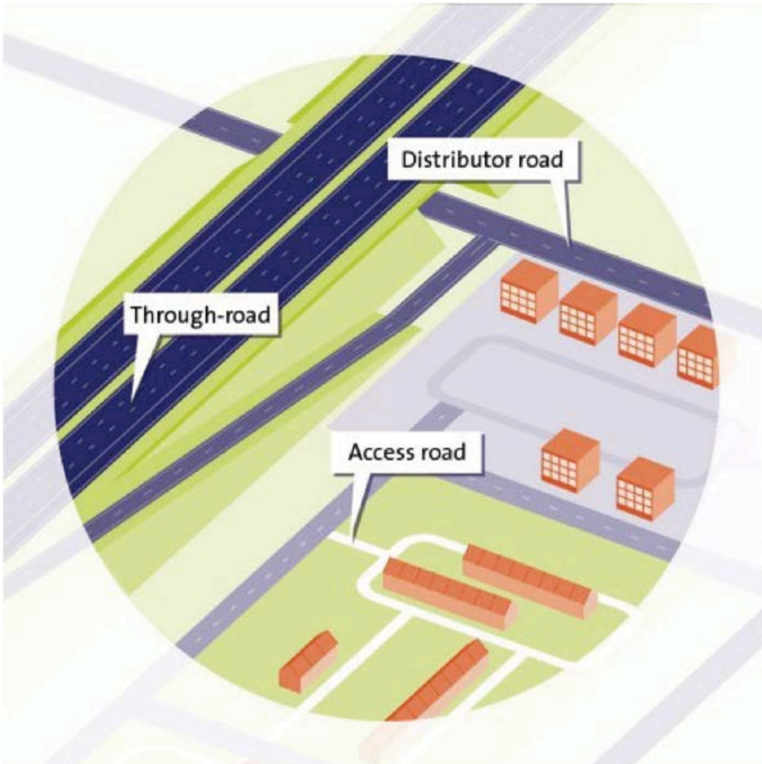
Merlin 2020; Dumbaugh et al. 2020). This approach to horizontal integration also holds promise to discourage the proliferation of cross-purpose, higher-speed arterial roads, which have been shown to disproportionally impact Black, Indigenous, and Latin pedestrians and cyclists in suburban and urban areas of the United States (Schneider 2020; Barajas 2018; Sanders, Schneider, and Proulx 2022).

Clearly Define the Functionality of Roads

For motor traffic to operate safely at high speeds, separation from conflicting uses such as on-street parking, driveways, frequent cross-streets, and uncontrolled pedestrian crossings must be considered. The most effective method of minimizing conflicting road uses is to separate motor traffic through-routes from areas where people live, work, and play. When planning road networks, this entails concentrating motor traffic onto the streets and areas where it has the least impact on the daily life of residents, and, when planning land uses, development can be directed away from roads that have been designated as through-movement corridors for motor traffic, as depicted in the functional road categories used in the Netherlands (see Figure 5).

In the United States, road classification is a well-established method for defining the purpose of roadways. Per the existing classification, streets fall along a spectrum of local streets, collectors, arterials, and interstates. Local streets are intended solely for local access and nontransportation functions (e.g., playing, gathering). On the other extreme, interstates are intended solely to move motorized vehicles at high speeds, so they do not have access to properties, they are fully grade-separated, and pedestrians are forbidden from using them (Stamatiadis et al. 2018).

In the United States, many streets that serve as destinations also act as arterial roads, carrying large volumes of fast-moving traffic. Yet in a Safe System, major arterial roads would provide little to no access to properties given their designated role of transporting large volumes of motor traffic (McCombs et al. 2024).



Source: SWOV 2023.

Figure 5. Dutch road categorization.

Separate Motor Vehicle Networks from Active Transportation Networks

As motor traffic speeds and volumes increase, the level of separation from vulnerable road users should also increase. This can occur within the streetscape in the form of separate infrastructure such as cycle tracks and median islands, but it can be even more effective to separate motor traffic from active transportation at a network level (van Ommeren et al. 2017).

In the Netherlands, this practice is referred to as "unbundling" or "detangling" networks. An example of this strategy is found in the network design of the Dutch town of Houten. Houten's street network is organized around the principle that trips for people walking, biking, and taking transit should be short and direct, while trips for private vehicles can take longer, more circuitous routes because these users are less sensitive to delay. Although the entire town is accessible by car, the only through-routes for private motor traffic are the ring road around the town and one crosstown connecting road. This means that cycling, walking, and transit are more attractive for most trips than private vehicles, and there are fewer traffic conflicts in the areas where people live, work, and play.

3.2 Study-Identified Planning Practices

Building on planning strategies leads to more specific practices. To identify Safe System–aligned planning practices, the team surveyed public health, planning, and engineering professionals regarding the challenges of Safe System planning. Survey participants were asked to rate the safety impact and the financial, social, and political feasibility of each practice, based on their professional experience and institutional knowledge. Analysis of the responses revealed a

wide range of feasibility scores, and a more modest range of impact scores, which can be found in Appendix B.

The research team identified 10 Safe System–aligned planning practices from the literature review phase of the research and presented them to safety practitioners via an online survey. Survey participants were asked to rate the safety impact and the financial, social, and political feasibility of each practice, based on their professional experience and institutional knowledge. Participants' responses on the perceived impact and feasibility of the 10 planning practices can be found in Appendix B.

In keeping with Safe System principles and planning strategies, the team determined whether each planning practice would reduce road users' exposure to severe crash types (e.g., run-off-road, head-on, intersection, pedestrian, bicyclist, or motorcyclist crashes) and the likelihood road users would be involved in one or more of these crash types.

- Exposure reflects the number of people with the potential to be involved in serious crash types.
- Likelihood reflects the probability road users will be involved in a crash.
- Severity reflects the chances a crash will result in a fatality or serious injury to the road users involved.
- Improves injury risk assessment, professional and community coordination, or crash diagnoses reflects a practice's ability to estimate road-user injury risks associated with land use, policy, or engineering interventions; improve coordination among professionals in different sectors and with the public; or uncover contributing factors to serious crash events.

Table 4 provides example planning practices and their change mechanisms (i.e., the steps or processes responsible for improving road users' safety).

Implementing Safe System–Aligned Planning Practices

Safe System planning practices center around strategies to start with a collective vision for a Safe System, integrate planning efforts vertically and horizontally, clearly define roads' functionality, and where possible, separate motor vehicle networks from active transportation networks.

To begin implementing Safe System–aligned planning practices, consider following these steps and substeps:

1. Identify at least one significant safety problem. Identification and prioritization of the problem might be based on the following:
   - Severity and magnitude of a safety problem
   - Disproportionate harm that the problem imposes on some community members
   - Stated importance of addressing the safety problem, according to community representatives
   - Availability of resources to address the problem
2. Once a safety problem has been identified and prioritized, ask the following two questions:
   - To what extent does the proposed practice align with Safe System–aligned planning strategies?
     - Start from a collective vision for a Safe System
     - Vertically and horizontally integrate planning
     - Clearly define the functionality of roads
     - Separate motor vehicle networks from active transportation networks
   - To what extent does the proposed practice address the following?
     - Users' exposure to serious crashes
     - Likelihood of serious crashes
     - Severity of crashes when they occur
     - Improvements to injury risk assessment, professional and community coordination, or crash diagnoses

Table 4. Safe System planning practices.

Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Incorporating road safety audits in project scoping/planning phases	Helps identify safety concerns prior to construction	–	–	–	☑	Low
Prioritizing injury risk-based (systemic) safety assessments over crash "hot spot" or "black spot" approaches	Assists in discerning crash potential before injurious crashes manifest	–	–	–	☑	Low
Prioritizing interventions to reduce severe-injury crashes over property-damage-only crashes	Focuses resources on interventions to reduce the odds of the most impactful crash types occurring	–	☑	☑	–	Low
Communicating with communities previously not involved in decision-making to learn about their safety issues and concerns on a routine basis (annually, quarterly)	Builds trust with community members and aligns practice with community concerns and values	–	–	–	☑	Medium
Coordinating with land-use planners to align land-use and roadway purposes	Results in greater agreement on roadway access and mobility purposes	☑	☑	☑	–	Low
Implementing or expanding car-free zones in areas with high pedestrian activity	Protects pedestrians by physically separating them from motor vehicles	☑	☑	☑	–	Medium
Setting a goal in safety plans to reduce road deaths by a specific amount (e.g., 50%, by 2030)	Sets a policy goal to motivate and drive safety investment	–	–	–	☑	Low
Encouraging and facilitating public use of self-reporting (via mobile app or survey) to capture collisions and other events falling outside the scope of traditional crash reporting (e.g., near misses, pedestrian and bicyclist falls)	Allows for more encompassing data collection of roadway features, characteristics, and conflicts	–	–	–	☑	Medium

(continued on next page)

Table 4. (Continued).

Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Simulating the safety effects of land developments and investments in long-range plans. Not only in the plan but implemented in practice	Applies a safety-oriented lens on redevelopment areas	–	–	–	☑	Medium
Incorporating nontraditional transportation safety data sources as part of problem identification and project prioritization processes	Leads to a broader understanding of safety and need	–	–	–	☑	Medium
Replacing travel forecasting ("predict and provide") with backcasting ("decide and provide")	Starts from a vision of safe, desirable travel patterns and works backward to realize the vision	–	–	–	☑	Low

Note: – = Not applicable.

[1] IRA = injury risk assessment, PCC = professional and community coordination, CD = crash diagnoses.

[2] Costs correspond to the total financial cost associated with a policy or practice, including labor, equipment, and infrastructure (Low ≤ \$100k; Medium = \$100k–\$1 million; and High ≥ \$1 million in total or per year).

For example, in step 1, if a safety team identifies and prioritizes addressing injurious crash potential on the road network, they might pursue prioritizing injury risk-based (systemic) safety assessments over crash "hot spot" or "black spot" approaches given the severity and magnitude of serious crash potential on the network and the disproportionate harm endured by some community members by failing to capture all injurious crashes in police crash data.

Then, in step 2, a safety team might conclude that prioritizing injury risk-based (systemic) safety assessments over hot spot analyses aligns with the Safe System strategy to clearly define the functionality of roads. They might also conclude that injury risk-based (systemic) safety assessments can reduce the likelihood of serious crashes on the network and the severity of crashes that occur.

At this point, a team should reflect on whether a selected safety practice (1) aligns with one or more Safe System design strategies; (2) can significantly reduce the likelihood of users' exposure to severe crash forces or enhance injury risk assessment, professional and community coordination, or crash diagnoses; and (3) is feasible given available resources to institute the practice. If the team concludes that all three criteria are satisfied, the practice should be considered for implementation, and the safety team could follow the steps outlined in Table 5. However, if one or more of these three criteria are not satisfied, teams are recommended to start over from step 1 until all three criteria are satisfied.

For illustrative purposes, a safety team looks to carry out injury risk-based (systemic) safety assessments across their roadway network. Table 5 provides recommended steps to implement this safety practice along with elements to consider within each step.

Table 5. Planning practice implementation steps and example elements.

Step	Example Step Elements
Determine the practice's intended goals, the factors that contribute to practice performance and interactions among factors, what key factors might look like in the future, and success indicators.	• The goals of this practice are to proactively assess the potential for serious crash outcomes on roadway networks. • The factors that contribute to practice performance include, at least, the availability of valid and reliable exposure data for all road users, staff's ability to appropriately estimate injurious crash potential, the availability of valid and reliable land-use data, and more. • Key factors in the future will likely involve changing land uses over time, state and federal investments in road infrastructure, housing policy changes, changing sociodemographics, advances in statistical methods to estimate serious crash potential, and more. • Success indicators might include increases in the number of implemented cost-efficient safety countermeasures, community member reports of feeling safer while traveling, decreases in serious and fatal traffic injuries, and more.
Enable innovation of practices to meaningfully respond to foreseen and unforeseen opportunities.	• Meaningfully responding to foreseen and unforeseen opportunities might include practice adjustments triggered by anticipated events (e.g., large-scale land developments planned over the next 20 years), yearly review to assess whether the practice is associated with increases in the number of implemented cost-efficient safety countermeasures, community member reports of feeling safer while traveling, decreases in serious and fatal traffic injuries, and granting authority to the local municipality to institute and adjust the practice based on local knowledge of anticipated and unanticipated events.
Monitor indicators of performance in relation to practice objectives, key factor indicators and thresholds for adjusting the practice, and interested party feedback on the practice.	• Indicators of practice performance would likely involve collecting data before and during practice implementation on number of implemented cost-efficient safety countermeasures, public feedback on their perceived levels of safety while traveling, the number and severity of crashes on the network, and more. • Key factor indicators and thresholds for adjusting the practice might include rising serious and fatal injury in the community, growing negative public feedback on the practice, a decline in the number of implemented cost-efficient safety countermeasures, planned land developments that could alter systemic safety analysis parameters, and more.
Improve learning of practice performance to make necessary adjustments to shore up practice performance or to change up the practice altogether.	• Learning about practice performance requires consistent measurement of practice performance indicators such as the number of implemented cost-efficient safety countermeasures, the number of serious and fatal injuries along the network, public perspectives of their safety while traveling, additional health metrics of interest (e.g., air quality, noise), and more. • Making necessary practice adjustments requires local agencies and partners to reflect on results of the measured performance indicators and decide to update practice parameters or change up the practice altogether (e.g., adjusting the methods used to estimate serious crash potential, identifying new ways to precure safety infrastructure).

Conclusion

The shift toward Safe System planning practice is possible and necessary for the United States to realize zero deaths and serious injuries on the nation's roadways. Planners can work with partners to develop a collective vision for a Safe System. They can integrate their practice vertically with partners operating at different levels of government and horizontally with road designers, land-use planners, coding officials, and developers. Planners can also coordinate with designers to establish a clear and legible priority for mobility or access functions on all roads. Planning is among the first steps toward building and modifying a street network aligned with a Safe System. Chapter 4 addresses Safe System design.

CHAPTER 4

Safe System Design

Road and street design shapes the behavior of road users from the mode they use to travel, the speed at which they do so, the routes they take to their destinations, to the perception of which road users have priority (legal right-of-way and preferred priority). Design is used to separate users in space and in time to prevent crashes and to minimize the kinetic energy (and therefore risk to human life and health) should a crash occur. Design also influences the delay people experience while traveling, the hazards they encounter, and the number of people who can be physically transported along a road or street within a certain time frame. This influence is compounded by the relative permanency of hard infrastructure—which can be maintained for decades—imparting long-lasting effects on entire populations' transportation-related choices, behaviors, health, and safety.

By aligning the design of the road system with the goal of fostering a Safe System, there is great potential to prompt road users to adjust their behaviors that inadvertently pose safety risks to themselves and others. In this way, Safe System–informed design promises to greatly enhance the safety of all road users.

The conventional road safety process employed in the United States is based primarily on ensuring the efficient movement of motor vehicle traffic and a reactive approach to resulting traffic injury (Michael et al. 2021). For example, agencies regularly provide roadway capacity based on present and forecasted motor vehicle traffic volumes at peak 15-minute periods aiming to minimize driver delay (e.g., via LOS metrics), even at the expense of potential road improvements that would improve safety and comfort for diverse people using any travel mode. The resultant increases to roadway capacity (e.g., additional lanes, parallel routes) tend to result in an increase in motor VMT and an increase in all road users' exposure to dangerous, higher-speed traffic (Ding and Taylor 2022).

While section 2B.21 in the *Manual on Uniform Traffic Control Devices for Streets and Highways* states that "On urban and suburban arterials, and on rural arterials that serve as main streets through developed areas of communities, the 85th-percentile speed should not be used" as the sole criteria for setting speed limits (FHWA 2023), many engineers and state legislators continue to place undue emphasis on the 85th percentile speed as the most important consideration for setting speed limits. This reactive approach to setting speed limits encourages practitioners to reinforce current driver behavior rather than proactively modifying street designs and setting context-appropriate, self-enforcing speed limits, based on factors such as surrounding land access and the level of separation required between motor vehicles and vulnerable road users to prevent serious and fatal traffic injury (Kumfer et al. 2023).

A shift toward a Safe System requires a transition to an approach that prioritizes safety and mobility choices for all road users. In a Safe System, road users' safety provides the foundation of all design decisions, and mobility choices stem from this safe foundation (Naumann

et al. 2020). This shift has begun at the federal level with recognition of FHWA Proven Safety Countermeasures (FHWA 2021a), and the U.S. DOT adoption of the Safe System approach as the core of the National Roadway Safety Strategy (U.S. DOT 2022). This new safety approach acknowledges human mistakes and vulnerability and requires the design of a redundant system that protects everyone, including the many people who use roads and streets outside of motor vehicles. A paradigm shift in design is necessary and possible, and the following sections outline design-oriented methods, strategies, and practices to employ in advancing toward a Safe System.

4.1 Key Design Strategies

The following design strategies for transportation networks and roadways can encourage practices that contribute to a Safe System. Design strategies in a Safe System include the following:

- Institute self-enforcing roads.
- Design around human tolerances to crash forces.
- Physically separate fast-moving motor vehicles from each other and from vulnerable road users.

Institute Self-Enforcing Roads

Human psychology plays a fundamental role in the safety of road designs. Safe System–informed roadway design presents environments that are self-enforcing, meaning that users are likely to interpret context-appropriate courses of action without the need for explicit signage or overt communication (Theeuwes 2021). For example, the speed at which drivers feel comfortable traveling should be equal to or less than the posted speed limit. If the comfortable driving speed is higher than appropriate for the environmental conditions, then the roadway design can be physically altered to enhance drivers' awareness of speed, encouraging them to slow down (U.S. DOT 2019).

Another application of self-enforcing design is to intuitively indicate the road-user movements that have the right-of-way (Dumbaugh and Gattis 2005). The path of road users who have priority should be continuous, rather than the path of road users required to yield the right-of-way to others. For example, where a driveway or minor street crosses a sidewalk or cycle track and drivers are required to yield to crossing pedestrians and cyclists, the sidewalk or cycle track should continue at the same elevation above the roadway (producing a continuous sidewalk) as it passes through the conflict area, as shown in Figure 6.

Photo courtesy of Mobycon.

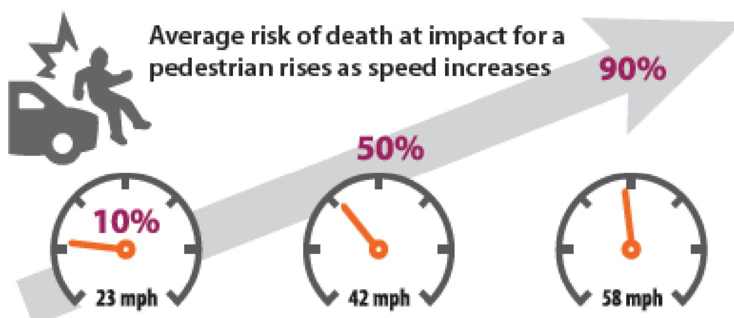
Figure 6. Continuous sidewalk and cycle track across a minor intersection in Portland, Oregon.

Design Around Human Tolerances to Crash Forces

Self-enforcing road designs can meaningfully reduce the likelihood of serious crashes given their alignment with human perceptual systems. Additionally, reliably protecting users from severe injury requires employing what is already known about the effects of kinetic energy in crashes to inform street design. The limits of the human body to withstand crash forces are well-known (Johansson 2009; Tingvall and Haworth 1999). As crash impact speeds increase, the probability of death or serious injury to pedestrians increases nonlinearly, as illustrated in Figure 7. The mass of the colliding vehicles also contributes to the probability of death, as does the vulnerability of people inside and outside of vehicles. Moreover, road users vary in their respective vulnerability, with older adults more likely to be seriously injured or killed in a crash than younger people (Tefft 2013).

A safe transportation system is designed in such a way that infrastructure can safely accommodate the speed and mass of vehicles. Where motor vehicles and nonmotorized road users share space, the speed of vehicles must be reduced to a point that collisions would not be lethal for the road users who will be present in the area.

For example, in areas where pedestrians would be expected to cross midblock at locations with restricted sightlines (e.g., residential streets) or where motor vehicles operate in the same space as people walking or playing, Safe System design requires that drivers operate their vehicles at or below speed thresholds for human tolerance to blunt force trauma, as depicted in the residential street in Figure 8.



Source: FHWA 2019a.

Figure 7. Relationship between impact speed and probability of severe injury and death for pedestrians.

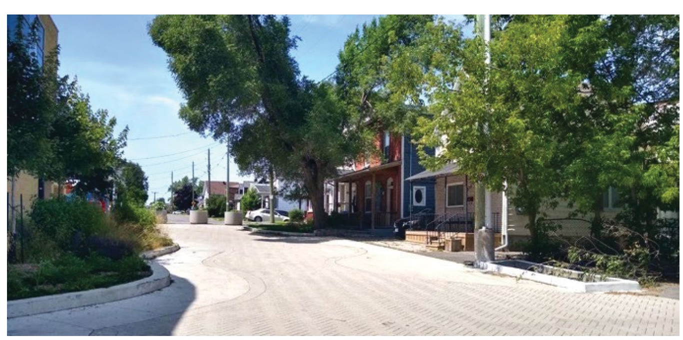


Photo courtesy of Mobycon.

Figure 8. Shared-space residential street in Ottawa, Ontario, Canada, with filtered permeability to prevent cut-through motor traffic and traffic calming to slow vehicles to less than 30 kilometers per hour (km/h) (19 mph).

Beyond impact speed, the types and angle of approach of crashes play a key role in shaping crash outcomes. For example, side-impact collisions between two motor vehicles are survivable at a higher impact speed than head-on collisions (Johansson 2009; Jurewicz et al. 2016). Further, crashes occurring at approach angles of less than 90° tend to be less severe than those occurring at more than 90°, which helps to explain why converting traditional signalized intersections to roundabouts often significantly improves safety (Savolainen et al. 2023; Gross et al. 2013). Designers can use this understanding in shaping roadway design to minimize conflicts between road users and their exposure to intolerable crash forces. In rural contexts, the 2+1 road in Sweden depicted in Figure 9 provides a through-function with operating speeds of about 50 mph (80 km/h) and a median cable barrier to prevent head-on collisions and encourages driver alertness via alternating the number of lanes every few kilometers (Belin et al. 2022).

Where drivers are invited to travel at high speeds, it is fundamental to consider the composition of traffic at links and intersections, such as the stopping distances and intersection sight distances of trucks, buses, and sport utility vehicles. If these characteristics are not compatible with the function of the street (e.g., if intersection sight distance limits visibility of a motorcycle using the same segment), the function of the street may need to be changed. Designers can coordinate with planners to determine the roadway function; this function should be designed around known human tolerances to crash forces. Thus, if vehicle-to-vehicle crashes could conceivably happen at angles of 90° or greater, such as at 4-way uncontrolled intersections, speeds should not exceed 30 mph, and if vulnerable road users are exposed to vehicles, speeds should not exceed 20 mph (Johansson 2009; Soames Job, Truong, and Sakashita 2022). Design tools such as access management, corner radii reduction, and intersection conversions to roundabouts can be used to reduce speeds, change approach angles, or manage user interactions at high-speed angle conflict points.

Source: Potts 2003.

Figure 9. A 2+1 road in Sweden, which is a three-lane road that consists of two lanes in one direction and one lane in the other, alternating every few kilometers to enable passing.

Physically Separate Fast-Moving Motor Vehicles from Each Other and from Vulnerable Road Users

Just as Safe System–aligned design prevents crash forces from severely or lethally injuring road users, a key Safe System design strategy is to physically separate fast-moving vehicle traffic from more vulnerable road users. For example, on roadways designed for motor vehicle travel at 25 mph or higher, a separated, protected space should be provided for people cycling (Schultheiss et al. 2019). Across entire road networks, agencies can unbundle bicycle networks from car networks (FHWA 2019b). Physical protection—with design features like curbs, barriers, planters, or bollards—provides for user safety. Where vulnerable road users are physically separated from motor vehicle traffic—by providing grade separation between road users of different masses and speeds as shown in Figure 10—and sufficient sightlines are provided for drivers to slow to survivable speeds prior to a collision, higher speeds can be safely accommodated. This strategy is consistent with a Tier 1 solution within the Safe System Design Hierarchy—i.e., "Remove Severe Conflicts" (Hopwood, Little, and Gaines 2024).

4.2 Study-Identified Design Practices

These overarching design strategies yield more specific safety design practices. The illustrated design practices in Table 1 align with the strategies of Safe System design in that they are intended to render traveling across entire road networks more intuitive (and thus less prone to recognition errors), more forgiving of mistakes, and in keeping with the human body's capacity to survive the kinetic energy transferred in crashes.

The team extracted 16 Safe System–aligned design practices from a literature review phase of the research and presented them to safety practitioners via an online survey (see Appendix C for the complete list). Survey participants were asked to rate the safety impact and the financial, social, and political feasibility of each practice based on their professional experience and institutional knowledge. Analysis of the responses revealed a wide range of feasibility scores, and a more modest range of impact scores, which can be found in Appendix C.

In keeping with Safe System principles and design strategies, the team determined whether each design practice would reduce road users' exposure to severe crash types (e.g., run-off-road,

Photo courtesy of Dan Burden, pedbikeimages.org.

Figure 10. Grade-separated multiuse trail crossing in Aspen, Colorado.

head-on, intersection, pedestrian, bicyclist, or motorcyclist crashes) and the likelihood road users would be involved in one or more of these crash types.

- Exposure reflects the number of people with the potential to be involved in serious crash types.
- Likelihood reflects the probability road users will be involved in a crash.
- Severity reflects the chances a crash will result in a fatality or serious injury to the road users involved.
- Improves injury risk assessment, professional and community coordination, or crash diagnoses reflects a practice's ability to estimate road-user injury risks associated with land use, policy, or engineering interventions; to improve coordination among professionals in different sectors and with the public; or to uncover contributing factors to serious crash events.

Table 6 provides example design practices and their change mechanisms (i.e., the steps or processes responsible for improving road users' safety).

Implementing Safe System Design Practices

Safe System design practices center around strategies to advance self-enforcing roads, structure street networks around human tolerance to crash forces, and where feasible, physically separate travel modes of different sizes, masses, and directions.

To begin implementing Safe System–aligned design practices, consider following these steps and substeps:

1. Identify at least one significant safety problem. Identification and prioritization of a safety problem might be based on the following:
   - Severity and magnitude of the safety problem (e.g., in the region, across the network, along a corridor)
   - Disproportionate harm that the problem imposes on some community members
   - Stated importance of addressing the problem, according to community representatives
   - Availability of resources to address the problem
2. Once a safety problem has been identified and prioritized, ask the following two questions:
   - To what extent does a proposed practice align with Safe System–aligned design strategies?
     - Institute self-enforcing roads
     - Design around human tolerances to crash forces
     - Separate fast-moving motor vehicles from vulnerable road users
   - To what extent does a proposed practice address the following?
     - Road users' exposure to serious crash forces
     - The likelihood of serious crashes
     - The severity of crashes when they occur
     - Improvements to injury risk assessment, professional and community coordination, or crash diagnoses

For example, in step 1, if a safety team identifies and prioritizes addressing high-speed angle crashes, they might pursue converting conventional signalized intersections to single-lane roundabouts given the severity and magnitude of this safety problem and the disproportionate harm that this problem imposes on some community members.

Then, in step 2, a safety team might conclude that roundabout conversions align with the Safe System strategy to design around human tolerances to crash forces. They might also conclude that roundabout conversions can significantly reduce the severity of crashes when they occur by reducing impact speeds and crash angles within the roundabout.

Table 6. Safe System design practices.

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Incorporating road safety audits in project development and design phases	Helps identify safety concerns prior to construction	–	–	–	☑	Low
Installing poles that break away when struck	Offers forgiving infrastructure in the event drivers run off the road	–	–	☑	–	Medium
Installing right-in/right-out junctions that only allow vehicles to enter and exit from the right	Reduces road-user conflicts by channelizing vehicle turning movements and eliminating some crossing conflicts	☑	☑	–	–	High
Installing cable barriers on the edges and in the medians of rural roads	Separates users in space to catch and protect drivers who drift over the centerlines or edges of roads	☑	☑	☑	–	High
Installing permanent barrier-protected bike lanes on arterial roads	Separates users in space with a physical separation between faster-moving vehicle traffic and slower-moving bicycle traffic	☑	☑	☑	–	High
Providing pedestrian/bicycle bridges or daylit tunnels at intersections	Physically separates pedestrians and bicyclists from through and turning vehicle movements at intersections	☑	☑	☑	–	High
Setting default local street travel lane widths to 10 ft.	Manages vehicle operating speeds	–	☑	☑	–	Low
Improving sight distance at intersections by restricting parking at the corners (daylighting)	Increases awareness by enhancing the visibility of other road users at intersections	–	☑	–	–	Low
Installing travel lane reconfigurations at multilane roads with fewer than 20,000 annual average daily traffic	Provides separated spaces for people riding bikes and e-scooters, can enable people to cross only one lane of traffic at a time, and prevents rear-end, left-turn, and side-swipe crashes	☑	☑	☑	–	Low

Table 6. (Continued).

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Installing centerline rumble strips on undivided highways	Provides tactile feedback to motorists who start to drift across the centerline, which can prompt drivers to return their vehicle to the travel lane	–	☑	–	–	Medium
Converting conventional signalized intersections to single-lane roundabouts	Reduces the speed of vehicles entering the intersection and decreases the angles at which crashes may occur, especially side-impact and head-on crashes	☑	☑	☑	–	High
Installing raised pedestrian/ bicyclist crossings at driveways, minor street intersections, and midblock transit stop locations	Reduces the severity of pedestrian and bicycle crashes by encouraging drivers to slow down on approaching non-intersection crossings	–	☑	☑	–	High
Installing shoulder or edge line rumble strips with bicycle gaps on undivided highways	Provides tactile feedback to motorists who start to drift across the edge line and offers bicyclists opportunities to merge into the travel lane without contending with rumble strips	–	☑	–	–	Medium
Creating "self-enforcing" road designs where local roads have narrow lanes and traffic calming, collector roads have bicycle lanes and safe pedestrian crossings, and arterial roads severely limit access and provide protected bicycle lanes and pedestrian crossings	Manages speeds via consistent cross-section design within road same classifications and distinct design between different road classifications	–	☑	☑	–	High

Note: – = Not applicable.

[1] IRA = injury risk assessment, PCC = professional and community coordination, CD = crash diagnoses.

[2] Costs correspond to the total financial cost associated with a policy or practice, including labor, equipment, and infrastructure (Low ≤ $100k; Medium = $100k–$1 million; and High ≥ $1 million in total or per year).

At this point, a team should reflect on whether a selected safety practice: (1) aligns with one or more Safe System design strategies; (2) can significantly reduce the likelihood of users' exposure to severe crash forces or enhance injury risk assessment, professional and community coordination, or crash diagnoses; and (3) is feasible given available resources to institute the practice. If the team concludes that all three criteria are satisfied, the practice should be considered for implementation, and the safety team could follow the steps outlined in Table 7. However, if one or more of these three criteria are not satisfied, teams are advised to start over from step 1 until all three criteria are satisfied.

Consider the example of a safety team looking to convert select signalized intersections to roundabout designs. Table 7 provides recommended steps to implement this safety practice along with elements to consider within each step.

Table 7. Design practice implementation steps and example elements.

Step	Example Step Elements
Determine the practice's intended goals, the factors that contribute to practice performance and interactions among factors, what key factors might look like in the future, and success indicators.	• The goals of this practice are to decrease the severity of intersection crashes by reducing vehicle-to-vehicle crash angles and increasing the proportion of drivers yielding to crossing pedestrians. • The factors that contribute to practice performance include at least the appropriate amount of deflection for each approach to the roundabout, the appropriate placement of splinter crossing islands to facilitate pedestrians' crossing of the facilities, public sentiment about roundabout conversions, the directness and comfort of pedestrian crossings, and more. • Key factors in the future will likely include the potential for favoring more advantaged populations with the safety benefits of roundabouts, the waxing and waning of public interest in roundabout conversions, expansion of roundabout conversions across geographies over time, and more. • Success indicators might include observed reductions in operating speeds within the roundabout, higher rates of drivers yielding to crossing pedestrians versus at midblock crossing locations, decreasing fatalities and serious injuries at roundabouts versus at signalized intersections, community member reports of feeling safer using roundabouts versus signalized intersections, increased pedestrian use of the intersection, and more.
Enable innovation of practices to meaningfully respond to foreseen and unforeseen opportunities.	• Meaningfully responding to foreseen and unforeseen opportunities might include practice adjustments triggered by anticipated events (e.g., expanding installation of roundabouts at new construction sites), yearly review to assess whether the practice is associated with increases in driver yielding and reductions in serious and fatal injury, improvements in community acceptance of roundabouts, granting authority to the local municipality to institute and adjust the practice based on local knowledge of anticipated and unanticipated events, and more.
Monitor indicators of performance in relation to practice objectives, key factor indicators and thresholds for adjusting the practice, and interested party feedback on the practice.	• Indicators of practice performance would likely involve collecting data before and during roundabout installation on serious and fatal injury at roundabout versus signalized intersection sites, public feedback on the roundabouts, and more. • Key factor indicators and thresholds for adjusting the practice might include rising numbers of drivers failing to yield to crossing pedestrians, rising serious and fatal injury in roundabouts, growing negative feedback on roundabouts, plans for converting roundabouts back to signalized or stop-controlled intersections designs, falling pedestrian use of converted roundabouts, and more.

Table 7. (Continued).

Step	Example Step Elements
Improve learning of practice performance to make necessary adjustments to shore up practice performance or to change up the practice altogether.	• Learning about practice performance requires consistent measurement of practice performance indicators such as the proportion of drivers yielding to crossing pedestrians at the roundabout sites, the number of serious and fatal injuries at roundabouts versus other intersections, public perspectives of the roundabouts, pedestrian use of the roundabout, and more. • Making necessary practice adjustments requires that local agencies and partners reflect on results of the measured performance indicators and decide to update practice parameters (e.g., maintaining the roundabouts, increasing the deflection within the roundabout, and more).

Conclusion

The shift toward Safe System–aligned design is possible and necessary for the United States to realize zero deaths and serious injuries on the nation's roadways. Road and street design shapes decisions about how people decide to travel, the speed at which they travel, and their opportunity to respond to potential conflicts. By aligning the design of the road system with the goal of fostering a Safe System, there is great potential to prompt road users to adjust routine behaviors that inadvertently contribute to a serious crash. Safe System–informed design can reshape the nation's streets and transportation system, creating gradual and long-lasting effects on entire populations' transportation-related choices, behaviors, health, and safety. Operating and maintaining these safety effects is the subject of Chapter 5, which covers Safe System–aligned operations and maintenance strategies and practices.

CHAPTER 5

Safe System Operations and Maintenance

Operations and maintenance are key components of advancing and maintaining a Safe System. Effective operations allow the system to adapt to shifting injury risk and safety realities like changing demographics, aging populations, and varying weather or climate patterns. For example, adequately timed signals that are routinely updated and coordinated for the desired travel speeds could be a step toward a Safe System. Additionally, robust asset management and inventory can facilitate safety effectiveness studies and indicate the need for infrastructure maintenance, repair, or replacement to ensure adequate performance of roadway surfaces, signing, pavement markings, barriers, and other features helping to inform drivers and keep vehicles safely on the roadway.

Integrating the Safe System into operations and maintenance complements safer roads by ensuring roadway pavement, signing, markings, and safety devices are in optimal condition for informing and protecting roadway users.

The current practice of evaluating operations and mobility is primarily focused on the efficient movement of motor vehicles, minimizing the vehicle delay incurred by focusing only on LOS (FHWA 2022). Many agencies have maximum thresholds built into their design manuals for allowable vehicular delays and LOS at intersections. However, a focus on improving or maintaining traffic flow can overshadow regard for road users' safety. Even when road-user safety is considered, improvements that might increase driver delay are often not viewed favorably. To realize a truly Safe System, there is a need to shift the operations paradigm from "balancing safety and mobility of vehicles" to prioritizing safety (i.e., harm minimization) for all users.

Additionally, safety considerations within maintenance regimes are often limited to work zone schemes and inclement weather issues (Nahed et al. 2023). Moreover, common procedures for maintaining road infrastructure tend to be reactive and organized around responding to user complaints rather than proactively ensuring facilities and their operations are functioning optimally and not compromising road users' safety. Furthermore, some Safe System infrastructure improvements face opposition because of the maintenance and upkeep required. There are many tradeoffs between maintenance and operations and safety. A part of adopting the Safe System includes understanding and accepting these tradeoffs. To better accommodate operations and maintenance, an agency may develop design standards and maintenance plans for these roadway elements to aid in maintaining the feature. An example includes raised crosswalks. Reasons for opposing raised crosswalks include maintenance concerns related to snow events and adequate drainage, as well as design concerns related to balancing desires to reduce vehicle speeds while avoiding damage to vehicles. FHWA has developed a case study to demonstrate how agencies design raised crosswalks for snow, rain, and heavy vehicles (FHWA n.d). Instead of opposing the installation of raised crosswalks anywhere, an agency can look at this case study, and others, and develop processes of their own for their crews to maintain raised crosswalks.

Operations and maintenance personnel can be proactive in preventing crashes from occurring. Maintaining assets through their useful life and replacing assets as they degrade beyond

repair provides a roadway system for safer travel. Often maintenance and operations personnel travel their roadways more frequently than the average roadway user. Being mindful of the impacts that asset management and traffic operations have on the Safe System, these personnel can make improvements to the system and potentially prevent a crash from occurring. For example, if a maintenance worker notices a sign that has lost its retroreflectivity, the worker may replace it as soon as possible, not waiting for a crash to occur or for the sign to be replaced on its regularly scheduled maintenance cycle. As a result of the new sign, a driver may be adequately informed of the upcoming curve and be able to slow down to safely traverse the curve in dark, rainy conditions.

With a Safe System as the desired state for the transportation system, operations and maintenance activities must be adaptable to changing conditions and protect all road users. Effective operations and maintenance activities can provide a level of redundancy within the roadway network so when a mistake is made, a serious crash does not occur. Examples of such redundancies in the maintenance and operations space include appropriate vehicular and pedestrian clearance intervals at traffic signals, the installation of crash-absorbing roadside barriers, well-maintained drainage structures, and pavement free of potholes and rutting. A proactive approach to operations and maintenance through asset management and inventory can also advance the Safe System.

This paradigm shift in operations and maintenance is necessary and possible. The following sections outline methods, strategies, and practices to employ in advancing toward a Safe System.

5.1 Key Operations and Maintenance Strategies

To apply the principles of a Safe System in the context of operations and maintenance, employ the following strategies:

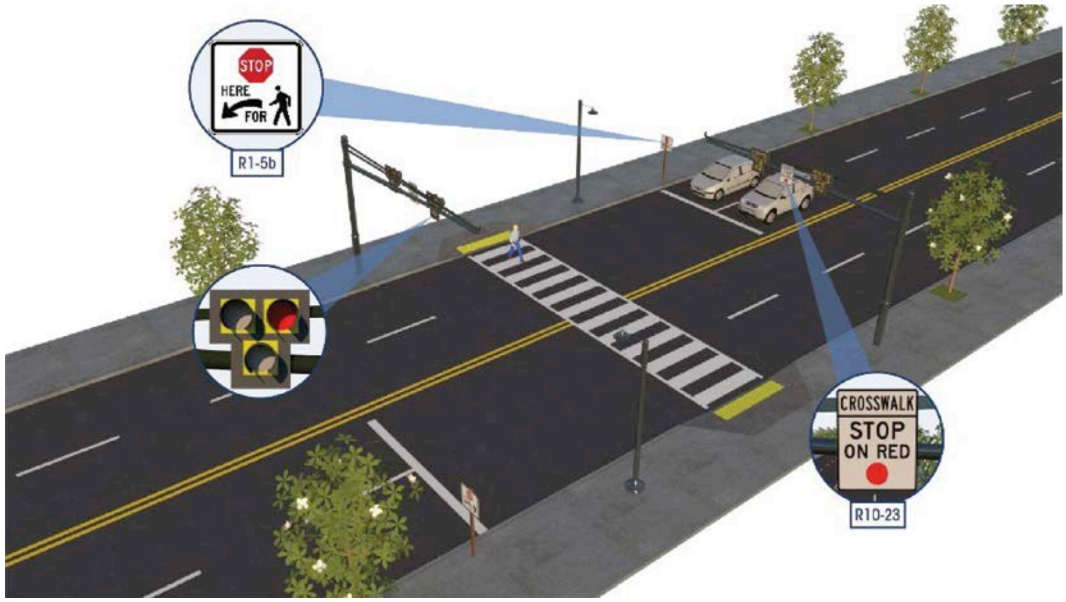
- Separate road users of different mass, directions, and speeds in time.
- Adapt road operations to changing environmental and social conditions.
- Inventory and manage infrastructure assets to sustain safety-related efficacy.

Separate Road Users of Different Mass, Directions, and Speeds in Time

Safe System–aligned traffic operations allow the separation of road users in time rather than relying on road users to simultaneously share road space. For example, this separation is accomplished by providing pedestrians opportunities to cross the roadways during a designated phase of traffic signals. Per FHWA's *Safe System Roadway Design Hierarchy*, managing conflicts in time is a Tier 3 solution within the Safe System Design Hierarchy—i.e., "Manage Conflicts in Time" (Hopwood, Little, and Gaines 2024). Providing discrete and alternating opportunities for users to safely navigate the roadway aligns with the Safety is Proactive principle of a Safe System. Not only a safety strategy, this separation in time also enhances user comfort and convenience, especially for nonmotorized users (Blackburn et al. 2022). Examples of these strategies outlined in FHWA's design hierarchy include clearance intervals, left-turn signal phasing, coordinated signal timing, leading pedestrian intervals, emergency vehicle preemption, and pedestrian hybrid beacons (Figure 11).

Adapt Road Operations to Changing Environmental and Social Conditions

Two of the many benefits of fostering a Safe System via operations are the immediacy of its effects and the temporary nature of implementation. Practitioners can track and assess environmental



Source: Hopwood, Little, and Gaines 2024.

Figure 11. Pedestrian hybrid beacon.

and social conditions and adapt road operations accordingly. Often these changes, driven by financial, political, health, and other social dynamics, are unpredictable and could impact the performance of traffic operations. Examples of such changes in recent history include lower traffic volumes and higher travel speeds due to the shelter-in-place policies instituted in the early months of the COVID-19 pandemic and the increased use of e-bikes or e-scooters (Buehler and Pucher 2024; NHTSA 2023a). More predictable changes like aging populations or an increase in pedestrian activity due to new development can alter traffic operations safety performance. Regardless of the predictability of the change, practitioners must be mindful of the effects of changes to the traffic operations. Regularly tracking operations performance and adjusting as needed—for example, every three to five years or more often if there are significant changes in traffic volumes, roadway conditions, land uses, travel patterns, vehicle mixes (FHWA 2021b)—is an integral part of fostering and sustaining a Safe System.

Additionally, the capacity to make midstream adjustments is at the heart of quick-build projects. With the urgent need for safety solutions and the introduction of the Safe Streets and Roads for All program, quick-build projects have become more common across the United States (Oluyede, Combs, and Pardo 2024). These projects can be installed roughly within one year of the start of planning and are built with materials that allow changes as needed (People for Bikes 2016). Ideally, quick builds are put in place for testing purposes or until the longer, more permanent solutions can be installed. If these projects are not proactively maintained, the original intent and purpose of the solutions can be lost, which could adversely affect the safety performance of the roadway. Furthermore, an agency might plan to remove a quick-build installation if evaluations and performance measures indicate the project is not effective. Regular performance monitoring should be conducted to measure the effectiveness of the solution and inform any modification necessary to improve performance. Another consideration for these temporary projects is snow and debris removal. For example, if an agency does not have equipment to remove snow within bike lanes, a maintenance plan may be needed before the installation of a separated bike lane. Maintenance considerations should be evaluated at the onset of every quick-build project.

Inventory and Manage Infrastructure Assets to Sustain Safety-Related Efficacy

As assets deteriorate over time, they can lose their safety effectiveness. Practitioners must assess when assets should be restored or replaced to maintain optimal safety performance. Austroads (2010) developed a report on road safety and maintenance that highlighted the implications of asset deterioration as they relate to safety. Some examples from the report include the following:

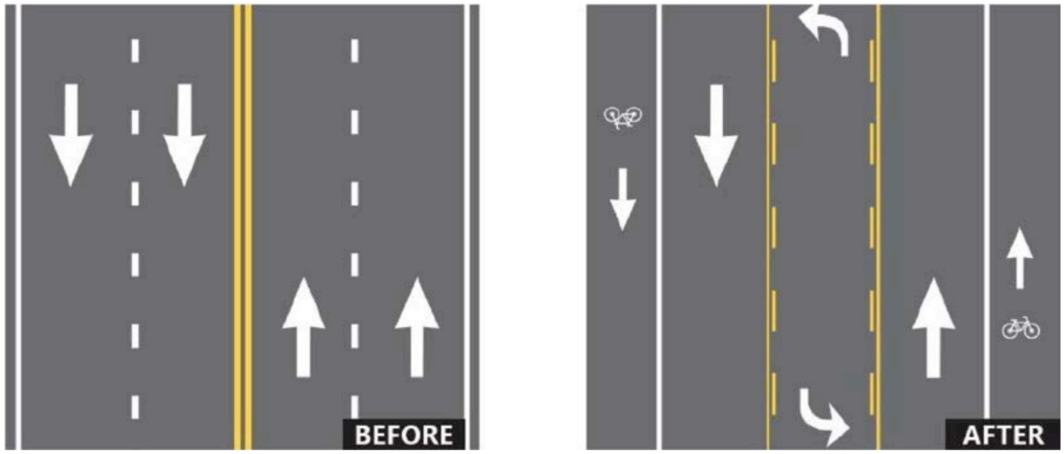
- Pavement rutting—Crash rates are shown to increase by 25 percent when rut depth exceeds 20 mm (about .75 inches), as shown in Figure 12.
- Drainage—If a water film forms across a road, it can result in partial or total loss of contact between the tire and the road surface, which greatly reduces the ability of the driver to stop and steer the vehicle.
- Pavement markings—The renewal of center-line and edge-line markings has shown a reduction in crash risk by 20 percent.
- Vegetation—Reducing sight distance at intersections increases the crash potential by 33 percent.

Additional studies indicate a crash reduction of 5 to 10 percent when older stop signs were replaced with signs of higher retroreflectivity (Persaud et al. 2008). According to the NHTSA (2023c), only about 25 percent of travel occurs in dark conditions, however, more than 50 percent of all crashes occur under dark conditions. Although the goal is to improve the visibility of signing for nighttime drivers, adequate signage and retroreflectivity benefit all road users in all lighting conditions (FHWA 2012).

One application of managing infrastructure assets is to "stripe it safer" with resurfacing projects. Many agencies maintain a regular or semiregular resurfacing schedule for their roadways. As part of the resurfacing efforts, considerations for safety improvements should be included. Figure 13 illustrates a four- to three-lane roadway reconfiguration—otherwise known as a "road diet" (Albee and Bobitz 2021). This sort of reconfiguration can occur when roadways are restriped during resurfacing. These modifications can also be included in agencies' resurfacing budgets, thereby avoiding the need to modify curb lines or acquire additional right-of-way. With a 47 percent average crash reduction factor, road diets, and the resurfacing improvements making them possible, can facilitate agencies' shift toward fostering a Safe System (Persaud et al. 2010).

Source: FHWA 2009.

Figure 12. Water ponding in wheel ruts.



Source: Albee and Bobitz 2021.

Figure 13. A road diet or roadway reconfiguration illustration.

Developing and maintaining an inventory and subsequently repairing or replacing degraded assets can help agencies sustain the safety-related efficacy of their roadway assets. Additionally, agencies should create a regularly scheduled inspection and maintenance cycle of the roadway assets to be more proactive in maintaining a Safe System.

5.2 Study-Identified Operations and Maintenance Practices

Stemming from these operations and maintenance strategies are more specific safety practices. To identify Safe System–aligned practices, the team extracted 21 of them from the literature review phase of the research (see Appendix D for a complete list) and presented them to safety practitioners via an online survey. Survey participants were asked to rate the financial, social, and political feasibility of each practice and the safety impact based on their professional experience and institutional knowledge. Analysis of the responses revealed a wide range of feasibility scores and a more modest range of impact scores (see Appendix D).

In keeping with Safe System principles and operations and maintenance strategies, the team determined whether each operations and maintenance practice would reduce road users' exposure to severe crash types [e.g., run-off-road, head-on, intersection, pedestrian, bicyclist, or motorcyclist crashes (Adapted from Waka Kotahi NZ Transport Agency 2022)] and the likelihood road users would be involved in one or more of these crash types.

- Exposure reflects the number of people with the potential to be involved in serious crash types.
- Likelihood reflects the probability road users will be involved in a crash.
- Severity reflects the chances a crash will result in a fatality or serious injury to the road users involved.
- Improves injury risk assessment, professional and community coordination, or crash diagnoses reflects a practice's ability to estimate road-user injury risks associated with land-use, policy, or engineering interventions; to improve coordination among professionals in different sectors and with the public; or to uncover contributing factors to serious crash events.

Table 8 provides example operations and maintenance practices and their change mechanisms (i.e., the steps or processes responsible for improving road users' safety).

Table 8. Safe System operations and maintenance practices.

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Installing leading pedestrian intervals with right-turn-on-red restrictions in areas with high pedestrian activity	Separates pedestrians and right-turning vehicles in time at signalized intersections	☑	☑	–	–	Low
Removing roadside objects posing a danger when impacted upon a lane departure	Removes the potential for a severe crash if a vehicle runs off the road	☑	☑	☑	–	Medium
Including crash risk potential in prioritizations of resurfacing schedules (e.g., prioritizing surfaces with low skid resistance for resurfacing)	Proactively minimizes the risks for crashes by improving pavement conditions	–	☑	–	☑	Low
Providing an exclusive signal phase for pedestrians in areas with high pedestrian volumes (e.g., pedestrian scramble or "Barnes Dance")	Separates pedestrians and vehicles in time at signalized intersections	☑	☑	–	–	Low
Developing joint action plans with emergency services partners to integrate operational planning with emergency services planning	Fosters collaboration between agencies and partners to provide adaptable operations to prevent crashes	–	–	–	☑	Low
Integrating asset management and crash analyses to determine when roadway conditions have degraded to the point of increasing the likelihood/ severity of crashes	Ensures optimal and effective roadway assets to reduce the likelihood and severity of crashes	–	–	–	☑	Medium
Improving signal progression on designated routes for emergency vehicles with predetermined signal linking plans	Separates slower-moving vehicles (queued traffic) with emergency vehicles at signalized intersections	–	–	–	☑	Low
Providing longer green times for cyclists at shared path crossings	Separates bicyclists and vehicles in time at signalized intersections	☑	☑	–	–	Low
Employing an active or passive equipment maintenance and replacement system	Maintains optimal and effective equipment	–	–	–	☑	Medium

(continued on next page)

Table 8. (Continued).

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Developing a traffic guidance scheme that details the use of specific traffic control devices (e.g., signs, barriers) during crash events	Uses adaptable traffic operations to prevent secondary crashes from occurring	–	✓	–	–	Medium
Keeping a detailed inventory on the condition of the agencies' transportation assets (e.g., bridges, tunnels, pavements, signs, signals, sidewalks, street furniture, vegetation)	Routinely evaluates the efficacy of assets which informs the need for replacement or repair to prevent crashes from occurring	–	–	–	✓	Medium
Routinizing network-comprehensive (including bike and sidewalk networks) winter road clearance operations (e.g., snow and ice clearing, salt spreading where applicable)	Ensures roadway assets (especially pavement) are free of hazards and are performing optimally	–	✓	–	–	Medium
Providing extended clearance intervals for passively detected pedestrians at signalized intersections	Separates pedestrians and vehicles in time at signalized intersections	✓	✓	–	–	Low
Implementing variable speed limits (VSL) on roads with high pedestrian activity at certain times and high potential for significant pedestrian-motor vehicle conflicts (e.g., school zones)	Reduces vehicular speeds in the presence of pedestrians and other vulnerable road users	–	✓	✓	–	Low
Incorporating roadway features beyond pavement and safety infrastructure (e.g., drainage features, street furniture, vegetation) into asset management programs	Provides a comprehensive database of assets with the potential to adversely affect safety performance (e.g., clogged drainage inlet causing ponding water, overgrown vegetation blocking traffic signals)	–	–	–	✓	Medium

Table 8. (Continued).

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Combining passive pedestrian detection and accessible pedestrian signals to help pedestrians with low vision safely traverse intersections	Separates pedestrians, especially those visually impaired, and vehicles in time at signalized intersections	☑	☑	–	–	Medium
Implementing VSL in the vicinity of traffic incidents	Provides speed harmonization near crash incident scenes and lowers the risk of secondary crashes	–	☑	☑	–	Low
Extending clearance intervals for passively detected cyclists at signalized intersections	Separates bicyclists and vehicles in time at signalized intersections	☑	☑	–	–	Low
Implementing Driving Safety Support Systems to avoid sign and signal violations and collisions	Removes reliance on the driver to properly detect and react to signs and signals	–	☑	–	–	High
Implementing VSL during adverse weather conditions	Provides speed harmonization and has the potential to reduce speeds during periods of low visibility or low friction	–	☑	☑	–	Low
Implementing VSL at nighttime in alcohol-serving districts	Has the potential to lower travel speeds of both impaired and non-impaired drivers which may lessen the severity of a crash should it occur	–	☑	☑	–	Low
Providing a check list to be used in regular maintenance efforts	When regular maintenance occurs, additional assets may be improved if deemed necessary to maintain a safe roadway network	–	–	–	☑	Low
Coordinating signal timings that promote safe speeds throughout a corridor	Encouraging safer speeds by timing coordinated signals for the desired travel speeds	–	☑	☑	–	Low

Note: – = Not applicable.

[1] IRA = injury risk assessment, PCC = professional and community coordination, CD = crash diagnoses.

[2] Costs correspond to the total financial cost associated with a policy or practice, including labor, equipment, and infrastructure (Low ≤ \$100k; Medium = \$100k–\$1 million; and High ≥ \$1 million in total or per year).

Implementing Safe System Operations and Maintenance Practices

Safe System operations and maintenance practices center around strategies to separate road users of different mass, directions, and speeds in time; adapt road operations to changing environmental and social conditions; and inventory and manage infrastructure assets to sustain safety-related efficacy.

To begin implementing Safe System–aligned operations and maintenance practices, consider following these steps and substeps:

1. Identify at least one significant safety problem. Identification and prioritization of a safety problem might be based on the following:
   - Severity and magnitude of the safety problem
   - Disproportionate harm endured by some community members by the problem
   - Importance of addressing the problem to community representatives
   - Availability of resources to address the problem
   - Opportunities to address safety more generally given routine maintenance schedules
2. Once a safety problem has been identified and prioritized, ask the following two questions:
   - To what extent does a proposed practice to address the identified problem align with Safe System strategies for operations and maintenance?
     - Separate road users of different mass, directions, and speeds in time
     - Adapt road operations to changing environmental and social conditions
     - Inventory and manage infrastructure assets to sustain safety-related efficacy
   - To what extent does a proposed practice address the following?
     - Users' exposure to serious crashes
     - Likelihood of these types of crashes
     - Severity of these types of crashes when they occur
     - Improvements to injury risk assessment, professional and community coordination, or crash diagnoses

For example, in step 1, if a safety team identifies and prioritizes reducing severe crashes in the wake of crash events, they might pursue implementing VSL in the vicinity of traffic incidents given the severity and magnitude of this safety problem and the availability of resources to address it.

Then, in step 2, a safety team might conclude VSL aligns with the Safe System strategy of adapting road operations to changing environmental and social conditions, such as serious traffic crashes happening on high-volume roadways in town. A team might also conclude VSL can reduce the likelihood and severity of the secondary crashes occurring near crash sites.

At this point, a team should reflect on whether a selected safety practice (1) aligns with one or more Safe System strategies; (2) can significantly reduce the likelihood of users' exposure to severe crash forces or enhance injury risk assessment, professional and community coordination, or crash diagnoses; and (3) is feasible given available resources to institute the practice. If the team concludes all three criteria are satisfied, the practice should be considered for implementation, and the safety team could follow the steps outlined in Table 9. However, if one or more of these three criteria are not satisfied, teams are recommended to start over from step 1 until all three criteria are satisfied.

For illustrative purposes, consider the example of a safety team looking to routinely implement VSL near traffic incidents. Table 9 provides recommended steps to implement this safety practice along with elements to consider within each step.

Table 9. Operations and maintenance practice implementation steps and illustrated step elements.

Step	Illustrated Step Elements
Determine the practice's intended goals, the factors contributing to practice performance and interactions among factors, what key factors might look like in the future, and success indicators.	• The goals of this practice are to reduce vehicle speed in the vicinity of crash sites and decrease the potential for injurious secondary crashes near crash sites. • The factors contributing to practice performance include the roadway geometry (number and width of travel lanes, density of driveways or intersections, vertical or horizontal curvature, etc.), the use of intelligent transportation systems (ITS) to relay timely speed limit reduction information to travelers, VSL sufficiently low to reduce the chances of serious secondary crashes and to protect emergency responders traveling to and from and remaining at crash sites, and more. • Key factors in the future will likely include the possibility of vehicles in the fleet possessing adaptive speed governance, the availability of ITS, the waxing and waning of public interest in speed management in general, changing law around speed violations, and more. • Success indicators might include observed reductions in operating speeds near VSL-equipped crash areas, decreasing fatalities and serious injuries associated with secondary crashes near crash sites, community member and first responder reports of feeling safer in the vicinity of crash sites, and more.
Enable innovation of practices to meaningfully respond to foreseen and unforeseen opportunities.	• Meaningfully responding to foreseen and unforeseen opportunities might include practice adjustments triggered by anticipated events (e.g., planned land developments and road expansions or widenings), yearly review to assess whether the practice is associated with reductions in serious and fatal injury, improvements in community acceptance of VSL, granting authority to the local municipality to institute and adjust the VSL practice based on local knowledge of anticipated and unanticipated events, and more.
Monitor indicators of performance in relation to practice objectives, key factor indicators and thresholds for adjusting the practice, and interested party feedback on the practice.	• Indicators of practice performance would likely involve collecting data before and after VSL implementation on operating speeds in proximity to crash sites; serious and fatal injury near crash sites; evidence of a "halo effect," whereby drivers reduce their speeds down- or upstream from the VSL site; public feedback on the VSL program; and more. • Key factor indicators and thresholds for adjusting the practice might include rising numbers of drivers failing to slow down in VSL-provisioned areas, rising serious and fatal injury in VSL-provisioned areas, recognition that VSL might be shifting higher travel speeds elsewhere in the roadway network, growing negative feedback on the VSL program, and more.
Improve learning of practice performance to make necessary adjustments to shore up practice performance or to change up the practice altogether.	• Learning about practice performance requires consistent measurement of practice performance indicators such as the proportion of drivers slowing down in VSL-provisioned and surrounding areas, the number of serious and fatal injuries in VSL-provisioned and surrounding areas, public and first responder perspectives of the VSL program, and more. • Making necessary practice adjustments requires local agencies and partners to reflect on results of the measured performance indicators and decide to update practice parameters (e.g., adjusting the displayed speeds in the VSL program, adjusting the placement of VSL in relation to crash sites, phasing out the VSL program with the introduction of more effective technologies or practices, reducing a roads' design speed during a maintenance cycle on reflecting on the persistent need to employ VSL, and more.)

Conclusion

The shift toward Safe System–aligned operations and maintenance practices is possible and necessary for the United States to realize zero deaths and serious injuries on the nation's roadways. These practices provide more reliable protection for all road users by separating vulnerable road users from vehicles in time, being adaptable to changing conditions and road-user needs, and ensuring the roadway assets are functioning at optimal safety performance. Assessing the safety performance of the roadway network is central to Safe System–aligned law enforcement strategies and practices, the subject of the Chapter 6.

CHAPTER 6

Safe System Law Enforcement

Law enforcement plays a pivotal role in fostering a Safe System. As users of the network and often being the first to respond to incidents, law enforcement officers see firsthand the potential for road-user injury. Additionally, they are responsible for enforcing the rules of the road and encouraging safe road-user behavior. Coordination among law enforcement personnel, planners, designers, and policymakers can result in proactively addressing officer-observed injury risks. Furthermore, penalizing transgressors of roadway laws can discourage unsafe behaviors.

The current law enforcement regime is rooted in the deterrence theory, which relies on the certainty, swiftness, and severity of punishments to be effective (Paternoster 2018; Barnum and Nagin 2023). Indeed, legal threats are most effective when potential rule violators perceive a high likelihood of being caught committing an unlawful act, believe the resulting punishment will be severe, and understand that the punishment will be applied quickly after the offense (Davey and Freeman 2011). Among these factors, certainty appears to be the most powerful deterrent to performing risky or unlawful behavior (Von Hirsch 1999; Truelove et al. 2017).

Unfortunately, violating traffic laws is commonplace, especially when it comes to driving above the posted speed limit. The AAA Foundation for Traffic Safety's 2022 Traffic Safety Culture Index study found that 40 percent of drivers stated they had exceeded the posted speed limit by 15 mph on a freeway in the past month, and nearly 30 percent reported exceeding the speed limit by 10 mph on a residential street (AAA Foundation for Traffic Safety 2023). However, more than 80 percent of respondents perceived this level of speeding to be moderately to extremely dangerous. Yet, 37 percent of respondents believed it was unlikely a driver would be caught by police for driving 15 mph over the speed limit on a freeway, and 51 percent of respondents believed drivers would not be caught by police for driving 10 mph over the speed limit on a residential street. These statistics suggest there is a perceived sense of danger with speeding; however, drivers are not deterred from this behavior perhaps because they do not perceive punishment as certain.

The events of May 2020 (the killing of George Floyd in Minneapolis, Minnesota, and uprising of the Black Lives Matter movement) reshaped how law enforcement officers interact with their communities and enforce the laws. These events coupled with reallocation of police funding has decreased the resources available to enforce basic traffic laws. According to the Police Executive Research Forum (PERF), 182 law enforcement agencies across the country noted a nearly 5 percent decline in sworn officers between January 2020 and January 2023 (PERF 2023). Fewer law enforcement staff has resulted in added challenges in implementing the Safe System approach through traffic law enforcement in isolation. Therefore, coordination with transportation professionals is critical.

Beyond ensuring certain punishment for traffic law violations, a Safe System–aligned law enforcement paradigm can contribute to cultural shifts, ones that lead to perceiving safe road-using behaviors as possible, desirable, and normal (Daugbjerg and Kay 2020). A paradigm shift

in law enforcement is necessary and possible, and the following sections outline methods, strategies, and practices to employ in advancing toward a Safe System. Although many challenges face law enforcement officers today, the strategies defined herein are intended to be performed with available resources and staffing.

6.1 Key Law Enforcement Strategies

To apply the principles of a Safe System in the context of law enforcement, the following strategies can contribute to a Safe System:

- Work collaboratively to investigate serious crashes and share contextual insights.
- Enforce road-user protective policies.
- Observe, document, and share risk patterns with road designers and planners.

Work Collaboratively to Investigate Serious Crashes and Share Contextual Insights

In 2017 the NSC reviewed crash reports from all 50 states and Washington, DC, and found that critical data were vastly underreported. Without this information, regulations, laws, and policies are difficult to justify, and some safety issues may not be addressed since a clear picture of the concern is not painted (NSC 2017). A call to action in this report included a shift from an "accident report" to a "crash investigation" mentality. An accident report is often seen as burdensome paperwork designed solely to capture law violations and update insurance companies. A crash investigation, on the other hand, requires consideration of the system within which road injuries occur. For example, the AcciMap approach to crash investigation presents a systems-based technique to analyze the causal chain of events that lead to serious crashes, from the immediate precursors to the crash, up to higher levels that consider the organizational, governmental, and regulatory factors that played a role in the crash (Salmon et al. 2020; Stanton et al. 2023). Thus, in collaborative crash investigations, law enforcement officers can work with professional and community partners to identify the network of factors that shape road users' behaviors that result in serious crashes, share results of the investigations with the public and policymakers, and ultimately inform road injury prevention efforts. Additionally, through this effort, there should be renewed focus on accurate crash reporting. Law enforcement is on the front line of providing this information, which is used for improving the safety performance of the roadway network. Part of this collaboration includes understanding the need for accurate and thorough data to guide reductions in serious crashes.

Enforce Road-User Protective Policies

Another change that could be made in the landscape of law enforcement is the enforcement of protective policies rather than punishing ones. One example of a protective enforcement policy includes installing ignition interlocks for all drivers convicted of driving under the influence (DUI) rather than relying solely on issuing fines to impaired drivers caught during saturation patrols. Although ignition interlocks would not prevent all instances of impaired driving, they can significantly reduce the frequency of offenses (Kaufman and Wiebe 2016; Nochajski et al. 2020). Another example of a protective enforcement practice is instituting immediate administrative license revocation or suspension (ALR/ALS) for alcohol- and drug-impaired-driving offenses, which swiftly eliminates offenders' ability to drive a motor vehicle for a meaningful period, such as 90 days (Fell 2019). Moreover, safety researchers have called for pairing ALR/ALS with vehicle impoundment to prevent offending drivers' ability to drive under the influence (Ferguson 2012; Kaur et al. 2023), thereby removing the safety threat of impaired driving and protecting other road users in the process.

Another example of a protective policy is the use of speed governors or ISA technology. An investigation into a crash resulting in nine fatalities in 2022 led the National Transportation Safety Board (NTSB) to recommend ISA in all new vehicles. The crash was determined to be caused by excessive speed, drug-impaired driving, and the failure to deter habitual speeding despite the driver having numerous recorded speeding citations (NTSB 2023). ISA would use a vehicle's Global Positioning System location, a database of posted speed limits, and an onboard camera to help ensure safe and legal speeds. Active systems would warn a driver through visual, sound, or haptic alerts when the vehicle exceeds the posted speed limit, but the driver is responsible for controlling the speed. Passive systems physically limit the speed at which the vehicle can travel. Both systems are examples of protective policy systems that could be employed, especially for habitual speed violators, to promote safer speeds.

Observe, Document, and Share Risk Patterns with Road Designers and Planners

A real potential for change comes with law enforcement personnel observing, documenting, and sharing risk patterns with road designers and planners rather than conducting isolated enforcement operations (Blank, Sandt, and O'Brien 2020). Law enforcement officers use the roadway network regularly and often know where the riskiest behaviors occur. Drivers may be more likely to travel at high speed along multilane roadway segments. Pedestrians may regularly cross outside of crosswalks near schools or businesses because of the lack of nearby crossing facilities (as seen in Figure 14). This information can be shared with roadway designers and planners so that infrastructure improvements may be considered to address riskier behaviors and minimize the need for persistent law enforcement intervention. Most commonly, these observations are noted as part of road safety audits when law enforcement officers collaborate with other safety professionals to assess the safety performance of a roadway or intersection. However, the communication of these observations should not be reserved only for official audits. Rather, open communication and collaboration with roadway designers and planners can occur on a regular basis, either as patterns are noted by law enforcement or through scheduled coordination meetings with road designers and planners.

Photo courtesy of Burgess & Niple.

Figure 14. A lack of midblock crossing infrastructure can lead to pedestrians choosing the most direct and convenient crossing location.

6.2 Study-Identified Law Enforcement Practices

Stemming from these law enforcement strategies are more specific safety practices. To identify Safe System–aligned practices, the team extracted 11 of them from the literature review phase of the research and presented them to safety practitioners via an online survey (see Appendix E). Survey participants were asked to rate the financial, social, and political feasibility of each practice and the safety impact based on their professional experience and institutional knowledge. Analysis of the responses revealed a modest range of feasibility scores and a wide range of impact scores, which can be found in Appendix E.

In coordination with Safe System principles and law enforcement strategies, the team determined whether each law enforcement practice would reduce road users' exposure to severe crash types (e.g., run-off-road, head-on, intersection, pedestrian, bicyclist, or motorcyclist crashes) and the likelihood road users would be involved in one or more of these crash types.

- Exposure reflects the number of people with the potential to be involved in serious crash types.
- Likelihood reflects the probability road users will be involved in a crash.
- Severity reflects the chances a crash will result in a fatality or serious injury to the road users involved.
- Improves injury risk assessment, professional and community coordination, or crash diagnoses reflects a practice's ability to estimate road-user injury risks associated with land use, policy, or engineering interventions; to improve coordination among professionals in different sectors and with the public; or to uncover contributing factors to serious crash events.

Table 10 provides example law enforcement practices and their change mechanisms (i.e., the steps or processes responsible for improving road users' safety).

Implementing Safe System Law Enforcement Practices

Safe System law enforcement strategies and practices advance coordination with other professional disciplines to investigate serious crashes; enforce road-user protective policies; and share observed risk patterns with planners, engineers, and policymakers.

To begin implementing Safe System–aligned law enforcement practices, consider following these steps and substeps:

1. Identify at least one significant safety problem. Identification and prioritization of a safety problem might be based on the following:
   - Severity and magnitude of the safety problem
   - Disproportionate harm endured by some community members by the problem
   - Importance of addressing the problem to community representatives
   - Availability of resources to address the problem
2. Once a safety problem has been identified and prioritized, ask the following two questions:
   - To what extent does a proposed practice to address the identified problem align with Safe System–aligned law enforcement strategies?
     - Work collaboratively to investigate serious crashes and share contextual insights
     - Enforce road-user protective policies
     - Observe, document, and share risk patterns with road designers and planners
   - To what extent does a proposed practice address the following?
     - Users' exposure to serious crashes
     - Likelihood of serious crashes
     - Severity of crashes when they occur
     - Improvements to injury risk assessment, professional and community coordination, or crash diagnoses

Table 10. Safe System law enforcement practices.

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Instituting immediate administrative license revocation or suspension (ALR/ALS) for alcohol- and drug-impaired-driving offenses	Discourages impaired driving with swift and severe punishment	☑	☑	–	–	Medium
Instituting or enforcing a statewide primary enforcement seat-belt-use law, which would require occupants to wear seatbelts in both the front and back seats and allow law enforcement officers to ticket occupants for not wearing a seatbelt, without other citable traffic infractions taking place	Promotes seatbelt usage so that in the event of a crash, the outcome may be less severe	–	–	☑	–	Medium
Instituting high-visibility saturation patrols for alcohol- or drug-impaired driving	Increases the certainty of offenders being caught for driving impaired and can remove impaired drivers from the road	☑	☑	–	–	Medium
Requiring alcohol ignition interlocks installed for all drivers convicted of driving under the influence (DUI)	Lowers the potential for DUI offenders to drive impaired without police intervention	☑	☑	–	–	Medium
Instituting or enforcing a statewide universal motorcycle helmet law, which would require all motorcyclists to wear U.S. DOT–compliant helmets, regardless of the rider's age or experience	Promotes helmet usage so that in the event of a crash, the outcome may be less severe	–	–	☑	–	Medium
Reframing the context of a crash (i.e., not victim-blaming, not calling the incident an accident) when engaging news media partners	Changes the narrative around crashes and supports the notion that crashes are preventable, even when humans make mistakes	–	–	–	☑	Low

(continued on next page)

Table 10. (Continued).

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Implementing speed safety cameras (automated speed enforcement) that use revenues to fund safety infrastructure	Reduces the prevalence of speeding behaviors given the certainty of punishment for offenders	–	✓	✓	✓	Medium
Implementing red-light camera enforcement that uses revenues to improve safety	Reduces the prevalence of red-light-running given the certainty of punishment for offenders	✓	✓	–	–	Medium
Linking police with emergency medical service (EMS)/hospital data for persons injured in motor vehicle crashes	Provides a more accurate and comprehensive understanding of the harm induced by road trauma that may not be available within crash data	–	–	–	✓	Medium
Forming a task force or community coalition of law enforcement, transportation, public health, members of the community, and other partners to investigate serious crashes (either before or after the crash report is complete) and report findings and proposed changes to the public	Strengthens the investigation of crash causes and provides contextual information that can be used to inform changes to policies and infrastructure	–	–	–	✓	Low
Encouraging and facilitating public use of self-reporting (via mobile app or survey) to capture collisions and other events falling outside the scope of traditional crash reporting (e.g., near misses, pedestrian and bicyclist falls) outside of the crash data system	Proactively informs law enforcement and design and planning practitioners about concerning locations so additional enforcement or infrastructure improvements could be implemented before serious crashes occur	–	–	–	✓	Low

Note: – = Not applicable.

[1] IRA = injury risk assessment, PCC = professional and community coordination, CD = crash diagnoses.

[2] Costs correspond to the total financial cost associated with a policy or practice, including labor, equipment, and infrastructure (Low ≤ \$100k; Medium = \$100k–\$1 million; and High ≥ \$1 million in total or per year).

For example, in step 1, if a safety team identifies and prioritizes addressing impaired driving, they might pursue requiring the installation of alcohol ignition interlocks for all drivers convicted of DUI given the importance of addressing the problem to community representatives and the availability of community resources to address impaired driving.

Then, in step 2, a safety team might conclude that an alcohol ignition interlock program aligns with the Safe System strategy to enforce road-user protective policies. They might also conclude that an alcohol ignition interlock program can reduce offending drivers' and other road users' exposure to serious crash risk, and the likelihood of serious crashes on the road network.

At this point, a team should reflect on whether a selected safety practice: (1) aligns with one or more Safe System strategies; (2) can significantly reduce the likelihood of users' exposure to severe crash forces or enhance injury risk assessment, professional and community coordination, or crash diagnoses; and (3) is feasible given available resources to institute the practice. If the team concludes that all three criteria are satisfied, the practice should be considered for implementation, and the safety team could follow the steps outlined in Table 11. However, if one or more of these three criteria are not satisfied, teams are recommended to start over from step 1 until all three criteria are satisfied.

For illustrative purposes, a safety team looks to install alcohol ignition interlocks for all drivers convicted of DUI. Table 11 provides recommended steps to implement this safety practice along with elements to consider within each step.

Conclusion

The shift toward Safe System–aligned law enforcement practices is possible and necessary for the United States to realize zero deaths and serious injuries on the nation's roadways. Law enforcement personnel collaborating with planners and road designers can proactively prevent serious crashes from reoccurring and can inform decisions about appropriate modifications to safety policy and infrastructure. This sort of collaboration is at the heart of the next chapter, which covers Safe System–aligned post-crash response strategies and practices.

Table 11. Law enforcement practice implementation steps and example elements.

Step	Example Step Elements
Determine the practice's intended goals, the factors that contribute to practice performance and interactions among factors, what key factors might look like in the future, and success indicators.	• The goals of this practice are to prevent drivers from operating their vehicles under the influence of alcohol and to reduce the incidence of serious and fatal crashes on the road network. • The factors that contribute to practice performance include, at least, the scale of impaired driving enforcement operations; the proper functioning of the alcohol ignition interlocks, including interlocks' susceptibility of being tampered with; the blood alcohol concentration (BAC) limit of the state; the vendor costs associated with procuring and installing ignition interlocks; and more. • Key factors in the future will likely involve the potential for burdening less advantaged populations by disproportionately concentrating impaired driving enforcement in areas where lower-income or racialized minority drivers are likely to drive, the waxing and waning of public interest in impaired driving prevention, increasing or decreasing impaired driving enforcement operations over time, changing ignition interlock contracts, and more. • Success indicators might include observed reductions in driving under the influence, decreasing impaired driving fatalities and serious injuries, community member reports of feeling safer, and more.
Enable innovation of practices to meaningfully respond to foreseen and unforeseen opportunities.	• Meaningfully responding to foreseen and unforeseen opportunities might include practice adjustments triggered by anticipated events (e.g., an increase in town approvals for alcohol-serving establishments), yearly review to assess whether the practice is associated with reductions in impaired driving and serious and fatal injury, legal challenges to the installation of ignition interlocks, and granting authority to the local municipality to institute and adjust the practice based on local knowledge of anticipated and unanticipated events.
Monitor indicators of performance in relation to practice objectives, key factor indicators and thresholds for adjusting the practice, and interested party feedback on the practice.	• Indicators of practice performance would likely involve collecting data before and during ignition interlock program implementation on serious and fatal injury, law enforcement personnel and public feedback on the program, and more. • Key factor indicators and thresholds for adjusting the practice might include rising numbers of impaired driver apprehensions, rising impaired driving-related serious and fatal injury, growing negative feedback on the installation of ignition interlocks, costly changes to vendor contracting and terms, and more.
Improve learning of practice performance to make necessary adjustments to shore up practice performance or to change up the practice altogether.	• Learning about practice performance requires consistent measurement of practice performance indicators such as the proportion of drivers driving impaired, the number of serious and fatal injuries in ignition interlock program areas, law enforcement personnel and public perspectives of the ignition interlock program, and more. • Making necessary practice adjustments requires local agencies and partners to reflect on results of the measured performance indicators and decide to update practice parameters (e.g., adjusting the timing or placement of impaired driving patrols and checkpoints, changing ignition interlock vendors, and more).

CHAPTER 7

Safe System Post-Crash Response

In a Safe System, post-crash response is the end and the beginning of the line. It is the last layer of protection and the first statement on the safety performance of the system. Safe System-consistent post-crash response bolsters reliable crash notification and data collection systems, efficient and effective emergency services and medical treatment, and a capacity to continually improve the quality of services (WHO 2017). In this way, post-crash response within a Safe System advances collaboration among medical professionals, law enforcement, emergency medical service (EMS) professionals—inclusive of emergency medical technicians (EMTs), advanced EMTs, and paramedics—and transportation professionals (Khan and Das 2024).

At present, EMS professionals in the United States are generally underresourced in the form of low salaries for paramedical clinicians and a lack of continuing education and training opportunities for these professionals. Post-crash response is also largely disconnected from partners in healthcare and often dangerous to emergency responding personnel, given their exposure to road and air ambulance crashes on the way to and from crash scenes and at crash scenes (Maguire 2011; Maguire et al. 2022). Further, cellphone coverage is often limited, which can lead to an increase in emergency response times (Gonzalez, Ems, and Suri 2016). Moreover, vehicles' event data recorders tend to be triggered by deployed airbags, which require striking a solid fixed barrier at 15 mph to deploy and, therefore, could potentially lead to an under-recording of crashes involving vulnerable road users (European Commission: Directorate-General for Mobility and Transport, McCarthy, and Hynd 2014; International Transport Forum 2019).

A paradigm shift in post-crash response is necessary and possible. This shift will require greater investment in reliable crash notification and communications, a major strengthening of various pre-hospital care functions, and improvements to safety investments (including post-crash rehabilitative care and crash data collection and storage) made possible through linked road safety and trauma data and research.

7.1 Key Post-Crash Response Strategies

To apply the principles of a Safe System in the context of post-crash response, the following strategies can contribute to a Safe System:

- Invest in crash notification and communications systems.
- Strengthen pre-hospital care functions.
- Enhance safety investments via research and sharing of trauma and road safety data.

Invest in Crash Notification and Communications

Robust and reliable post-crash responses rely on the effective functioning of integrated systems to detect serious crashes on the network and communicate important details about crash incidents to emergency responders. As crash events are often difficult to predict, the adoption, diffusion, and integration of advanced automatic crash notification (AACN) systems is central to notifying emergency services of where potentially life-threatening crashes occur on the roadway network. As observed by Valente (2024), AACN systems can greatly reduce the time elapsed between a crash event and the activation of the 911 system. This is especially true for more remote roadway departure crashes and ones in which crash victims have become incapacitated (Institute of Transportation Engineers 2019). Other scholars agree that automated communication of crash location is critical to reducing the severity of injuries that take place after EMS arrives at the crash scene (Ritter, Williams, and Wijetunge 2022) and that post-crash care should be incorporated into safety planning to improve crash scene management and prevent secondary crashes and injuries (Liu 2022). AACN systems of the near future will be able to share information on the probable injury severity of crash-involved parties by way of telemetry-measured operating speeds of crash-involved vehicles (Institute of Transportation Engineers 2019).

Strengthen Pre-Hospital Care Functions

To foster a Safe System, post-crash response would benefit from buttressing pre-hospital care functions. Pre-hospital interventions aim to reduce the severity of injury consequences once a traffic crash has occurred. This involves supporting roadside and in-emergency-vehicle care provision and transport to hospitals and trauma centers. As Mohan and colleagues (2020) argue, post-crash, pre-hospital care requires strengthening of the following emergency service elements:

- Extrication capabilities—the ability to safely and swiftly remove occupants who have been trapped in crash-involved vehicles
- Vehicle capabilities—the ability for ambulance and emergency vehicles to safely convey injured parties to hospitals and trauma centers in emergency cases
- EMS professionals' and first responders' capabilities—medical training for stabilizing acute trauma cases on scene, for example, being able to recognize opioid overdoses and appropriately administer opioid antagonists (e.g., naloxone) and to stop patients' bleeding
- Broader distribution of trauma-equipped hospitals across the region to reduce the time of transport
- The capacity to safely and efficiently transport patients to trauma-equipped hospitals from incident sites [e.g., investing in emergency vehicle priority schemes (Frith et al. 2018)]

Enhance Safety Investments Via Research and Sharing of Trauma and Road Safety Data

Integrating trauma with road safety data can significantly improve decision-making on emergency medical care for road crash victims (Hakkert, Gitelman, and Vis 2007; Hosseinzadeh et al. 2022). A trauma registry would allow analysts to monitor the performance of post-crash response and associated qualities of emergency care (Fosdick et al. 2024). Further, rigorous data collection and data sharing across agencies (e.g., police departments, transportation departments, and hospitals) can lead to a better understanding of road safety issues and enhance the context-appropriateness of safety investments (Finkel et al. 2020; International Transport Forum 2016).

Severe injury prevention, subsequently, would be facilitated by equitable access to holistic rehabilitation services, which could mitigate the risk of long-lasting physical and psychological damage among people involved in serious crashes (Fosdick et al. 2024). It is worth noting that, via

the Decade of Action for Road Safety, the World Health Organization (WHO) has been advocating for decades for the provision of early rehabilitation for crash victims and integrated support for bereaved family and friends of victims (WHO 2011; WHO 2021).

Linked road safety and trauma data could eventually contribute to a rise in emergency service professionals' crash predictive capabilities and in vehicle safety design features (Liu 2022). For example, by regularly coordinating with planners and engineers to discern those locations on the transportation network that harbor serious crash potential and those times of year and day during which injurious crashes are more likely to occur, EMS and transportation professionals could enhance their abilities to anticipate serious crashes. In fact, research indicates locations and times severe crashes are more likely to manifest:

- Lane departure fatalities are most likely to occur along rural roads with high horizontal curve density, or the number of horizontal curves per mile of roadway (Lord et al. 2011), especially at curves with radii ≤ 500 ft and at hillcrest locations under cloudy weather conditions (Hossain et al. 2023).
- Motorcyclist fatalities are more likely to occur at curves on rural two-lane undivided highways (Xin et al. 2019). Further, left turns at intersections coupled with wet pavement conditions can lead to serious injuries for motorcyclists (Das, Mousavi, and Shirinzad 2022).
- Pedestrian fatalities tend to occur on higher-speed (≥ 30 mph) urban principal arterials surrounded by land uses designed to predominantly accommodate automobile use (e.g., regional highway corridors) (Schneider et al. 2021). Further, most pedestrian fatalities occur under dark conditions (Sanders, Schneider, and Proulx 2022).
- Severe injury among bicyclists is more likely to occur at nonorthogonal (or skewed) intersections, along straight street segments, and at nighttime and involve large trucks or buses (Asgarzadeh et al. 2017).
- All fatal and serious crashes begin rising in July and peak in October each year. These crashes are also more likely to occur between the hours of 3:00 p.m. and midnight (National Center for Statistics and Analysis 2023).

7.2 Study-Identified Post-Crash Response Practices

Branching off from post-crash response strategies are more specific safety practices. The example practices outlined in Table 12 align with the strategies of Safe System post-crash response in that they are designed to strengthen crash notification systems and pre-hospital care functions and enhance safety interventions via research and the cross-sectoral sharing of trauma and road safety data.

The research team identified 11 Safe System–aligned post-crash response practices from the literature review phase of the research and presented them to safety practitioners via an online survey (see Appendix F). Survey participants were asked to rate the safety impact and the financial, social, and political feasibility of each practice based on their professional experience and institutional knowledge. Participant responses on the perceived impact and feasibility of the 11 post-crash response practices can be found in Appendix F.

In keeping with Safe System principles and policy strategies, the team determined whether each post-crash response practice would reduce road users' exposure to severe crash types (e.g., run-off-road, head-on, intersection, pedestrian, bicyclist, or motorcyclist crashes) and the likelihood road users would be involved in one or more of these crash types:

- Exposure reflects the number of people with the potential to be involved in serious crash types.
- Likelihood reflects the probability road users will be involved in a crash.
- Severity reflects the chances a crash will result in a fatality or serious injury to the road users involved.

Table 12. Safe System post-crash response practices.

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Forming a task force or community coalition of law enforcement, transportation, public health, members of the community, and other partners to investigate serious crashes and report findings and proposed changes to the public	Incorporates multiple perspectives on crash contributing factors and introduces system administrator accountability to prevent further incidents	–	–	–	☑	Low
Training law enforcement and transportation staff to coordinate post-crash reporting at crash sites	Places crashes into a broader transportation context, thereby minimizing focus on the errors of individual road users	–	–	–	☑	Low
Developing joint action plans with emergency services partners to integrate operational planning with emergency services planning	Aligns roadway operations with emergency services thereby streamlining emergency response	–	–	–	☑	Medium
Linking police with EMS/ hospital data for persons injured in motor vehicle crashes	Provides injury surveillance teams with more accurate and complete data on the state of road trauma in a region	–	–	–	☑	Medium
Upgrading analog 911 infrastructure to Next Generation 911 (commonly referred to as NG911) to create a faster, more resilient system that facilitates public reporting to the 911 network	Hastens and shores up the public's ability to report geolocated crashes on the network	–	–	☑	☑	High
Placing serious crashes in a time- or place-based context when engaging news media partners	Encourages the public to perceive the transportation system as needing addressing rather than the people involved in crashes	–	–	–	☑	Low

Table 12. (Continued).

Example Practice	How Safety Is Improved	Exposure	Likelihood	Severity	Improves IRA, PCC, or CD[1]	Costs[2]
Establishing a traffic incident management system that documents roadway and incident clearance times, as well as secondary crashes	Provides a means of documenting the performance of emergency service operations and can be used to improve the traffic incident management if the documentation were required, e.g., what did not work, how can the system be improved, etc.	–	–	–	☑	Medium
Instituting automatic crash notification (ACN) for vehicle collisions with people walking, cycling, or rolling	Hastens the reporting of crashes involving road users who may be unable to self-report crash incidents (e.g., via crash notification on road users' smartphones)	–	–	☑	☑	Medium
Installing ACN systems on more remote, rural roadways	Hastens the reporting of crashes that occur in more remote, rural locations (e.g., via embedding crash notification in guardrails or on road users' smartphones)	–	–	☑	☑	High
Encouraging and facilitating public use of self-reporting (via mobile app or survey) to capture collisions and other events falling outside the scope of traditional crash reporting (e.g., near misses, pedestrian and bicyclist falls)	Adding self-reported crashes to traditional crash reporting can provide system administrators with a more holistic sense of single-user injuries and crash potential throughout the network	–	–	–	☑	Low
Deploying unmanned aerial systems to conduct route monitoring, crash incident verification, secondary crash detection, and response vehicle routing to and from the crash site	Improves emergency service units' ability to efficiently and safely access crash sites	–	–	–	☑	Medium

Note: – = Not applicable.

[1] IRA = injury risk assessment, PCC = professional and community coordination, CD = crash diagnoses.

[2] Costs correspond to the total financial cost associated with a policy or practice, including labor, equipment, and infrastructure (Low ≤ \$100k; Medium = \$100k–\$1 million; and High ≥ \$1 million in total or per year).

- Improves injury risk assessment, professional and community coordination, or crash diagnoses reflects a practice's ability to estimate road-user injury risks associated with land use, policy, or engineering interventions; to improve coordination among professionals in different sectors and with the public; or to uncover contributing factors to serious crash events.

Table 12 provides example post-crash response practices and their change mechanisms (i.e., the steps or processes responsible for improving road users' safety).

Implementing Safe System Post-Crash Response Practices

Safe System post-crash response strategies and practices strengthen crash notification systems and pre-hospital care functions and enhance safety investments via research and the sharing of trauma and road safety data.

To begin implementing Safe System–aligned post-crash response practices, consider the following steps and substeps:

1. Identify at least one significant safety problem. Identification and prioritization of a safety problem might be based on the following:
   - Severity and magnitude of the safety problem
   - Disproportionate harm endured by some community members by the problem
   - Importance of addressing the problem to community representatives
   - Availability of resources to address the problem
2. Once a safety problem has been identified and prioritized, ask the following two questions:
   - To what extent does a proposed practice to address the identified problem align with Safe System–aligned post-crash response strategies?
     - Invest in crash notification and communications
     - Strengthen pre-hospital care functions
     - Enhance safety investments via research and the sharing of trauma and road safety data
   - To what extent does a proposed practice address the following?
     - Users' exposure to serious crashes
     - The likelihood of serious crashes
     - The severity of crashes when they occur
     - Improvements to injury risk assessment, professional and community coordination, or crash diagnoses

For example, in step 1, if a safety team identifies and prioritizes responding more rapidly to severe intersection crashes, they might pursue developing joint action plans with emergency services partners to integrate operational planning with emergency services given the disproportionate harm endured by some community members by the problem and the availability of resources to address the problem.

Then, in step 2, a safety team might conclude that integrating operational planning and emergency services aligns with the Safe System strategy to strengthen pre-hospital care functions. They might also conclude that integrated operations and emergency service planning can improve professional coordination between operations and emergency services planners.

At this point, a team should reflect on whether a selected safety practice (1) aligns with one or more Safe System strategies; (2) can significantly reduce the likelihood and severity of users' experience with crashes or enhance injury risk assessment, professional and community coordination, or crash diagnoses; and (3) is feasible given available resources to institute the practice. If the team concludes that all three criteria are satisfied, the practice should be considered for implementation, and the safety team could follow the steps outlined in Table 13. However, if one or more of these three criteria are not satisfied, teams are recommended to start over from step 1 until all three criteria are satisfied.

Table 13. Post-crash response practice implementation steps and example elements.

Step	Example Step Elements
Determine the practice's intended goals, the factors that contribute to practice performance and interactions among factors, what key factors might look like in the future, and success indicators.	• The goal of this practice is to better align emergency services with traffic operations. • The factors that contribute to practice performance include, at least, the level and quality of coordination between traffic operations and emergency service planning professionals, the degree of performance measure integration between the two functions, the capabilities of traffic operations and emergency services personnel to upgrade or maintain traffic operations and allocate reliable emergency services in ways that lower the likelihood and severity of crashes (e.g., emergency vehicle signal preemption), and more. • Key factors in the future will likely involve political and professional support for aligning emergency service and traffic operations functions, the professional normalization of aligning the two functions in operations and emergency service plans, the emergence and uptake of automated traffic operations and asset condition reporting technologies, the geographic availability and distribution of level 1 and level 2 trauma centers, the extent to which serious crash preventive measures have been implemented in other practical domains (e.g., policy, planning, design), and more. • Success indicators might include documented reductions in emergency response times, increased responsiveness to malfunctioning signal operations, reductions in 911 center triage of calls to most proximal call centers, increases in the proportion of victims who survive and suffer less severe injury post-crash, and more.
Enable innovation of practices to meaningfully respond to foreseen and unforeseen opportunities.	• Meaningfully responding to foreseen and unforeseen opportunities might include practice adjustments triggered by anticipated events (e.g., upgrades to traffic signal systems, increased funding for emergency responder training), grants available to maintain automated traffic operations and asset condition reporting or to train emergency responders on prehospital care provision, hiring of leaders who perceive the value of cross-disciplinary training and of goal and action alignment, and more.
Monitor indicators of performance in relation to practice objectives, key factor indicators and thresholds for adjusting the practice, and interested party feedback on the practice.	• Indicators of practice performance would likely involve the level and quality of coordination between traffic operations and emergency service planning professionals, the degree of performance measure integration between the two functions, the observed capabilities of traffic operations and emergency services personnel to upgrade or maintain traffic operations and allocate reliable emergency services, reductions in the occurrence and severity of crashes in regions where operations and emergency services have been integrated versus those areas these functions have not been integrated, feedback from personnel in traffic operations and emergency services on the partnership, and more. • Key factor indicators and thresholds for adjusting the practice might include elevated emergency response times to crash scenes and transport to hospitals and trauma centers, rising serious and fatal injury in the alignment region, growing negative feedback on the alignment of traffic operations and emergency services from stakeholders, apparent lack of interest from one or more parties in continuing the cross-functional coordination, and more.
Improve learning of practice performance to make necessary adjustments to strengthen practice performance or to change up the practice altogether.	• Learning about practice performance requires consistent measurement of practice performance indicators such as emergency response times to crash scenes and transport time to hospitals, the number of serious and fatal injuries in the operations-emergency services alignment region, traffic operations and emergency services personnel perspectives on the cross-functional partnership, and more. • Making necessary practice adjustments requires local agencies and partners to reflect on results of the measured performance indicators and decide to update practice parameters (e.g., deciding to meet more or less frequently, placing more or less emphasis on upgrading signal operations versus increasing the capabilities of emergency responders), or to scale down the degree of coordination between traffic operations and emergency services altogether.

For illustrative purposes, a safety team looks to develop joint action plans with emergency services partners to integrate operational planning with emergency services planning. Table 13 provides recommended steps to implement this safety practice along with elements to consider within each step.

Conclusion

A shift toward Safe System–aligned post-crash response practices is possible and necessary for the United States to realize zero deaths and serious injuries on the nation's roadways. Post-crash response professionals and partners can be supported through advanced crash notification and communications about probable injuries. These professionals would also benefit from a strengthening of prehospital care functions, such as roadside and in-vehicle care provision. Moreover, post-crash response would be enhanced via research and the sharing of trauma registry data among EMS professionals, law enforcement, and transportation professionals to inform the development of serious crash preventive policies, as well as proactive planning and design practices.

Acronyms and Abbreviations

AACN	advanced automatic crash notification
ACN	automatic crash notification
ALR/ALS	administrative license revocation or suspension
BAC	blood alcohol concentration
CD	crash diagnoses
CMF	crash modification factor
DOT	department of transportation
DUI	driving under the influence
EMS	emergency medical services
EMT	emergency medical technician
IRA	injury risk assessment
ISA	intelligent speed assist
ITS	intelligent transportation systems
km/h	kilometers per hour
LOS	level of service
mph	miles per hour
NCAP	New Car Assessment Program
NG911	Next Generation 911
NSC	National Safety Council
PCC	professional and community coordination
PERF	Police Executive Research Forum
SD	standard deviation
STEER	Strengthening Traffic Enforcement, Education, and Responsibility
VMT	vehicle miles traveled
VSL	variable speed limits
WHO	World Health Organization

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APPENDIX A

Safe System Policy Practices

Appendix A provides data on how respondents appraised various Safe System policy practices. See Table A-1 for scores related to each practice's feasibility and impact.

Interpretive categorization of *Z*-scores (Feasibility and Impact columns), with a mean of zero (0) and standard deviation (SD) of one (1).

Categories	***Z*-scores**
High	> 1 SD above mean
Moderate	< 1 and > 0
Low	> –1 and < 0
Very Low	< –1 SD below mean

Note: SD = standard deviation round the mean score of zero (0).

Table A-1. Policy practice feasibility and impact scores (*n* = 85).

Practice	Feasibility	Impact	Category
Installing leading pedestrian intervals with right-turn-on-red restrictions in areas with high pedestrian activity.	1.078	0.385	High Feasibility/ Moderate Impact
Updating NHTSA's New Car Assessment Program to include pedestrian detection and collision avoidance safety tests.	0.604	0.403	Moderate Feasibility/ Moderate Impact
Requiring alcohol ignition interlocks installed for all drivers convicted of driving under the influence.	0.501	0.293	Moderate Feasibility/ Moderate Impact
Developing policies requiring forward- and near-side-facing sensors on heavy vehicles to detect pedestrians and cyclists.	0.337	0.324	Moderate Feasibility/ Moderate Impact
Setting posted speed limits based on harm minimization principles, road function, and severe crash types rather than an 85th percentile rule.	0.290	0.097	Moderate Feasibility/ Moderate Impact
Instituting or enforcing a statewide primary enforcement seat-belt-use law.	0.169	0.179	Moderate Feasibility/ Moderate Impact
Implementing speed safety cameras (automated speed enforcement) that use revenues to improve safety.	–0.259	0.459	Low Feasibility/ Moderate Impact
Instituting or enforcing a statewide universal motorcycle helmet law that would require all motorcyclists to wear U.S. DOT–compliant helmets, regardless of the rider's age or experience.	–0.100	0.197	Low Feasibility/ Moderate Impact
Installing seat belt interlocks in vehicles.	–0.055	0.150	Low Feasibility/ Moderate Impact
Implementing red-light-camera enforcement that uses revenues to fund safety infrastructure.	–0.046	0.133	Low Feasibility/ Moderate Impact
Installing speed governors in all municipal fleet vehicles.	0.592	–0.712	Moderate Feasibility/ Low Impact
Extending graduated driver licensing requirements to include all novice drivers regardless of age.	0.136	–0.258	Moderate Feasibility/ Low Impact
Establishing a default speed limit of 20 mph or lower in every business or residential district.	–0.062	–0.271	Low Feasibility/ Low Impact
Instituting immediate administrative license revocation or suspension for alcohol- and drug-impaired driving offenses.	–0.312	–0.085	Low Feasibility/ Low Impact
Lowering the blood alcohol concentration limit for driving from 0.08 to 0.05.	–0.146	–0.463	Low Feasibility/ Low Impact
Requiring location-based speed limiters in all commercial and private vehicles in areas with high pedestrian activity.	–0.796	0.080	Low Feasibility/ Moderate Impact
Instituting a driver license renewal program that requires passing an on-road driving test every 5–10 years.	–0.477	–0.295	Low Feasibility/ Low Impact
Promoting the installation of technology in private automobiles that records drivers' distraction, drowsiness, and other forms of incapacitation.	–0.788	–0.133	Low Feasibility/ Low Impact
Establishing maximums in vehicle size (in terms of width, length, height, weight) permitted in areas with high pedestrian activity.	–0.666	–0.486	Low Feasibility/ Low Impact

APPENDIX B

Safe System Planning Practices

Appendix B provides data on how respondents appraised various Safe System planning practices. See Table B-1 for scores related to each practice's feasibility and impact.

Interpretive categorization of *Z*-scores (Feasibility and Impact columns), with a mean of zero (0) and standard deviation of one (1).

Categories	***Z*-scores**
High	> 1 SD above mean
Moderate	< 1 and > 0
Low	> –1 and < 0
Very Low	< –1 SD below mean

Note: SD = standard deviation round the mean score of zero (0).

Table B-1. Planning practice feasibility and impact scores (*n* = 60).

Practice	Feasibility	Impact	Category
Incorporating road safety audits in project scoping/planning phases.	0.724	0.302	Moderate Feasibility/ Moderate Impact
Prioritizing injury risk-based (systemic) safety assessments over crash "hot spot" or "black spot" approaches.	0.225	0.417	Moderate Feasibility/ Moderate Impact
Communicating with communities previously not involved in decision-making to learn about their safety issues and concerns on a routine basis (annually, quarterly).	0.402	0.225	Moderate Feasibility/ Moderate Impact
Coordinating with land-use planners to align land use and roadway purposes (e.g., deciding whether the road's purpose is access- or mobility-centered).	0.052	0.257	Moderate Feasibility/ Moderate Impact
Simulating the safety effects of land developments and investments in long-range plans.	–0.233	–0.019	Low Feasibility/ Low Impact
Incorporating nontraditional transportation safety data sources [e.g., emergency medical services, hospital, social determinants of health, environmental, and historical (e.g., redlining)] as part of problem identification and project prioritization processes.	–0.307	–0.012	Low Feasibility/ Low Impact
Implementing or expanding car-free zones in areas with high pedestrian activity.	–0.702	0.370	Low Feasibility/ Moderate Impact
Setting a goal to reduce road deaths by 50% by 2030 in safety plans.	0.071	–0.532	Moderate Feasibility/ Low Impact
Replacing travel forecasting ("predict and provide") with backcasting ("decide and provide," i.e., starting from a vision of desirable travel patterns and working backward to realize the vision).	–0.294	–0.257	Low Feasibility/ Low Impact
Encouraging and facilitating public use of self-reporting (via mobile app or survey) to capture collisions and other events falling outside the scope of traditional crash reporting (e.g., near misses, pedestrian and bicyclist falls).	0.062	–0.751	Moderate Feasibility/ Low Impact

APPENDIX C

Safe System Design Practices

Appendix C provides data on how respondents appraised various Safe System design practices. See Table C-1 for scores related to each practice's feasibility and impact.

Interpretive categorization of *Z*-scores (Feasibility and Impact columns), with a mean of zero (0) and standard deviation of one (1).

Categories	***Z*-scores**
High	> 1 SD above mean
Moderate	< 1 and > 0
Low	> –1 and < 0
Very Low	< –1 SD below mean

Note: SD = standard deviation round the mean score of zero (0).

Table C-1. Design practice feasibility and impact scores (*n* = 44).

Practice	Feasibility	Impact	Category
Improving sight distance at intersections by restricting parking at the corners (daylighting).	0.972	0.296	Moderate Feasibility/ Moderate Impact
Installing centerline rumble strips on undivided highways.	1.010	0.225	High Feasibility/ Moderate Impact
Installing poles that break away when struck.	0.882	0.111	Moderate Feasibility/ Moderate Impact
Installing travel lane reconfigurations (road diets) at multilane roads with fewer than 20,000 annual average daily traffic.	0.219	0.604	Moderate Feasibility/ Moderate Impact
Installing edge line rumble strips with bicycle gaps on undivided highways.	0.726	–0.442	Moderate Feasibility/ Low Impact
Setting default local road travel lane widths to 10 ft.	0.636	–0.397	Moderate Feasibility/ Low Impact
Installing right-in–right-out junctions that only allow vehicles to enter and exit from the right.	0.161	0.064	Moderate Feasibility/ Moderate Impact
Installing cable barriers in the medians of rural roads.	0.223	–0.206	Moderate Feasibility/ Low Impact
Installing cable barriers on the edges of rural roads.	–0.114	–0.081	Low Feasibility/ Low Impact
Installing pedestrian hybrid beacons along arterials with 4+ travel lanes.	–0.134	–0.142	Low Feasibility/ Low Impact
Converting conventional signalized intersections to single-lane roundabouts.	–0.703	0.294	Low Feasibility/ Moderate Impact
Installing raised pedestrian and bicyclist crossings at driveways, minor street intersections, and midblock transit stop locations.	–0.364	–0.073	Low Feasibility/ Low Impact
Installing permanent barrier-protected bike lanes on arterial roads.	–0.869	0.280	Low Feasibility/ Moderate Impact
Employing people with skills in perceptual psychology to help design "self-explaining" roads.	–0.396	–0.322	Low Feasibility/ Low Impact
Creating self-explaining road designs where all local roads have narrow lanes and traffic calming, all collector roads have bicycle lanes and safe pedestrian crossings, and all arterial roads severely limit access and provide protected bicycle lanes and pedestrian crossings.	–1.142	0.196	Very Low Feasibility/ Moderate Impact
Providing pedestrian and bicyclist bridges or daylit tunnels at intersections.	–1.108	–0.407	Very Low Feasibility/ Low Impact

APPENDIX D

Safe System Operations and Maintenance Practices

Appendix D provides data on how respondents appraised various Safe System operations and maintenance practices. See Table D-1 for scores related to each practice's feasibility and impact.

Interpretive categorization of *Z*-scores (Feasibility and Impact columns), with a mean of zero (0) and standard deviation of one (1).

Categories	***Z*-scores**
High	> 1 SD above mean
Moderate	< 1 and > 0
Low	> –1 and < 0
Very Low	< –1 SD below mean

Note: SD = standard deviation round the mean score of zero (0).

Table D-1. Operations and Maintenance practice feasibility and impact scores (*n* = 33).

Practice	Feasibility	Impact	Category
Installing leading pedestrian intervals with right-turn-on-red restrictions in areas with high pedestrian activity.	0.750	0.545	Moderate Feasibility/ Moderate Impact
Removing roadside objects that pose a danger when impacted on a lane departure.	0.291	0.597	Moderate Feasibility/ Moderate Impact
Including crash risk potential in prioritizations of resurfacing schedules (e.g., prioritizing surfaces with low skid resistance for resurfacing).	0.418	0.327	Moderate Feasibility/ Moderate Impact
Providing an exclusive signal phase for pedestrians in areas in high pedestrian volumes (e.g., pedestrian scramble or “Barnes Dance”).	0.067	0.286	Moderate Feasibility/ Moderate Impact
Developing joint action plans with emergency services partners to integrate operational planning with emergency services planning.	0.200	0.091	Moderate Feasibility/ Moderate Impact
Integrating asset management and crash analyses to determine when roadway conditions have degraded to the point that they are increasing the likelihood and severity of crashes.	0.062	0.155	Moderate Feasibility/ Moderate Impact
Improving signal progression on designated routes for emergency vehicles with predetermined signal linking plans.	0.134	0.039	Moderate Feasibility/ Moderate Impact
Providing longer green times for cyclists at shared path crossings.	0.338	–0.236	Moderate Feasibility/ Low Impact
Employing an active or passive equipment maintenance and replacement system.	0.166	–0.127	Moderate Feasibility/ Low Impact
Developing a traffic guidance scheme that details the use of specific traffic control devices (e.g., signs, barriers) during crash events.	0.444	–0.410	Moderate Feasibility/ Low Impact
Keeping a detailed inventory on the condition of the agencies' transportation assets (e.g., bridges, tunnels, pavements, signs, signals, sidewalks, street furniture, vegetation).	–0.040	–0.002	Low Feasibility/ Low Impact
Routinizing network-comprehensive (including bike and sidewalk networks) winter road clearance operations (e.g., snow and ice clearing, salt spreading where applicable).	0.025	–0.073	Moderate Feasibility/ Low Impact
Providing extended clearance intervals for passively detected pedestrians at signalized intersections.	–0.046	–0.053	Low Feasibility/ Low Impact
Implementing variable speed limits (VSL) on roads with high pedestrian activity at certain times and high potential for significant pedestrian-motor vehicle conflicts (e.g., school zones).	–0.332	0.162	Low Feasibility/ Moderate Impact
Incorporating roadway features beyond pavement and safety infrastructure (e.g., drainage features, street furniture, vegetation) into asset management programs.	–0.056	–0.162	Low Feasibility/ Low Impact
Combining passive pedestrian detection and accessible pedestrian signals to help pedestrians with low vision safely traverse intersections.	–0.236	0.008	Low Feasibility/ Moderate Impact
Implementing VSL in the vicinity of traffic incidents.	–0.579	0.169	Low Feasibility/ Moderate Impact
Extending clearance intervals for passively detected cyclists at signalized intersections.	–0.145	–0.334	Low Feasibility/ Low Impact
Implementing driving safety support systems to avoid sign and signal violations and collisions.	–0.546	–0.039	Low Feasibility/ Low Impact
Implementing VSL during adverse weather conditions.	–0.346	–0.372	Low Feasibility/ Low Impact
Implementing VSL at nighttime in alcohol-serving districts.	–0.569	–0.572	Low Feasibility/ Low Impact

APPENDIX E

Safe System Law Enforcement Practices

Appendix E provides data on how respondents appraised various Safe System law enforcement practices. See Table E-1 for scores related to each practice's feasibility and impact.

Interpretive categorization of *Z*-scores (Feasibility and Impact columns), with a mean of zero (0) and standard deviation of one (1).

Categories	***Z*-scores**
High	> 1 SD above mean
Moderate	< 1 and > 0
Low	> –1 and < 0
Very Low	< –1 SD below mean

Note: SD = standard deviation round the mean score of zero (0).

Table E-1. Enforcement practice feasibility and impact scores (*n* = 61).

Practice	Feasibility	Impact	Category
Instituting immediate administrative license revocation or suspension for alcohol- and drug-impaired driving offenses.	0.225	0.424	Moderate Feasibility/ Moderate Impact
Instituting or enforcing a statewide primary enforcement seat-belt-use law that would require occupants to wear seatbelts in the front and back seats and allow law enforcement officers to ticket occupants for not wearing a seatbelt, without other citable traffic infractions taking place.	0.204	0.426	Moderate Feasibility/ Moderate Impact
Instituting high-visibility saturation patrols for alcohol- or drug-impaired driving.	0.157	0.287	Moderate Feasibility/ Moderate Impact
Requiring alcohol ignition interlocks installed for all drivers convicted of driving under the influence.	0.035	0.406	Moderate Feasibility/ Moderate Impact
Instituting or enforcing a statewide universal motorcycle helmet law that would require all motorcyclists to wear U.S. DOT–compliant helmets, regardless of the rider's age or experience.	0.116	0.177	Moderate Feasibility/ Moderate Impact
Placing serious crashes in a time- or place-based context when engaging news media partners.	0.134	–0.321	Moderate Feasibility/ Low Impact
Implementing speed safety cameras (automated speed enforcement) that use revenues to fund safety infrastructure.	–0.170	–0.061	Low Feasibility/ Low Impact
Implementing red-light-camera enforcement that uses revenues to improve safety.	–0.222	–0.169	Low Feasibility/ Low Impact
Linking police with emergency medical services/hospital data for persons injured in motor vehicle crashes.	–0.088	–0.344	Low Feasibility/ Low Impact
Forming a task force or community coalition of law enforcement, transportation, public health, members of the community, and other partners to investigate serious crashes and report findings and proposed changes to the public.	–0.340	–0.127	Low Feasibility/ Low Impact
Encouraging and facilitating public use of self-reporting (via mobile app or survey) to capture collisions and other events falling outside the scope of traditional crash reporting (e.g., near misses, pedestrian and bicyclist falls).	–0.051	–0.698	Low Feasibility/ Low Impact

APPENDIX F

Safe System Post-Crash Response Practices

Appendix F provides data on how respondents appraised various Safe System post-crash response practices. See Table F-1 for scores related to each practice's feasibility and impact.

Interpretive categorization of *Z*-scores (Feasibility and Impact columns), with a mean of zero (0) and standard deviation of one (1).

Categories	***Z*-scores**
High	> 1 SD above mean
Moderate	< 1 and > 0
Low	> −1 and < 0
Very Low	< −1 SD below mean

Note: SD = standard deviation round the mean score of zero (0).

Table F-1. Post-Crash Response practice feasibility and impact scores (*n* = 66).

Practice	Feasibility	Impact	Category
Forming a task force or community coalition of law enforcement, transportation, public health, members of the community, and other partners to investigate serious crashes and report findings and proposed changes to the public.	0.418	0.300	Moderate Feasibility/ Moderate Impact
Training law enforcement and transportation staff to coordinate post-crash reporting at crash sites.	0.332	0.153	Moderate Feasibility/ Moderate Impact
Developing joint action plans with emergency services partners to integrate operational planning with emergency services planning.	0.328	–0.145	Moderate Feasibility/ Low Impact
Linking police with emergency medical services/hospital data for persons injured in motor vehicle crashes.	–0.038	0.208	Low Feasibility/ Moderate Impact
Upgrading analog 911 infrastructure to Next Generation 911 (commonly referred to as NG911) to create a faster, more resilient system that facilitates public reporting to the 911 network.	–0.073	0.242	Low Feasibility/ Moderate Impact
Placing serious crashes in a time- or place-based context when engaging news media partners.	0.473	–0.369	Moderate Feasibility/ Low Impact
Establishing a traffic incident management system that documents roadway and incident clearance times, as well as secondary crashes.	–0.033	–0.085	Low Feasibility/ Low Impact
Instituting automatic crash notification for vehicle collisions with people walking, cycling, or rolling.	–0.452	0.312	Low Feasibility/ Moderate Impact
Installing automatic collision notification systems on more remote, rural roadways.	–0.335	0.137	Low Feasibility/ Moderate Impact
Encouraging and facilitating public use of self-reporting (via mobile app or survey) to capture collisions and other events falling outside the scope of traditional crash reporting (e.g., near misses, pedestrian and bicyclist falls).	–0.080	–0.566	Low Feasibility/ Low Impact
Deploying unmanned aerial systems to conduct route monitoring, crash incident verification, secondary crash detection, and response vehicle routing to and from the crash site.	–0.540	–0.187	Low Feasibility/ Low Impact

APPENDIX G

Safe System Strategy Implementation Self-Assessment

Instructions and Recommendations: Coordinate with at least two colleagues within your practice domain (e.g., planning, design, law enforcement) and at least two colleagues each for other practice domains (e.g., policy, operations and maintenance, post-crash response) to discuss and arrive at an agreement on the extent to which your Safe System or safety coalition has implemented strategies outlined in the **Strategy** table. Consult with the **Score Interpretation** section at the end of this assessment to discern where your coalition stands with respect to Safe System implementation. Consider referencing and recompleting this assessment each year to inform your coalition's improvement efforts and to document your progress toward implementing a Safe System.

Date of the assessment:

Name of Safe System (or Safety) coalition:

Score	Meaning
0	The strategy has not yet been implemented.
1	The strategy has started to be implemented within the past 6 months.
2	The strategy has been implemented for between 6 and 12 months.
3	The strategy has been implemented and has been the way we do things for at least the past 12 months.

Strategy		0	1	2	3	Score
Policy	**Example Practice(s)**					
Advance adaptive safety policies	Adjusting policies automatically based on anticipated events; Conducting regularly scheduled policy review; Diversifying the types of implemented policies					
Build up Safe System-consistent practices AND break down inconsistent practices	Allocating revenues generated from speed safety and red-light-running cameras to filling network gaps in safety infrastructure, especially in areas that have not been involved in decision-making to date					
Provide reliable and protective system redundancies	Pairing automated vehicle lane-keeping technology with cable-wire barriers on the edges of rural roads					
					Policy Total	
Planning	**Example Practice(s)**					
Start from a collective vision for a Safe System	Defining what the future of the system should be and implementing policies that can help bring about desired changes					
Vertically and horizontally integrate planning	Embedding Safe System principles across policy, network planning, and implementation of street design projects (vertical integration) Requiring transportation planners and urban designers to coordinate their site plan reviews, corridor audits, and street standard policies with local land-use planners (horizontal integration)					
Clearly define the functionality of roads	At a network level, determining which roadways will serve an access function and which will serve a mobility function, striving not to blend access and mobility where possible					
Separate motor vehicle networks from active transportation networks	At a network level, separating motor vehicle traffic from vulnerable road users as vehicle speeds and volumes increase					
					Planning Total	

Strategy		0	1	2	3	Score
Design	**Example Practice(s)**					
Institute self-explaining/enforcing roads	Designing roads with the same function, speed profile, and type of road users to (a) look similar, (b) look different from roads with different functions, speed profiles, and types of road users, and to (c) clearly communicate the desired driver behavior on a route					
Design around human tolerances to crash forces	If vehicle-to-vehicle crashes could conceivably happen at angles of 90º or greater, introducing design speeds to not exceed 30 mph, and if vulnerable road users are exposed to vehicles, introducing design speeds to not exceed 20 mph					
Physically separate fast-moving motor vehicles from vulnerable road users	Providing physical protection (e.g., via curbs, barriers, planters or bollards) to protect vulnerable road users along roads, and grade separation between road users of different masses and speeds at intersections					
					Design Total	
Operations and Maintenance	**Example Practice(s)**					
Separate road users of different mass, directions, and speeds in time	Providing discrete and alternating temporal opportunities for users to safely navigate the roadway (e.g., left-turn signal phasing, coordinated signal timing, leading pedestrian intervals)					
Adapt road operations to changing environmental and social conditions	Regularly tracking operations performance and adjusting as needed (e.g., every three years or more often)					
Inventory and manage infrastructure assets to sustain safety-related efficacy	Developing and maintaining a physical asset inventory and subsequently repairing or replacing assets that have degraded					
					Operations and Maintenance Total	
Law Enforcement	**Example Practice(s)**					
Work collaboratively to investigate serious crashes and share contextual insights	Coordinating with professional and community partners to identify the network of factors that shape road users' behaviors that result in serious crashes, and share results of the investigations with the public and policymakers					

(continued on next page)

Strategy		0	1	2	3	Score
Enforce road-user protective policies	Preventing drunk driving (e.g., by installing ignition interlocks for all drivers convicted of driving under the influence) in addition to issuing fines for impaired driving					
Observe, document, and share risk patterns with road designers and planners	Observing, documenting, and sharing risk patterns with road designers and planners to inform safety infrastructure improvements					
Law Enforcement Total						
Post-Crash Response	**Example Practice(s)**					
Invest in crash notification and communications	Instituting advanced automatic crash notification (AACN) systems that share information on the probable injury severity of crash-involved parties with call centers					
Strengthen pre-hospital care functions	Shoring up roadside and in emergency vehicle care provision via pre-hospital care training and resourcing					
Enhance safety investments via research and sharing trauma and road safety data	Connecting trauma with police-reported crash data to improve decision-making on emergency medical care, vehicle designs that reduce injury impacts to occupants and vulnerable road users, and safety infrastructure investments					
Post-Crash Response Total						
Grand Total (across all Domains)						

Score Interpretation

Total Possible Score = 57

0–14: Exploration. In this phase, Safe System coalition members assess and create readiness for change through an appreciation of how each role's leadership, resources, interorganizational coordination, and funding play in experimenting with Safe System strategies and practices across the domains of Safe System: policy, planning, design, operations and maintenance, law enforcement, and post-crash response.

15–28: Installation. In this phase, Safe System coalition members acquire or repurpose the resources (e.g., hiring and training staff) needed to fully and effectively install Safe System–aligned strategies and practices. Topics discussed in the Exploration phase—and often captured in safety action plans (promises made)—become realized in the Installation phase (promises kept), wherein coalition members begin implementing Safe System strategies and practices.

29–43: Initial Implementation. In this phase, Safe System coalition members attempt to use newly learned Safe System strategies and practices within organizations just learning how to adjust to and support new ways of planning, designing, operating, and maintaining safe roadways. This stage includes staff developing their Safe System competencies and organizational administrators rearranging roles and functions to align with Safe System strategies and practices,

and leaders fully supporting the change to Safe System management via offering access to safety resources and training.

44–57: Full Implementation. In this phase, Safe System–aligned strategies and practices become the standard ways of understanding and improving safety via planning, design, operations, and maintenance. To sustain full implementation, leaders reliably provide Safe System coalition members with access to safety-based resources and training, and involved organizations work more effectively with one another via the sharing of data, funding, skills, and other resources. In full implementation, Safe System–aligned strategies and practices, along with their implementation supports (e.g., training, funding, leadership) become the new status quo.

Note: Full implementation of Safe System strategies and practices will likely require at least two (2) to four (4) years of committed work.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GHSA	Governors Highway Safety Association
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001

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ISBN 978-0-309-99350-0
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