

Engineering Approaches to Reducing Pedestrian Fatalities in the US



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COURSE DESCRIPTION

This course examines the recent rise in pedestrian fatalities across the United States, with particular focus on engineering factors that contribute to this trend and the solutions available to mitigate it. The course explores roadway design, vehicle technology, traffic operations, and urban planning approaches, along with data-driven insights into why pedestrian deaths have increased in the past two decades despite overall advancements in vehicle safety. Practical engineering countermeasures, design innovations, and future strategies are analyzed to provide transportation engineers with the knowledge to design safer roadways, intersections, and multimodal networks.

Course Learning Objectives

Upon completion of this course, participants will be able to:

1. Analyze the historical and recent trends in U.S. pedestrian fatalities.
2. Identify engineering and infrastructural causes contributing to the rise in deaths.
3. Evaluate roadway design features that either exacerbate or reduce pedestrian risk.
4. Assess the role of vehicle size, speed, and driver behavior in pedestrian safety.
5. Apply engineering solutions, such as traffic calming, improved crosswalk design, and signalization, to reduce pedestrian deaths.
6. Integrate data analytics, new technologies, and urban planning strategies to enhance pedestrian safety.
7. Develop practical approaches to engineering safer transportation systems for mixed-use environments.

INTRODUCTION TO PEDESTRIAN SAFETY TRENDS IN THE UNITED STATES

Pedestrian safety has long been a central concern in the practice of transportation engineering. Walking is the most fundamental form of human mobility, and in nearly all communities pedestrians share the roadway network with vehicles of varying speeds, sizes, and purposes. Despite efforts in past decades to reduce roadway fatalities, the United States has witnessed a troubling reversal in pedestrian safety outcomes (Figure 1).

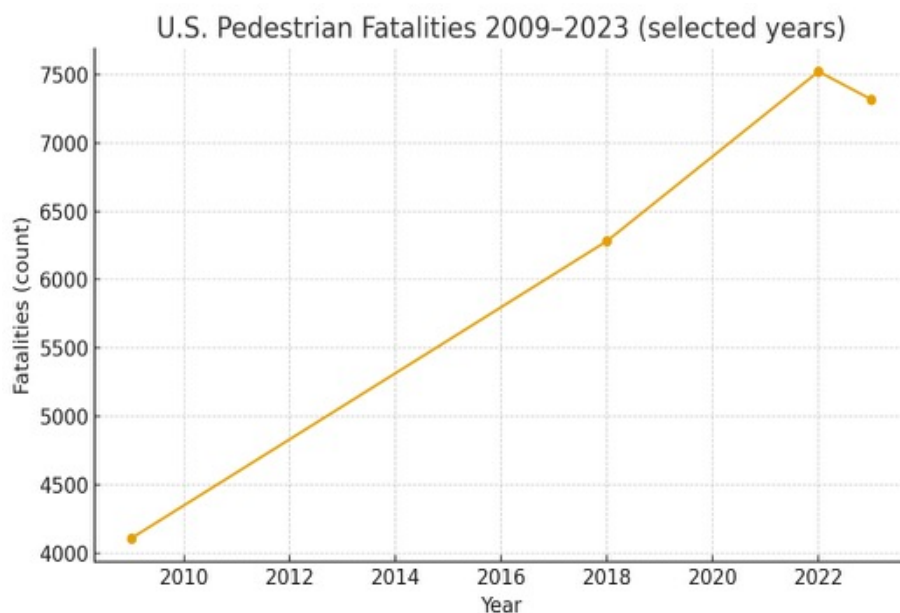


Figure 1: Pedestrian fatalities in the US from 2009 - 2023

In particular, since approximately 2009, pedestrian deaths have steadily risen, erasing years of progress and creating a renewed public safety challenge. This chapter introduces the scope of

the issue and lays the foundation for exploring the engineering causes and solutions that will be discussed throughout the course.

From the late 1970s through the early 2000s, pedestrian fatalities in the United States generally declined. Improvements in roadway design, crosswalk treatments, traffic enforcement, and vehicle safety technologies contributed to this reduction. By 2009, the annual number of pedestrian deaths had reached a low point near 4,100 fatalities nationwide, a substantial improvement over prior decades. However, this trend did not continue. Between 2009 and 2022, pedestrian fatalities increased by nearly 80 percent, with more than 7,500 deaths recorded in 2022, marking one of the highest totals in over 40 years.

Even when adjusted for population growth, the fatality rate per 100,000 residents has risen significantly, demonstrating that the problem cannot be attributed solely to increased numbers of road users.

Contributing Factors and Systemic Pressure

Several factors have been identified as contributing to this disturbing trend. The growing prevalence of larger vehicles such as sport utility vehicles and pickup trucks has increased the severity of collisions. Higher vehicle speeds, urban roadway designs that prioritize vehicle flow over pedestrian safety, and insufficient infrastructure for non-motorized users have also played a role. In addition, the widespread use of mobile devices has introduced new forms of distraction for both drivers and pedestrians.

The interplay of these conditions has created a transportation environment that is increasingly hostile to vulnerable road users. Table 1 links key contributing factors to impact mechanisms and typical engineering levers.

Role of Transportation Engineers and Technology

Transportation engineers are uniquely positioned to address these challenges. Engineering design decisions shape roadway geometry, traffic control, lighting, signage, and crossing facilities, all of which influence pedestrian risk. Beyond the built environment, engineers contribute to the integration of intelligent transportation systems, sensor technologies, and data analytics that can predict high-risk areas and guide proactive interventions.

At the same time, the profession must contend with external forces such as urban development patterns, driver behavior, and evolving vehicle fleets. The solutions therefore require both technical innovation and systemic thinking, applying a “safe systems” approach that recognizes human limitations while designing redundancies that reduce the likelihood of fatal crashes.

Table 1: Contributing factors, the mechanisms they affect and practical engineering levers.

Contributing Factor	Primary Impact Mechanism	Example Engineering Lever
Larger vehicle fleet (SUVs/ PUVs)	Higher front-end geometry → greater injury severity	Front-end design standards; lower design speeds
Higher operating speeds	Reduced stopping distance; higher crash energy	Traffic calming; narrower lanes; speed management
Auto-centric urban design	Long crossings; exposure time; limited refuge	Shorter crossings; medians; protected intersections
Inadequate ped infrastructure	Forced midblock crossing; exposure to turning flows	Continuous sidewalks; protected crossings; signals
Distraction (drivers/pedestrians)	Delayed perception-response; missed conflicts	Leading ped intervals; conflict warnings; lighting

Ethical Imperative and Societal Stakes

The rise in pedestrian fatalities represents not only a statistical reversal but also a profound human cost. Each fatality carries with it the loss of life, family trauma, and societal costs in terms of healthcare, productivity, and community trust in transportation networks. For professional engineers, the ethical obligation to protect public safety demands a clear understanding of this crisis and a commitment to apply best practices and emerging solutions to reverse the trend.

This course begins by examining the data and underlying causes, then progresses into a detailed exploration of engineering solutions. As such, this introductory chapter establishes the purpose: to equip transportation engineers with the knowledge and tools to reduce pedestrian deaths through design, innovation, and responsible practice.

HISTORICAL DECLINE AND THE REVERSAL SINCE 2009

The Long-Term Trajectory of Pedestrian Fatalities

Understanding the trajectory of pedestrian fatalities in the United States requires a historical perspective. For much of the twentieth century, roadway safety initiatives focused on reducing the overall number of traffic deaths, and during this time pedestrian fatalities were a significant share of the total. In the early 1970s, the annual number of pedestrian deaths often exceeded 8,000. A combination of regulatory reforms, engineering improvements, and public safety campaigns gradually reduced this toll over the next three decades.

Engineering and Policy Drivers of Decline

One of the key drivers of decline was the introduction of federally mandated vehicle safety standards. These included requirements for improved braking systems, impact-absorbing bumpers, and enhanced crashworthiness of passenger compartments. Roadway design also advanced, with better signage, wider sidewalks in urban settings, and enhanced crosswalks.

In many areas, community-level safety programs emphasized the separation of pedestrians from fast-moving traffic, the construction of overpasses or underpasses at high-risk corridors, and improved street lighting. By the late 1980s and early 1990s, these efforts helped bring down the annual pedestrian death toll. Table 2 summarizes major engineering and regulatory interventions that contributed to the mid- to late-century safety gains.

The Role of Safety Culture and Enforcement

Traffic safety culture also shifted during this period. Public awareness campaigns raised concerns about impaired driving, encouraging both enforcement and personal responsibility. The emergence of Mothers Against Drunk Driving (MADD) and similar organizations placed pressure on policymakers to strengthen impaired driving laws, which indirectly benefited pedestrians by reducing the number of high-risk motorists on the road. Law enforcement campaigns targeting speeding and red-light running further contributed to the safety improvements.

Table 2: Key interventions contributing to historical decline in pedestrian fatalities

Intervention Type	Example Measures	Typical Implementation Era	Primary Safety Effect
Vehicle Safety Regulations	Crashworthy vehicle standards, bumpers, braking systems	1970s–1980s	Reduced impact severity
Roadway Design Improvements	Sidewalk widening, crosswalk upgrades, lighting	1980s–1990s	Improved pedestrian visibility and refuge
Separation Infrastructure	Pedestrian overpasses, underpasses, barriers	1980s–2000s	Reduced direct exposure to traffic
Behavioral & Enforcement Campaigns	DUI enforcement, speed limit compliance	1980s–2000s	Lowered incidence of high-risk driving

By 2009, the United States recorded just over 4,100 pedestrian deaths, the lowest level in modern history. The decline reflected decades of progress and provided evidence that engineering and public policy interventions could produce meaningful results. However, beginning in 2010, a reversal became evident. Year by year, the numbers climbed, culminating in over 7,500 pedestrian deaths in 2022, the highest level in more than four decades.

Causes Behind the Modern Resurgence

Several hypotheses explain this resurgence. A critical factor is the changing U.S. vehicle fleet. Larger vehicles such as SUVs and pickup trucks, which now dominate sales, pose a higher risk to pedestrians because of their higher front-end profile, increased weight, and greater likelihood of causing severe trauma in a collision.

Roadway design trends also shifted in ways that disadvantaged pedestrians. Suburban arterial roads, characterized by wide lanes, high speed limits, and limited pedestrian crossings, became more common. These road types prioritize vehicle throughput over pedestrian safety and are especially dangerous in communities where walking remains an essential mode of travel. Table 3 shows how vehicle fleet changes have influenced injury severity.

Table 3: Pedestrian fatality risk by vehicle class (relative odds of death per collision)

Vehicle Type	Relative Fatality Risk (car = 1.0)
Passenger car	1.0
SUV	2.0–2.5
Pickup truck	2.3–2.8
Van	1.8–2.0

Technologies and Behavioral Shifts

Technological and behavioral factors must also be considered. The widespread use of smartphones has introduced new sources of distraction for both drivers and pedestrians. While in-vehicle technology has improved driver comfort and convenience, it has also created additional cognitive demands that can impair reaction times. At the same time, increases in population and urban development have placed more pedestrians into environments where roadway design is inadequate for safe crossings.

Lessons for Modern Engineering Practice

This reversal highlights the vulnerability of safety gains when systemic changes occur. The engineering community must recognize that past solutions, while effective in reducing fatalities for several decades, are not sufficient for the challenges posed by modern transportation systems. A new approach is needed—one that integrates engineering, behavioral science, and technological innovation in a coordinated strategy. The lessons of history make clear that progress is possible, but they also show that complacency can result in regression.

THE ROLE OF VEHICLE DESIGN AND FLEET COMPOSITION

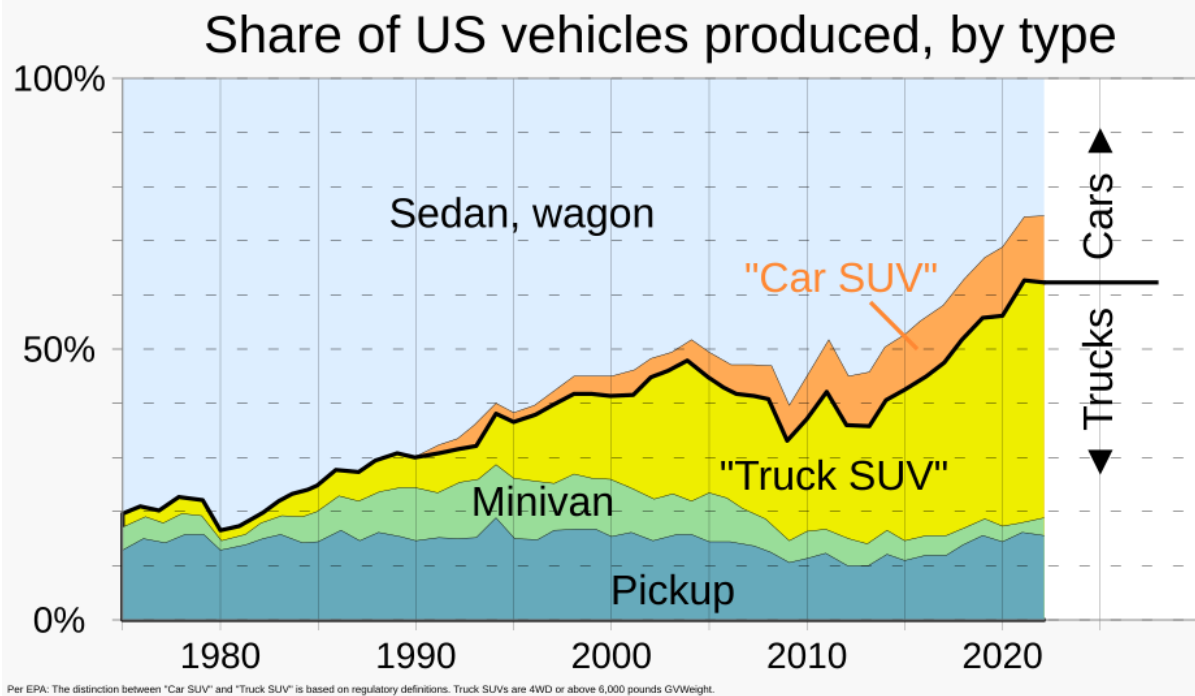


Figure 2: Vehicle production share in the US by vehicle type
Credit: RCraig09, via Wikimedia Commons

The Rise of Larger Vehicles in the U.S. Fleet

One of the most significant contributors to the modern rise in pedestrian fatalities is the changing composition of the U.S. vehicle fleet. Over the past two decades, sales of sport utility vehicles (SUVs) and light trucks have surged, while traditional sedans have declined in popularity (see Figure 2). This shift has profound implications for pedestrian safety because the physical geometry and crash dynamics of larger vehicles create a substantially higher risk of death or serious injury when collisions occur.

Crash Geometry and Injury Severity

Passenger sedans, which dominated the fleet in the latter half of the twentieth century, generally have lower hoods and bumpers, meaning that impacts with pedestrians tend to occur at the legs or lower body. Although still dangerous, such impacts more often allow for survivability if medical treatment is quickly available. In contrast, SUVs and pickups have higher front-end profiles, which cause initial impact forces to strike a pedestrian's torso or head.

This difference greatly increases the likelihood of catastrophic injuries. Additionally, the higher mass of larger vehicles results in greater energy transfer upon impact, making even low-speed collisions more lethal compared to smaller vehicles. Larger, heavier vehicles shift the point of impact upward and transfer greater kinetic energy, substantially increasing fatality risk (Table 4).

Visibility and Blind Spot Limitations

Beyond crash geometry, larger vehicles also impair visibility. Higher hoods and extended blind spots reduce the driver's ability to see pedestrians, particularly small children or individuals crossing directly in front of the vehicle. Studies have shown that pedestrian fatalities involving SUVs have grown at a much faster rate than those involving smaller passenger cars. This correlation is difficult to dismiss, and it highlights the role of fleet composition in shaping pedestrian risk.

Table 4: Comparison of pedestrian impact dynamics by vehicle class

Vehicle Type	Primary Impact Zone	Average Vehicle Mass (kg)	Relative Fatality Risk (car = 1.0)
Passenger car	Legs / lower body	1,400	1.0
SUV	Torso / head	2,000	2.3
Pickup truck	Torso / head	2,300	2.6
Van	Mid-body / shoulder	2,100	1.9

Speed, Weight and Stopping Distance

Vehicle design also affects pedestrian safety through speed. Heavier vehicles require longer stopping distances, and their acceleration characteristics can encourage higher operating

speeds in certain conditions (Figure 3). When combined with roadway designs that permit or encourage fast travel, the risk to pedestrians is compounded. Engineers must recognize that roadway design and vehicle fleet composition are interconnected elements of pedestrian safety outcomes.

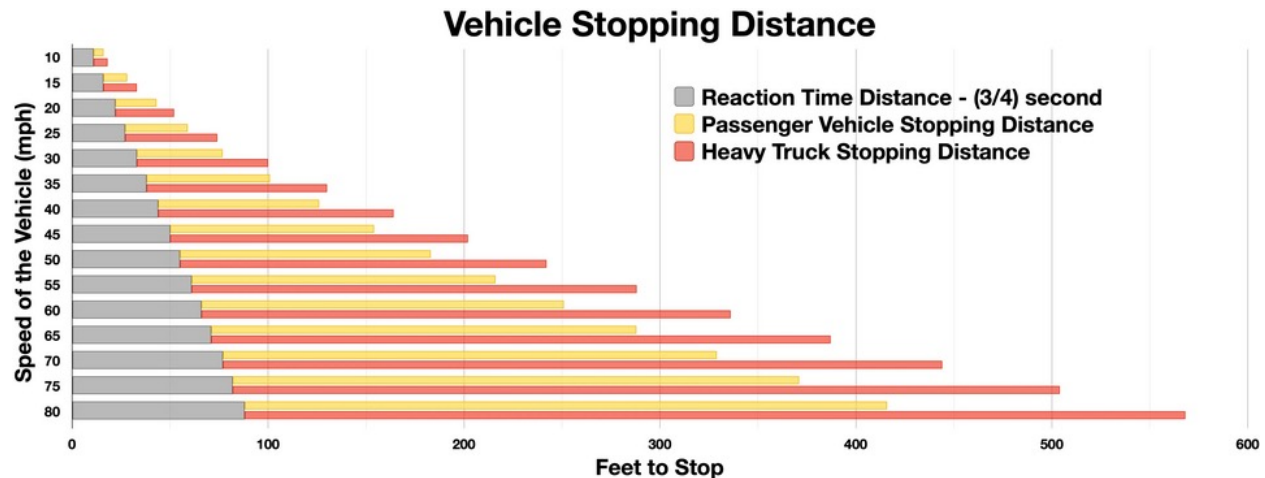


Figure 3: Estimated vehicle stopping distance

AEB and Pedestrian Detection

Regulatory bodies and manufacturers have begun to respond to these concerns. The inclusion of pedestrian detection and automatic emergency braking (AEB) in new vehicles represents an important step forward. These systems use cameras, radar, or lidar to identify pedestrians and automatically apply brakes if the driver fails to react in time. Early studies suggest such technologies can prevent or reduce the severity of collisions, particularly in urban environments. However, their effectiveness is limited by technology adoption rates, weather conditions, nighttime visibility, and the need for consistent maintenance and calibration.

International Safety Standards and Comparative Practice

Some countries have gone further by integrating pedestrian crashworthiness into vehicle safety rating systems. The European New Car Assessment Programme (Euro NCAP), for example, requires vehicles to undergo pedestrian impact testing, influencing manufacturers to design hoods, bumpers, and windshields that reduce the likelihood of fatal injuries.

The U.S. has not fully adopted such standards, though discussions have begun within regulatory agencies and safety organizations. For transportation engineers, understanding these global

practices provides insight into how future vehicle design standards may influence pedestrian safety in the domestic context.

Engineering Response to Fleet Realities

The challenge of fleet composition is particularly difficult to address because it is tied to consumer preferences and market economics. Engineers cannot directly dictate the types of vehicles people choose to drive, but they can design roadways, intersections, and pedestrian facilities with these realities in mind. Acknowledging the risks associated with a heavier, taller vehicle fleet is essential to creating engineering solutions that compensate for these dangers through roadway design and traffic management strategies.

CONCLUSION

The shift toward larger, heavier vehicles has significantly increased pedestrian risk by raising impact forces, expanding blind zones, and extending stopping distances. While technologies like automatic emergency braking offer partial mitigation, engineering solutions must adapt to these fleet realities through safer roadway design and updated vehicle standards.

ROADWAY DESIGN FACTORS CONTRIBUTING TO FATALITIES

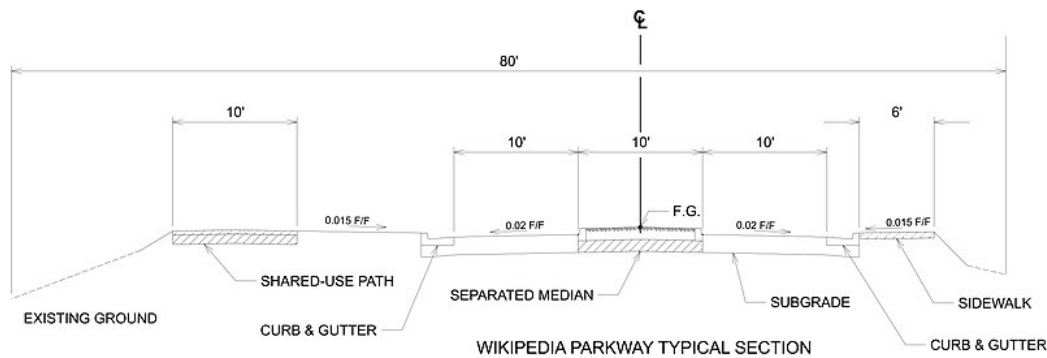


Figure 4: Typical roadway cross-section sheet in transportation engineering

While vehicle design influences the severity of pedestrian collisions, the roadway environment itself is often the determining factor in whether such collisions occur in the first place. Roadway design choices reflect decades of priorities that have historically favored vehicle throughput over pedestrian safety (Figure 4). As a result, many of today's transportation networks contain features that increase risk for those traveling on foot.

This chapter examines the principal roadway design factors contributing to pedestrian fatalities and establishes the foundation for engineering interventions.

Suburban Arterials and Crossing Exposure

One of the most prominent contributors is the design of arterial roadways in suburban and urban fringe areas. These corridors often feature multiple wide lanes, high speed limits, and infrequent controlled crossings. Pedestrians attempting to cross must often navigate several lanes of fast-moving traffic without refuge islands or adequate signal timing. The probability of a

fatal outcome in such environments is far greater than in compact urban centers where slower speeds and shorter crossings prevail. These conditions are particularly dangerous in communities where economic or cultural factors necessitate high rates of pedestrian travel along corridors not designed for foot traffic.

Lane Width, Geometry, and Speed Behavior

Lane width and roadway geometry also affect pedestrian safety. Wider lanes encourage higher operating speeds, while straight, uninterrupted corridors reduce driver attentiveness. Conversely, narrower lanes, curves, and visual friction introduced by roadside design features can naturally calm traffic, reducing collision risk. For engineers, the design of the roadway cross-section—including lane width, median configuration, and the presence of pedestrian refuge areas—plays a direct role in safety outcomes.

Crosswalk Placement and Accessibility

The placement and design of crosswalks represent another critical factor. Many pedestrian deaths occur outside designated crossing areas, often because crosswalks are spaced too far apart. In some corridors, signalized intersections may be separated by half a mile or more, creating strong incentives for pedestrians to cross mid-block. Even when crosswalks are present, inadequate marking, poor lighting, and short signal cycles can make them ineffective. Engineers must recognize that pedestrians will take the most direct path available, and designs that ignore this reality increase exposure to risk.

Sidewalk Continuity and Accessibility

Sidewalk design and continuity also play a central role. In many suburban and rural areas, sidewalks are incomplete or nonexistent, forcing pedestrians to walk along roadway shoulders or grassy verges. These conditions not only place pedestrians closer to fast-moving vehicles but also limit accessibility for children, elderly individuals, and those with disabilities. Gaps in sidewalk networks can transform otherwise safe walking environments into dangerous stretches, particularly at points where pedestrians must enter the travel lane to continue their journey.

Lighting and Nighttime Visibility

Lighting and visibility are critical considerations that intersect roadway design with human behavior. A large proportion of pedestrian fatalities occur at night, often on poorly lit corridors. Inadequate illumination reduces driver reaction times and makes it difficult to detect pedestrians until it is too late. Roadway lighting design must therefore consider not just vehicular visibility but also pedestrian detection.

Engineers must account for glare, uniformity of light distribution, and the placement of lighting relative to crossings and intersections. Table 5 summarizes optimal lighting levels for various roadway environments to enhance pedestrian visibility and driver awareness.

Traffic Calming and Speed Management

The presence or absence of traffic calming measures significantly influences pedestrian safety. Features such as speed humps, raised crosswalks, curb extensions, and chicanes alter driver behavior by physically reshaping the roadway environment. In many areas, however, roadway designs still emphasize wide turning radii, multiple approach lanes, and high design speeds that encourage vehicle dominance at the expense of pedestrian survival.

Table 5: Recommended Illumination Levels for Pedestrian Safety

Roadway Environment	Recommended Illumination (lux)	Primary Design Consideration
Urban Intersection	20–30	Glare control and pedestrian detection
Mid-block Crossing	10–20	Uniformity and approach visibility
Suburban Arterial	15–25	Extended coverage along sidewalks
Rural Highway Crossing	5–10	Focused lighting at crossing points

CONCLUSION

The cumulative effect of these design elements is an environment that often places pedestrians at a systemic disadvantage. Recognizing the shortcomings of past roadway design paradigms allows engineers to reevaluate priorities and move toward practices that emphasize the safety of all users. In doing so, transportation professionals must balance mobility needs with the ethical imperative to protect life, ensuring that roadway networks serve both efficiency and human safety.

INTERSECTION DESIGN AND CROSSWALK SAFETY



Intersections represent some of the most complex environments in the roadway network and are disproportionately represented in pedestrian fatality data. Because they are locations where multiple modes of travel converge, their design directly influences both the likelihood of collisions and the severity of outcomes. Improving intersection safety is therefore one of the most effective strategies transportation engineers can employ in reducing pedestrian fatalities.

Insufficient Crossing Time

One of the primary issues is insufficient crossing time. Many signalized intersections are timed to maximize vehicle throughput, often at the expense of pedestrian needs. Standard pedestrian signal phases may not provide enough time for slower individuals, such as children, elderly pedestrians, or those with disabilities, to cross safely.

Short signal cycles increase the likelihood that pedestrians remain in the crosswalk when vehicles are given a green signal, raising the risk of conflict. Extending pedestrian clearance intervals, implementing countdown timers, and applying adaptive signal technology are proven countermeasures that can reduce these risks.

Crosswalk Placement and Turning Movements

Crosswalk placement is equally critical. Intersections with channelized right-turn lanes or slip lanes often allow vehicles to maintain higher speeds when turning, which can be lethal to pedestrians attempting to cross. Reducing turning radii, elevating crosswalks, and using curb extensions can physically slow turning vehicles and shorten crossing distances. In some cases, restricting right turns on red has been shown to reduce conflicts, especially in high-pedestrian-volume areas.

Markings and Visibility

Markings and visibility also influence crosswalk safety. High-visibility treatments such as ladder or continental striping improve driver awareness of crossings, particularly at night. The use of raised or textured crosswalks provides both tactile and visual cues to drivers, reinforcing the presence of pedestrian priority. Supplemental lighting focused directly on crosswalks further increases detection, reducing collisions in nighttime conditions.

Table 6 compares common crosswalk marking patterns based on visibility and suitable application context.

Table 6: Comparison of crosswalk marking types and visibility

Marking Type	Description	Visibility Level	Common Application
Parallel Lines	Two basic stripes	Low	Local or residential streets
Ladder (Zebra)	Bold horizontal bars	High	Urban intersections
Continental	Solid rectangular markings	Very High	High-volume arterials
Textured or Raised	Physical surface elevation	Very High	Traffic-calmed zones

Signal Phasing Strategies

Signal phasing strategies play a major role in shaping pedestrian outcomes. The implementation of Leading Pedestrian Intervals (LPIs), where pedestrians receive a head start before vehicles are given a green signal, has been shown to reduce conflicts at signalized intersections by giving pedestrians additional time to establish themselves in the crosswalk.

Exclusive pedestrian phases, sometimes referred to as “Barnes Dance” crossings, allow pedestrians to cross in all directions, including diagonally, while halting vehicle traffic entirely. Though they can reduce vehicular efficiency, in high-risk or high-volume areas these phasing strategies create a safer pedestrian environment.

Unsignalized Intersections

Unsignalized intersections present their own challenges. Drivers often fail to yield to pedestrians in crosswalks, even where laws mandate yielding. Engineering solutions such as pedestrian refuge islands, in-roadway signs, flashing beacons, and raised medians can reinforce pedestrian priority and provide a degree of protection. Rectangular Rapid Flashing Beacons (RRFBs), when installed at unsignalized crosswalks, have been shown to significantly increase yielding rates by capturing driver attention.

Accessibility and ADA Compliance

Another design consideration is accessibility. Compliance with the Americans with Disabilities Act (ADA) requires curb ramps, detectable warning surfaces, and appropriate slopes to ensure that all individuals, regardless of mobility limitations, can cross safely. Inadequate or poorly maintained ADA features not only reduce accessibility but also increase the time vulnerable pedestrians require to navigate intersections, thereby raising exposure risk.

Context-Sensitive Design

Finally, engineers must account for context. The appropriate design solution depends on land use, pedestrian volume, and traffic characteristics. In central business districts with heavy pedestrian flows, wide crosswalks, LPIs, and restricted turns may be appropriate. In suburban arterials, mid-block crossings with refuge islands and RRFBs may offer greater benefit. Successful intersection design balances efficiency with protection of life, ensuring that the most vulnerable users are prioritized in an environment historically designed for vehicles.

CONCLUSION

By integrating these engineering strategies, intersections can be transformed from high-risk conflict points into safer, more predictable environments for pedestrians. Achieving this requires recognition that pedestrian protection is not a secondary consideration but a central design objective.

SPEED MANAGEMENT AND TRAFFIC CALMING MEASURES

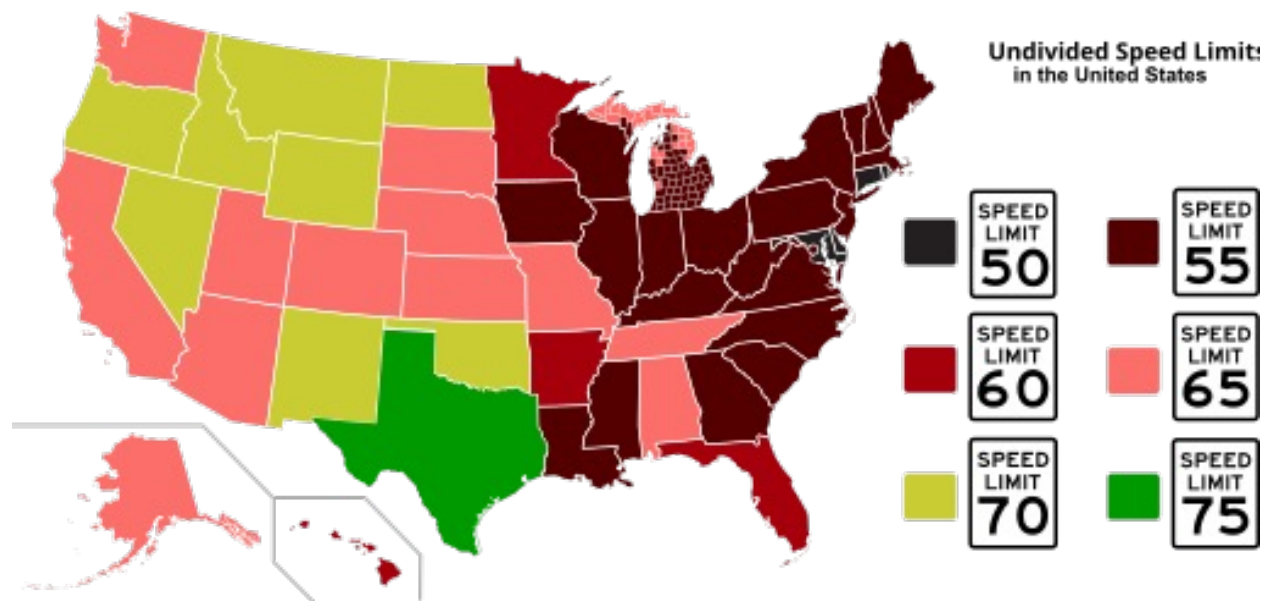


Figure 5: Maximum undivided state speed limits in the United States

Credit: Michiganguy123via Wikimedia Commons

Speed is one of the most critical factors influencing pedestrian safety. The likelihood of a pedestrian surviving a collision decreases sharply as vehicle speeds increase. At 20 miles per hour, most pedestrians survive a collision; at 40 miles per hour, the probability of death exceeds 80 percent. For this reason, managing vehicular speed through design and operational measures is an essential aspect of pedestrian safety engineering.

Traditional Speed Management Approaches

Traditional approaches to speed management have often relied on enforcement. Police patrols, radar monitoring, and automated speed cameras are tools intended to deter drivers from exceeding posted speed limits. While effective in some contexts, enforcement alone is insufficient because it requires sustained resources and cannot reshape driver behavior on a systemic level.

By contrast, engineering interventions that physically alter the roadway environment can produce more consistent results, creating conditions in which drivers naturally operate at safer speeds. Table 7 compares the typical characteristics and effectiveness of enforcement versus design-based speed management strategies.

Table 7: Comparison of Enforcement-Based vs. Engineering-Based Speed Control

Approach Type	Examples	Duration of Effectiveness	Resource Requirement	Behavior Change Mechanism
Enforcement-Based	Police patrols, radar traps, speed cameras	Short-term	High (staff, technology)	Fear of penalties
Engineering-Based	Speed humps, lane narrowing, raised intersections	Long-term	Moderate (capital investment)	Environmental cues and self-enforcement

Traffic Calming Interventions

Traffic calming is the primary engineering approach to reducing vehicle speeds in pedestrian-priority environments. Techniques such as speed humps, raised crosswalks, and speed tables create vertical deflections that force drivers to slow down. Curb extensions, chicanes, and mini-roundabouts provide horizontal deflections, narrowing sightlines and travel paths in ways that discourage high speeds. These measures, when applied strategically, transform the character of the roadway and signal to drivers that they are entering pedestrian-sensitive zones.

Lane Width and Road Diet Strategies

Narrower lane widths are another effective tool. Studies consistently demonstrate that wide lanes encourage higher speeds, while narrower lanes promote caution without significantly reducing capacity in urban environments. Road diets, which reduce the number of travel lanes and reallocate space for bike lanes, wider sidewalks, or median refuges, have been particularly effective in reducing both speeds and pedestrian collisions.

In corridors with high crash rates, converting four-lane undivided roads into three-lane cross sections with a center turn lane has proven to reduce overall crashes by up to 30 percent while improving pedestrian crossing conditions. Table 8 shows that lane reallocation strategies, often termed “road diets”, improve safety without major loss of traffic efficiency.

Table 8: Impact of Road Diet Conversions on Crash and Speed Reduction

Roadway Configuration	Average Speed Reduction (%)	Crash Reduction (%)	Pedestrian Safety Outcome
4-lane → 3-lane (with center turn lane)	10–20	25–35	Improved crossing safety
4-lane → 2-lane (with protected bike lanes)	15–25	30–40	Significant reduction in pedestrian crashes

Intersection-Level Speed Management

Speed management also intersects with intersection design. Reducing turning radii, elevating crosswalks, and implementing raised intersections all serve to lower turning speeds and enhance pedestrian safety. These measures are particularly important at locations where large vehicles, such as trucks and buses, frequently interact with pedestrians.

Visual and Environmental Cues

Lighting and visual cues can also influence perceived speed. Gateway treatments, tree canopies, and roadside landscaping narrow the driver’s field of vision, creating a sense of enclosure that encourages slower speeds. Similarly, pavement markings such as transverse bars that appear to “compress” as drivers approach intersections create a visual illusion that reinforces the need to slow down.

Technological Interventions in Speed Control

Technological interventions are increasingly being incorporated into speed management. Intelligent transportation systems can adjust signal timing to favor lower speeds, enforce speed compliance through average-speed monitoring, and communicate speed advisories directly to vehicles. Connected vehicle technologies offer the potential for speed warnings or automated interventions when approaching high-risk pedestrian areas.

The Safe System Approach

Ultimately, the goal of speed management is not to eliminate vehicle mobility but to align speeds with survivable outcomes for vulnerable users. A safe system approach accepts that human errors will occur and designs the roadway environment so that such errors do not result in fatalities. This philosophy requires shifting the emphasis from driver responsibility alone to a shared responsibility between drivers, engineers, and policymakers.

CONCLUSION

By adopting traffic calming and speed management measures, transportation engineers can create roadway environments where pedestrian survival is more likely, collisions are less frequent, and community trust in transportation systems is enhanced.

CHAPTER 7

LIGHTING, VISIBILITY, AND ROADSIDE ENVIRONMENT



Visibility is one of the most fundamental elements of pedestrian safety. A large share of pedestrian fatalities, more than two-thirds in recent years, occur during low-light conditions, either at night or in poorly illuminated environments. Even when drivers are attentive, inadequate lighting and visual obstructions can severely reduce reaction times, making it difficult to detect pedestrians in time to prevent collisions. Roadway lighting design, visibility management, and roadside environment considerations therefore form a critical component of pedestrian safety engineering.

The Science of Roadway Lighting

The science of roadway lighting is rooted in the concept of luminance and contrast. A pedestrian is more likely to be detected when they stand out against the background environment. Table 9 highlights that crosswalks and pedestrian pathways require significantly higher luminance levels than general roadway surfaces to ensure pedestrian visibility.

Table 9: Typical Luminance Levels for Roadway and Pedestrian Zones

Area Type	Recommended Average Luminance (cd/m ²)	Primary Safety Objective
Urban Arterial (vehicular lanes)	1.0–1.5	Driver visibility and contrast
Pedestrian Crosswalk	5.0–10.0	Pedestrian detection and identification
Sidewalk or Shared Path	2.0–5.0	Trip prevention and personal security
Residential Street	0.6–1.0	General safety and visibility

Insufficient or poorly placed lighting reduces this contrast, effectively concealing pedestrians until they are dangerously close to moving vehicles. This is especially true when pedestrians wear dark clothing, a common factor in nighttime fatalities. Engineers must therefore design lighting systems that maximize pedestrian visibility by illuminating not just the roadway for vehicles but also sidewalks, crosswalks, and intersection approaches.

Lighting Placement and Uniformity

Placement of lighting poles is as important as illumination intensity. Lights positioned solely for vehicular lanes often cast shadows across sidewalks or crosswalks, diminishing pedestrian visibility. Supplemental lighting targeted directly at crossings can substantially reduce nighttime collisions.

The use of overhead fixtures, bollard lighting, or mast-arm mounted luminaires at intersections provides focused illumination that enhances driver awareness of pedestrian activity. Uniformity is also critical; inconsistent lighting can create alternating bright and dark zones that hinder visual detection.

Managing Glare and Adaptive Lighting

Glare is another consideration in lighting design. Overly bright or poorly shielded fixtures can create visual discomfort or temporary blindness for drivers, counteracting the intended safety benefits. Table 10 provides practical measures to balance illumination quality with visibility and energy efficiency.

Proper shielding, appropriate mounting heights, and use of modern LED fixtures with controlled light distribution help ensure that illumination improves visibility without creating additional hazards. Advances in adaptive lighting technology now allow for dimming or brightening based on traffic volumes, time of night, or pedestrian activity, further improving safety while conserving energy.

Table 10: Common Lighting Design Issues and Engineering Solutions

Issue	Safety Impact	Engineering Solution
Excessive Glare	Driver discomfort, reduced detection	Use shielded luminaires, lower mounting height
Shadowed Crosswalks	Pedestrian concealment	Add targeted crosswalk lighting or bollards
Uneven Lighting	Delayed recognition	Increase uniformity ratio ($U_0 > 0.4$)
Energy Inefficiency	Cost, limited operation	Adaptive LED systems with dimming control

Roadside Environment and Sightline Management

The roadside environment also influences visibility. Overgrown vegetation, poorly placed signage, or parked vehicles near intersections can obstruct sightlines between drivers and pedestrians. Clear zones must be maintained so that drivers have unobstructed views of crossing areas.

Roadway design standards often prescribe minimum sight distances, but these requirements must be adapted to real-world conditions where pedestrians may be present. Regular maintenance, including vegetation trimming and enforcement of parking restrictions near crosswalks, is essential for sustaining safe sightlines.

High-Speed Corridors and Visibility Challenges

High-speed corridors pose particular challenges because even modest reductions in driver detection distance can render evasive maneuvers impossible. In these environments, lighting and visibility must be coupled with pedestrian refuge islands, mid-block crossings, or signalized control to create safe opportunities to cross. Without such interventions, pedestrians face unacceptable risks when attempting to navigate wide and poorly lit arterials.

Emerging Technologies in Pedestrian Visibility

Emerging technologies provide new opportunities for improving visibility. Infrared detection systems, illuminated in-roadway warning lights, and smart crosswalks that activate lighting when pedestrians are present are all examples of innovations that extend beyond traditional fixed lighting. These solutions can adapt dynamically to pedestrian activity, offering enhanced visibility in locations where pedestrian volumes are irregular or unpredictable.

CONCLUSION

Ultimately, visibility is not a secondary concern but a core safety requirement. The combination of appropriate lighting design, roadside environment management, and innovative technology can significantly reduce nighttime fatalities. For transportation engineers, the challenge lies not only in designing effective systems but also in ensuring they are properly maintained and adapted to the evolving needs of the communities they serve.

THE IMPACT OF DRIVER BEHAVIOR AND DISTRACTION



While roadway and vehicle design strongly influence pedestrian safety, human behavior remains a decisive factor in collision outcomes. Even in well-designed environments, driver inattention, impairment, and unsafe decision-making can undermine safety systems and expose pedestrians to fatal risks. The modern era has introduced new behavioral challenges, particularly through the rise of mobile device use, which has transformed distraction into one of the most pressing issues in traffic safety.

Distracted Driving

Distracted driving encompasses a wide range of activities that divert attention from the task of driving. These include visual distractions, such as looking away from the road; manual distractions, such as manipulating a phone or infotainment system; and cognitive distractions, such as engaging in conversations or mentally focusing on tasks unrelated to driving. Pedestrians are especially vulnerable to these lapses because they are smaller, less predictable, and less conspicuous than other vehicles.

Table 11 shows how different forms of distraction reduce situational awareness and increase pedestrian exposure to danger. A driver who looks down at a phone for even a few seconds can travel the length of a football field at highway speeds, providing ample opportunity for a collision with a pedestrian to occur.

Table 11: Categories of Driver Distraction and Associated Risks

Type of Distraction	Example Behavior	Primary Effect	Pedestrian Risk Implication
Visual	Looking at phone, GPS, or billboard	Eyes off road	Delayed detection of pedestrians
Manual	Adjusting controls or texting	Hands off wheel	Slower reaction, lane drift
Cognitive	Talking, daydreaming, multitasking	Mind off driving	Failure to recognize hazards

Mobile Devices and In-Vehicle Technology

Mobile phone use is the most widely discussed form of distraction, but in-vehicle technologies also play a role. Modern vehicles incorporate increasingly complex infotainment systems, touch screens, and driver assistance features that demand attention. While many of these technologies are intended to improve safety, they can create new forms of cognitive overload that impair situational awareness. The result is that drivers may fail to detect pedestrians even in environments where visibility and roadway design are adequate.

Impaired Driving and Its Effects

Impaired driving continues to be a persistent factor in pedestrian fatalities. Alcohol, drugs, and fatigue each reduce reaction time, impair judgment, and increase the likelihood of risk-taking behavior. Table 12 illustrates that all major forms of impairment substantially increase crash risk, particularly during nighttime pedestrian activity.

Pedestrian deaths associated with alcohol impairment remain disproportionately high, both on the part of drivers and pedestrians. While enforcement campaigns and cultural shifts have reduced drunk driving incidents over past decades, impairment still accounts for a significant percentage of nighttime pedestrian fatalities.

Table 12: Effects of Common Impairment Factors on Driving Performance

Impairment Type	Primary Effect on Driver	Relative Risk of Crash (vs. sober)	Typical Pedestrian Collision Context
Alcohol	Reduced coordination and reaction time	5–7× higher	Nighttime urban crossings
Drugs (e.g., cannabis, opioids)	Impaired judgment, slower processing	2–5× higher	Mixed lighting environments
Fatigue	Microsleeps, delayed decision-making	3–6× higher	Early morning / late night

Speeding as a Behavioral Issue

Speeding, though often considered a roadway design issue, is also strongly tied to behavior. Drivers may ignore posted limits, accelerate aggressively, or misjudge their speed in environments where pedestrians are present. The behavioral tendency to prioritize convenience or efficiency over safety underscores the importance of engineering systems that mitigate the consequences of these choices. The Safe System approach recognizes that human beings are prone to error, and that infrastructure must be designed to absorb those errors without producing fatal outcomes.

Pedestrian Behavior and Shared Responsibility

Pedestrian behavior also contributes to collision risk, though engineers must be careful not to place undue blame on vulnerable users. Jaywalking, crossing outside designated areas, or entering roadways at night without reflective clothing can increase exposure. However, such behaviors are often a product of inadequate infrastructure, where pedestrians lack safe and convenient crossing opportunities. For engineers, the emphasis should be on designing systems that anticipate predictable human behaviors and accommodate them safely, rather than assuming ideal compliance.

Education, Enforcement, and Technology Countermeasures

Education and enforcement remain essential complements to engineering measures. Public campaigns aimed at reducing distracted and impaired driving can influence cultural norms, while automated enforcement tools such as red-light cameras and speed cameras reduce reliance on constant human enforcement. Advanced driver assistance systems, including pedestrian detection and collision warnings, provide a technological safeguard that can counteract some forms of inattention, though they cannot fully replace responsible human behavior.

CONCLUSION

In the end, the relationship between driver behavior and pedestrian safety reinforces the need for redundancy in transportation systems. Roads, vehicles, and human actions must work together to minimize the chances that an error leads to tragedy. Recognizing the limitations of human performance and designing systems accordingly is at the heart of modern traffic safety engineering.

URBAN SPRAWL AND LAND USE PLANNING FACTORS

The configuration of the built environment has a profound effect on pedestrian safety. Beyond the immediate design of roadways and intersections, the larger patterns of urban development and land use play a decisive role in shaping how and where people walk. The phenomenon of urban sprawl, a development model characterized by low-density residential areas, segregated land uses, and heavy reliance on automobiles, has been a major contributor to pedestrian fatalities in the United States. This chapter examines how land use patterns influence pedestrian safety and explores planning and engineering strategies to mitigate the risks.

Characteristics of Urban Sprawl

Urban sprawl is associated with wide arterial roads, expansive parking lots, and large distances between origins and destinations. Such conditions discourage walking for many daily activities, but they do not eliminate the need for pedestrian travel. People still walk to bus stops, schools, shops, and workplaces, often in environments that were never designed with their safety in mind. The result is a mismatch between pedestrian demand and roadway design, exposing individuals to high-speed traffic without the protection of adequate sidewalks, crossings, or traffic controls.

Separation of Land Uses and Hazardous Walking Environments

One of the defining features of sprawling development is the separation of land uses. Residential neighborhoods are often located far from commercial and employment centers, requiring long travel distances. For those without access to a vehicle, this creates hazardous walking environments along arterial corridors, where pedestrians must navigate multiple lanes of fast-moving traffic. The lack of connected street grids also reduces alternative routes, forcing pedestrians onto high-risk roads. In many cases, bus stops are located on opposite sides of arterials, leading to dangerous mid-block crossings because signalized intersections may be half a mile or more apart.

Driver Expectation and Pedestrian Exposure

Urban design also influences the frequency of pedestrian exposure. In compact, mixed-use neighborhoods, pedestrians are common and expected, leading drivers to anticipate their presence and adjust behavior accordingly. In sprawling environments, pedestrians are relatively rare, making drivers less vigilant. This lack of expectation exacerbates collision risk, as motorists are less prepared to yield or slow down when encountering a pedestrian.

Equity and Accessibility Considerations

Land use planning decisions also affect the distribution of pedestrian risk across different socioeconomic groups. Lower-income populations are more likely to live in areas with limited pedestrian infrastructure and greater reliance on walking or public transit. These communities often face disproportionate exposure to unsafe roadway environments, contributing to inequities in fatality rates. For engineers and planners, addressing pedestrian safety therefore involves not only technical solutions but also questions of equity and access.

Integrated Solutions: Engineering and Land Use Reform

Mitigating the effects of sprawl requires an integrated approach that combines engineering interventions with land use reforms. Complete Streets policies, which require roadway designs to accommodate all users, represent one step in this direction. By ensuring that sidewalks, bike lanes, and safe crossings are included in roadway projects, engineers can retrofit sprawling environments to provide safer options for pedestrians.

Transit-oriented development, which clusters housing and businesses near public transit hubs, reduces the need for dangerous long-distance pedestrian travel. Mixed-use zoning policies, when combined with supportive infrastructure, shorten trip lengths and encourage walking in safer contexts.

In addition, roadway retrofits can address immediate risks in sprawling areas. Mid-block crossings with pedestrian refuge islands, improved bus stop design, and traffic calming on arterials can reduce fatalities even in environments dominated by automobiles. Long-term, however, reducing pedestrian deaths will require a shift in development models toward more compact, connected, and mixed-use urban forms. Engineers, working alongside planners and policymakers, play a vital role in shaping this transition.

Table 13 demonstrates that focused engineering retrofits can improve pedestrian safety even within automobile-oriented settings.

Table 13: Engineering Interventions for Retrofitting Sprawling Corridors

Intervention Type	Example Application	Expected Safety Outcome
Mid-block crossings	Refuge islands, RRFBs	Safer pedestrian access to transit
Bus stop improvements	Shelters, setback designs	Reduced roadside waiting exposure
Arterial traffic calming	Road diets, raised medians	Lower operating speeds
Enhanced lighting	Focused crosswalk illumination	Better nighttime visibility

CONCLUSION

Urban sprawl illustrates the limits of purely engineering-based interventions. Roadway design cannot be separated from the broader patterns of development that dictate how people move through space. By understanding the interplay between land use and pedestrian safety, transportation engineers can advocate for and implement solutions that not only reduce fatalities but also create healthier, more walkable communities.

SOCIOECONOMIC AND DEMOGRAPHIC INFLUENCES

Pedestrian fatalities in the United States are not distributed evenly across the population. Certain demographic and socioeconomic groups face a much higher risk of being struck and killed than others. Understanding these disparities is critical for transportation engineers, as it provides insight into the communities most affected by unsafe roadway environments and highlights the ethical responsibility to ensure equitable protection for all users.

The Role of Income and Infrastructure Deficiency

One of the most consistent findings in pedestrian safety research is that lower-income communities experience disproportionately high fatality rates. Several factors contribute to this outcome. Residents of these neighborhoods are more likely to rely on walking or public transportation as their primary modes of travel.

Because many low-income communities lack sufficient pedestrian infrastructure, such as sidewalks, safe crossings, or adequate lighting, pedestrians are forced into hazardous environments. Furthermore, transit stops are often located along wide arterial roads, requiring dangerous crossings with long exposure times. The interaction of necessity and inadequate design creates an elevated risk profile that persists across much of the country.

Age-Related Vulnerabilities

Demographic patterns also reveal disparities in pedestrian fatalities. Older adults face higher risks due to slower walking speeds, reduced mobility, and decreased ability to react quickly in emergencies. Even modest crossing distances can become unsafe for older pedestrians when signal cycles are too short.

Children are vulnerable as well, particularly in areas near schools, playgrounds, and residential neighborhoods with poor traffic calming. Their smaller size makes them less visible to drivers, and their unpredictable movements increase the likelihood of conflicts.

Racial and Ethnic Disparities

Racial and ethnic disparities are evident in national data as well. Research indicates that Black, Hispanic, and Native American populations suffer higher pedestrian fatality rates compared to White populations. While multiple factors are at play, many of these disparities stem from environmental inequities.

Communities of color are more likely to be situated in areas with high-speed arterials, fewer pedestrian protections, and lower levels of infrastructure investment. These inequities are compounded by socioeconomic challenges that increase reliance on walking as a primary means of travel.

Geographic and Environmental Variation

Geographic variation adds another layer of complexity. Pedestrian deaths are more common in the southern United States, where sprawling development patterns, warmer climates, and higher vehicle speeds converge to increase risk. Rural areas also present elevated risks due to the lack of sidewalks, poor lighting, and longer distances to medical care after collisions.

By contrast, dense urban areas with comprehensive transit networks and lower vehicle speeds, while not free of risk, often provide safer walking environments when appropriate infrastructure is in place.

Alcohol, Impairment, and Public Health Links

The role of alcohol and impairment is also closely tied to socioeconomic conditions. Both drivers and pedestrians may be impaired in high-fatality events, and rates of impairment-related pedestrian deaths remain disproportionately high among certain populations. These patterns underscore the need for holistic solutions that address not only roadway engineering but also public health, education, and community planning.

Equity and Professional Responsibility

For transportation engineers, recognizing these disparities is more than an analytical exercise; it is an essential part of professional responsibility. Equity-based safety planning requires that engineers allocate resources where the risks are greatest and design interventions that account for vulnerable populations. For example, in low-income neighborhoods, mid-block crossings, extended signal times, and improved lighting can directly address conditions that lead to fatalities. In areas with older populations, refuge islands and reduced crossing distances may be prioritized.

The Safe System Approach and Equity Integration

The Safe System approach emphasizes that no single death is acceptable and that all roadway users should be protected regardless of socioeconomic or demographic status. For engineers, this means adopting a mindset that prioritizes equity as a guiding principle in design and implementation. By doing so, transportation professionals not only reduce fatalities but also contribute to more just and resilient communities.

CONCLUSION

Socioeconomic and demographic factors profoundly shape pedestrian safety outcomes. Lower-income, minority, elderly, and rural populations face disproportionate risks due to inadequate infrastructure and systemic inequities. Addressing these disparities requires transportation engineers to embed equity within the Safe System framework, ensuring that every community benefits equally from safer roads, better design, and responsible policy.

ENGINEERING COUNTERMEASURES FOR HIGH-RISK CORRIDORS



Figure 6: Wide pedestrian refuge island

While pedestrian safety is a broad concern across all roadway environments, certain corridors consistently emerge as high-risk locations. These are typically arterial roads characterized by multiple travel lanes, high operating speeds, limited pedestrian crossings, and adjacent land uses that generate foot traffic. In many U.S. cities, a relatively small percentage of roadways accounts for a disproportionately large share of pedestrian deaths. Engineering countermeasures targeted to these corridors can therefore have an outsized impact on reducing fatalities.

Pedestrian Refuge Islands

One of the most effective approaches is the installation of pedestrian refuge islands (Figure 6). These raised median areas provide pedestrians a safe space to pause while crossing wide, multi-

lane roads. By breaking the crossing into two stages, refuge islands reduce exposure time and allow pedestrians to focus on traffic from one direction at a time. They are especially beneficial in corridors where traffic signals are widely spaced and mid-block crossings are necessary.

High-Visibility Crosswalks and Flashing Beacons

High-visibility crosswalks are another key countermeasure. Ladder-style markings or continental striping patterns increase driver awareness of crossings, especially when combined with advanced stop bars that require vehicles to stop farther back from the crosswalk. Where volumes justify it, signalized pedestrian crossings with Rectangular Rapid Flashing Beacons (RRFBs) can dramatically improve driver yielding behavior at unsignalized locations.

Table 14 shows that RRFBs and high-visibility markings significantly improve driver compliance compared to standard crosswalks. RRFBs have been shown to increase compliance rates to over 80 percent in many settings, making them a cost-effective safety improvement.

Table 14: Comparison of Common Crosswalk Enhancements

Treatment Type	Key Feature	Typical Yielding Rate	Installation Context
Standard crosswalk	Two parallel lines	20–30%	Basic intersections
Ladder-style marking	High-contrast striping	40–60%	Urban arterials
RRFB	Flashing LED lights	70–90%	Unsignalized mid-block crossings
Signalized crossing	Full red phase control	90%+	High-volume corridors

Road Diets and Corridor Reconfiguration

Road diets, which reconfigure four-lane undivided roads into three-lane cross sections with a center turn lane, are among the most impactful corridor-wide treatments. This change not only reduces vehicle speeds but also shortens pedestrian crossing distances and improves sightlines between pedestrians and drivers. Road diets can also free up roadway space for bike lanes or wider sidewalks, supporting multimodal travel. Empirical studies demonstrate that road diets reduce total crashes by as much as one-third, with clear safety benefits for pedestrians.

Traffic Signal Modifications

Traffic signal modifications offer additional countermeasures. The introduction of Leading Pedestrian Intervals (LPIs) provides pedestrians with a head start before vehicles are released, reducing conflicts at intersections within high-risk corridors. Longer pedestrian clearance intervals and the addition of exclusive pedestrian phases can also address timing deficiencies that put pedestrians in conflict with vehicles.

In some locations, pedestrian hybrid beacons, also known as HAWK signals, provide mid-block control that balances pedestrian needs with vehicle efficiency, particularly on wide arterial roads. Table 15 summarizes signal modifications that enhance pedestrian visibility and crossing safety in high-risk corridors.

Table 15: Signal-Based Countermeasures for Pedestrian Corridors

Measure	Function	Key Benefit	Ideal Application
Leading Pedestrian Interval (LPI)	Gives pedestrians 3–7 second head start	Reduces turning conflicts	Signalized intersections
Exclusive pedestrian phase	All-vehicle stop	Eliminates conflicts entirely	High-pedestrian zones
Pedestrian hybrid beacon (HAWK)	Activates mid-block red phase	Safe mid-block crossing	Arterials with bus stops
Extended clearance interval	Increases walking time	Supports slower users	Aging populations

Lighting and Sightline Improvements

Lighting enhancements are critical along high-risk corridors, especially since many pedestrian fatalities occur in dark conditions. Adding overhead illumination focused on crosswalks, transit stops, and mid-block crossings significantly improves visibility. Complementary roadside treatments, such as clearing vegetation, restricting on-street parking near crossings, and repositioning bus stops, also improve sightlines and reduce conflict points.

Curb Extensions and Traffic Calming

Curb extensions, also called bulb-outs, are an effective way to shorten crossing distances while enhancing pedestrian visibility. By extending the sidewalk into the parking lane, these treatments reduce the time pedestrians spend in the roadway and increase the likelihood that drivers will see them before entering the intersection. Coupled with narrower lane widths, curb extensions contribute to overall corridor speed reduction.

Grade Separation for High-Demand Corridors

For corridors with very high pedestrian demand, grade separation may be considered. Overpasses and underpasses eliminate conflicts altogether, though they must be designed with accessibility and convenience in mind to ensure that pedestrians actually use them. Poorly designed grade separations can lead to avoidance, leaving pedestrians exposed to risk on the surface level. Table 16 shows that while grade separation removes conflicts entirely, success depends on accessibility and user acceptance.

Table 16: Comparison of At-Grade and Grade-Separated Crossing Treatments

Crossing Type	Pedestrian Exposure	Cost Level	Accessibility	User Compliance
Standard at-grade crosswalk	High	Low	High	High
Refuge island	Medium	Moderate	High	High
Grade-separated overpass	None	High	Moderate (depends on design)	Variable
Grade-separated underpass	None	High	Moderate	Variable

Context-Sensitive Application of Countermeasures

Ultimately, engineering countermeasures must be selected based on context. A rural highway near a transit stop may benefit most from an RRFB and refuge island, while an urban arterial in a commercial district may require a road diet, LPIs, and upgraded lighting. The key principle is to treat high-risk corridors systematically, addressing speed, crossing opportunities, visibility, and

traffic behavior in a coordinated manner. By doing so, engineers can significantly reduce fatalities in the locations where they are most concentrated.

CONCLUSION

High-risk corridors represent concentrated opportunities for life-saving interventions. Through targeted countermeasures, ranging from refuge islands and RRFBs to lighting upgrades and road diets, engineers can substantially reduce pedestrian fatalities. The most effective solutions are context-sensitive, data-driven, and integrated, ensuring that design responds directly to the risks pedestrians face along the most dangerous roadways.

CASE STUDIES IN SAFE SYSTEM DESIGN



Figure 7: Safe System Approach as the guiding paradigm to address roadway safety (U.S. DOT)

The Safe System approach has become an increasingly influential framework for addressing roadway fatalities, including those involving pedestrians (Figure 7). Unlike traditional strategies that focus primarily on preventing crashes, the Safe System philosophy assumes that human error is inevitable and designs transportation networks to minimize the likelihood that those errors result in death or serious injury. This chapter examines several case studies that illustrate how Safe System principles have been applied in practice to reduce pedestrian fatalities.

Sweden's Vision Zero Initiative

One of the most notable examples comes from Sweden, where the Vision Zero initiative was introduced in the late 1990s. Vision Zero is built on the Safe System concept, emphasizing that no loss of life is acceptable and that the transportation system must be designed accordingly. Swedish engineers implemented extensive traffic calming in urban areas, constructed pedestrian overpasses in high-volume corridors, and introduced median barriers on rural highways. These measures, coupled with strict enforcement of speed limits, reduced pedestrian deaths significantly and made Sweden one of the global leaders in roadway safety.

The Netherlands and "Sustainable Safety"

In the Netherlands, the concept of "Sustainable Safety" has guided roadway design for decades. This approach focuses on aligning road function with design speed, separating modes of travel wherever possible, and creating environments that are forgiving of human mistakes. Dutch cities have pioneered pedestrian-priority zones, woonerfs (shared streets with very low vehicle speeds), and protected intersections that physically separate pedestrian and cyclist movements from vehicles.

These treatments reflect a systemic view of safety rather than isolated countermeasures, and they have produced consistently low pedestrian fatality rates compared to countries with similar levels of motorization.

New York City's Vision Zero Implementation

Closer to the United States, New York City provides a useful case study in adapting Safe System principles to a dense urban environment. Beginning in 2014, the city adopted its own Vision Zero program, which included reducing citywide speed limits, redesigning dangerous intersections, and installing Leading Pedestrian Intervals (LPIs) at hundreds of crossings.

Data from the first five years of the program showed significant reductions in pedestrian fatalities, demonstrating that even in a highly complex urban network, engineering interventions based on Safe System principles can yield measurable results.

Safe System Applications in Suburban Contexts

In suburban contexts, smaller municipalities have also successfully applied Safe System strategies. For example, the city of Bellevue, Washington, implemented a comprehensive data-driven approach to identify high-risk corridors and deployed treatments such as pedestrian hybrid beacons, RRFBs, and targeted traffic calming. By combining predictive analytics with infrastructure improvements, Bellevue achieved reductions in pedestrian crashes despite rapid population growth and increased vehicle volumes.

Implementation Challenges in the United States

International and domestic case studies also reveal challenges in implementation. In the United States, where roadway networks are heavily influenced by sprawl, large-scale redesigns often encounter funding constraints, political opposition, or resistance from motorists. Nonetheless, projects that apply Safe System principles, even incrementally, have demonstrated clear safety benefits. Road diets, mid-block crossings, and corridor-wide lighting upgrades have consistently reduced pedestrian risk where deployed.

Lessons and Key Takeaways

The key lesson from these case studies is that Safe System design requires a paradigm shift. Instead of focusing narrowly on compliance with traffic laws or isolated safety features, engineers must think holistically about how roadway environments, vehicle technologies, and human behaviors interact. A Safe System acknowledges that mistakes will occur but ensures that they are not fatal. This systemic perspective aligns closely with the ethical responsibility of engineers to safeguard public welfare.

CONCLUSION

By studying global and domestic examples of Safe System applications, transportation engineers can draw practical lessons for their own communities. The evidence shows that when principles of speed management, separation, redundancy, and predictability are applied consistently, pedestrian fatalities can be significantly reduced. These case studies provide both inspiration and practical guidance for engineers committed to reversing the rising tide of pedestrian deaths in the United States.

TECHNOLOGY INTEGRATION: SENSORS, AI, AND SMART SIGNALS

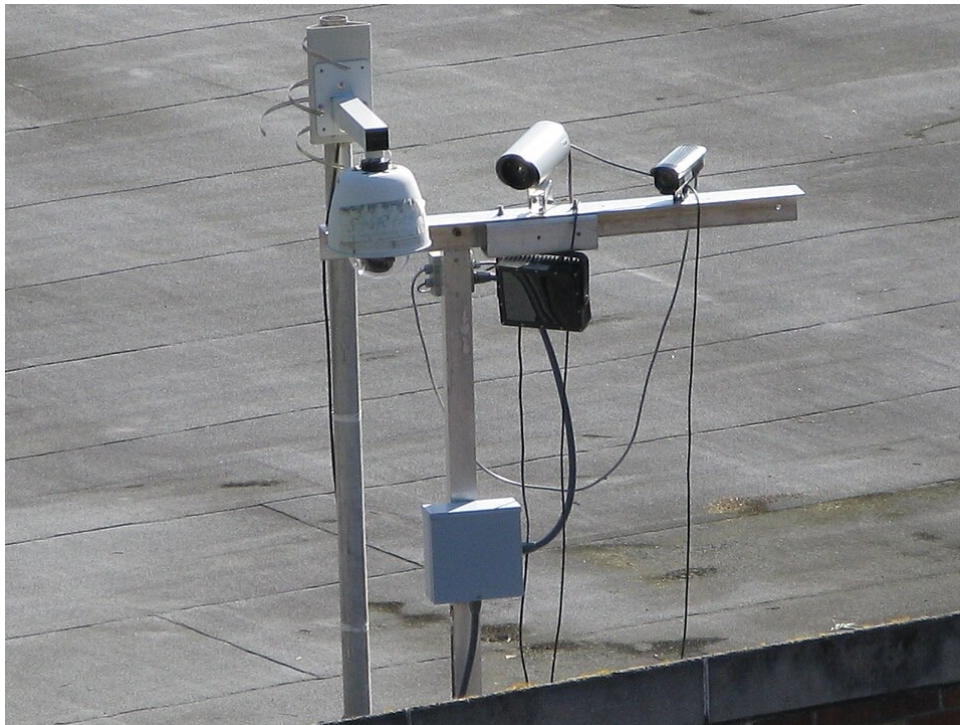


Figure 8: Visual and infrared cameras used in intelligent transportation systems like vehicle/ pedestrian detection

Credit: Oran Viriyincy from Bothell, WA, United States, via Wikimedia Commons

Advances in technology are reshaping the ways transportation engineers can address pedestrian safety. While traditional design improvements such as crosswalks, refuge islands, and traffic calming remain essential, emerging tools in sensors, artificial intelligence (AI), and smart traffic control systems are providing new opportunities to detect risks, predict behaviors, and intervene before collisions occur (Figure 8). This chapter explores how these innovations are being applied to mitigate the rise in pedestrian fatalities.

Sensor Technologies in Pedestrian Detection

Sensor technologies are at the forefront of modern pedestrian safety systems. Table 17 compares sensor modalities and their trade-offs in accuracy, cost, and performance under different conditions.

Table 17: Comparison of Pedestrian Detection Sensor Types

Sensor Type	Detection Principle	Key Advantages	Common Limitations
Camera (optical)	Visual image recognition	Low cost, simple installation	Poor low-light performance
Radar	Radio wave reflection	Works in rain and fog	Limited precision for small objects
Lidar	Laser-based distance mapping	High spatial accuracy	Expensive and weather-sensitive
Infrared	Heat detection	Strong night-time performance	Can be affected by sunlight and ambient heat

Cameras, radar, lidar, and infrared devices are increasingly deployed to monitor intersections and crossings. These systems can detect pedestrians waiting at curbs, entering crosswalks, or moving through areas of limited visibility. When integrated with traffic signals, sensors can extend pedestrian phases, activate flashing beacons, or trigger adaptive lighting to improve visibility. Infrared sensors are especially valuable at night, when traditional cameras are less effective, and they have been deployed in several U.S. cities to enhance detection accuracy during low-light conditions.

Artificial Intelligence and Predictive Analytics

Artificial intelligence (AI) expands the utility of sensor data by enabling predictive analytics. AI algorithms can analyze traffic flows, identify near-miss events, and anticipate high-risk interactions between vehicles and pedestrians. This predictive capacity allows agencies to proactively target interventions before fatal collisions occur. For instance, AI-based systems can adjust traffic signal timing dynamically in response to detected pedestrian volumes, ensuring that crossings are protected during periods of high demand. In addition, machine learning

models can identify patterns across vast datasets, helping engineers prioritize corridors and intersections for safety improvements.

Smart Traffic Signals and Adaptive Control

Smart traffic signals represent another powerful tool. Traditional fixed-time signals are limited in their ability to respond to real-world conditions, but modern adaptive signals can adjust phases in real time.

Leading Pedestrian Intervals (LPIs) can be automatically applied when pedestrian demand is detected, and clearance intervals can be lengthened if sensors indicate a slower-moving individual is still within the crosswalk. Some systems integrate with mobile applications, allowing pedestrians with disabilities to request longer crossing times or trigger auditory signals for improved accessibility. Table 18 summarizes adaptive control strategies that enhance safety through real-time responsiveness and user inclusion.

Table 18: Smart Signal Functions for Pedestrian Protection

Function	Description	Safety Benefit	Example Application
Adaptive LPIs	Extends pedestrian head start when presence detected	Reduces turning conflicts	Busy urban intersections
Dynamic clearance timing	Lengthens “walk” time for slow-moving pedestrians	Improves accessibility	School zones, senior areas
App-based signal requests	Mobile device triggers crossing or audio cue	Inclusive for visually impaired	Downtown and transit hubs
Nighttime activation	Signal cycles only when pedestrians are present	Energy efficiency and reduced delay	Low-volume crossings

Connected Vehicle Technology and V2I Communication

Connected vehicle technology further enhances the integration of roadway and vehicle systems. Vehicles equipped with pedestrian detection systems can communicate with roadside units to receive alerts about nearby pedestrian activity. In time, this vehicle-to-infrastructure (V2I) communication could enable vehicles to automatically adjust speed or braking in response to pedestrian presence, reducing reliance on driver attentiveness alone. Although widespread deployment remains in development, pilot projects have shown promising results in reducing pedestrian conflicts.

Corridor-Level Technology Integration

Beyond intersections, technology integration extends to corridor management. Intelligent lighting systems can adjust brightness based on pedestrian activity, conserving energy while improving safety when needed. Data collected from mobile phones and wearable devices can supplement traffic counts, providing engineers with more precise information about pedestrian movement patterns. These datasets, when analyzed with AI tools, allow for more accurate forecasting of pedestrian exposure and risk. Table 19 highlights how corridor-level integration improves pedestrian safety while supporting sustainability goals.

Table 19: Smart Corridor Technologies and Applications

Technology	Primary Function	Implementation Example	Benefit
Adaptive lighting	Adjusts illumination based on activity	London and Los Angeles pilots	Reduced energy use, improved visibility
Pedestrian flow sensors	Detects movement patterns	Smart corridor deployments	Informs timing and infrastructure design
Mobile data integration	Uses anonymized phone data	Citywide analytics platforms	Improves risk prediction accuracy

Implementation Challenges and Ethical Considerations

However, challenges remain in deploying these technologies equitably and effectively. Cost is a major barrier, particularly for smaller municipalities. Privacy concerns also arise when using cameras and mobile data for pedestrian monitoring. Additionally, the reliability of sensor

systems can be compromised by weather, maintenance lapses, or technical malfunctions. Engineers must therefore treat technology as a complement to, not a substitute for, sound roadway design and fundamental safety measures.

CONCLUSION

The integration of sensors, AI, and smart signals represents an evolution in the engineering approach to pedestrian safety. Rather than relying solely on static design, transportation systems can now adapt dynamically to human behavior and environmental conditions. When combined with proven engineering countermeasures, these technologies offer a path toward achieving significant reductions in pedestrian fatalities. They embody the Safe System principle of building redundancy into transportation networks, ensuring that even when human error occurs, technology can intervene to prevent loss of life.

VEHICLE-BASED SAFETY FEATURES FOR PEDESTRIAN PROTECTION

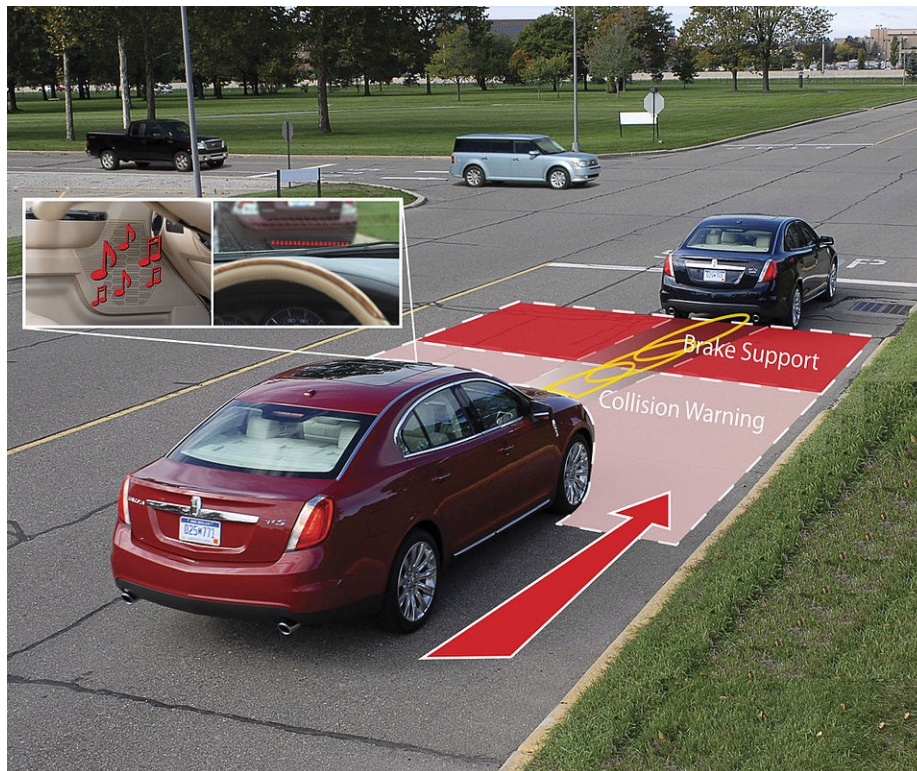


Figure 9: Collision Warning with Brake Support

Credit: Ford Motor Company from USA, via Wikimedia Commons

While roadway and infrastructure improvements remain central to pedestrian safety, modern vehicle technologies play an increasingly important role in reducing the likelihood and severity of collisions. Advances in engineering have enabled the integration of safety systems designed specifically to detect and protect pedestrians, representing a critical complement to roadway-

based countermeasures. This chapter explores the evolution and current state of vehicle-based pedestrian safety features, their effectiveness, and their limitations.

Automatic Emergency Braking (AEB) with Pedestrian Detection

One of the most significant developments is Automatic Emergency Braking (AEB) with pedestrian detection. These systems use forward-facing cameras, radar, or lidar to identify pedestrians in the vehicle’s path. If the driver does not react in time, the system automatically applies the brakes to avoid or reduce the severity of a collision.

Studies from the Insurance Institute for Highway Safety (IIHS) indicate that pedestrian-detection AEB systems can reduce pedestrian crashes by significant margins, particularly in daylight and low-speed conditions. However, effectiveness decreases in nighttime or poor weather conditions, where detection is more challenging. Table 20 summarizes AEB performance variations, highlighting the need for robust sensor calibration and multimodal detection.

Table 20: AEB System Effectiveness Under Different Conditions

Driving Condition	Average Crash Reduction	Key Limitation
Daylight, dry road	40–50%	Excellent visibility
Nighttime, poor lighting	10–20%	Sensor accuracy decreases
Rain or fog	15–25%	Radar less effective in dense precipitation
Urban congestion	30–40%	Multiple objects may confuse detection

Forward Collision Warning (FCW) Systems

Forward Collision Warning (FCW) systems also enhance pedestrian safety. These systems issue visual or audible alerts when a collision is imminent, giving the driver additional time to react. While they rely on driver response rather than automatic intervention, FCWs have been shown to reduce crashes in which drivers had limited time to recognize a hazard. Some vehicles combine FCW and AEB for a layered defense.

Vehicle Design and Crashworthiness Innovations

Beyond collision-avoidance technologies, vehicle design modifications have also been employed to mitigate injury severity when impacts occur. In Europe, vehicle crashworthiness standards include pedestrian protection requirements, encouraging manufacturers to design hoods, bumpers, and windshields that absorb impact energy more effectively.

Features such as deformable bumpers, energy-absorbing hood structures, and deployable “pop-up” hoods that create a cushioning effect between the hood and engine components have been adopted in some markets. These innovations reduce the risk of catastrophic head or torso injuries, which are common when pedestrians are struck by the higher front ends of modern SUVs and pickups. Table 21 shows how passive vehicle design can substantially mitigate pedestrian injury severity.

Table 21: Pedestrian-Friendly Vehicle Design Features

Feature	Function	Example Market	Effect on Injury Severity
Deformable bumper	Absorbs impact energy	EU, Japan	Reduces leg trauma
Energy-absorbing hood	Distributes impact force	EU	Reduces head injuries
Pop-up hood	Raises hood during impact	Premium vehicles	Minimizes skull fractures
Soft windshield zone	Flexes on contact	Select models	Reduces facial trauma

Adaptive Headlights and Visibility Enhancements

Adaptive Headlights represent another important feature. These systems pivot or adjust the beam of the headlights based on steering input, improving visibility of pedestrians at curves and intersections during nighttime driving. By extending the driver’s field of vision, adaptive headlights reduce the chance that pedestrians remain undetected until it is too late to react.

Driver Monitoring Systems (DMS)

In addition, Driver Monitoring Systems (DMS), which use cameras or sensors to track driver attentiveness, are being developed to address distraction and fatigue. Table 22 highlights how DMS supports proactive intervention by identifying inattentive driving behaviors.

By alerting drivers who look away from the road or show signs of drowsiness, these systems indirectly enhance pedestrian safety. Future iterations may integrate with pedestrian detection systems, providing an added safeguard when the driver's attention falters.

Table 22: Driver Monitoring Features and Functions

Detection Type	Monitoring Method	Intervention	Impact on Safety
Eye tracking	Infrared camera	Audio/ visual alert	Prevents distraction-related misses
Head position	Motion sensors	Steering wheel vibration	Reduces fatigue-related drift
Physiological signals	Heart rate monitoring	Adaptive cruise slowdown	Early warning of drowsiness

Vehicle-to-Pedestrian (V2P) Communication

Connected vehicle technologies also hold promise. Vehicle-to-Pedestrian (V2P) communication, still in early development, could allow vehicles to detect signals from smartphones or wearable devices carried by pedestrians. In theory, vehicles could receive alerts about pedestrians approaching crosswalks, even if they are obscured by parked cars or other obstructions.

While widespread adoption faces challenges related to privacy, standardization, and infrastructure, V2P represents a potential breakthrough in extending safety measures beyond the limits of line-of-sight detection.

Limitations and Systemic Considerations

Despite these advances, limitations remain. Many safety features are currently limited to newer or higher-end vehicles, leaving older fleet vehicles without such protections. Moreover, while technology can reduce crash likelihood, it cannot eliminate risks posed by excessive speed,

impaired driving, or fundamentally unsafe roadway design. Engineers must therefore view vehicle-based safety features as part of a broader system of protections, not a standalone solution.

Integration and Future Directions

The increasing integration of pedestrian-focused vehicle technologies reflects a recognition that pedestrian safety requires interventions on multiple fronts. By combining advances in vehicle engineering with roadway redesign and traffic management strategies, transportation professionals can create overlapping layers of protection that significantly reduce the probability of fatal outcomes.

CONCLUSION

Vehicle-based safety systems are redefining how pedestrian protection is achieved. From AEB and adaptive lighting to V2P communication and driver monitoring, these technologies form essential layers in a Safe System framework. However, equitable access, affordability, and integration with infrastructure remain key challenges. Engineers must ensure that these innovations are implemented as part of a holistic safety strategy that safeguards all road users, not just those in modern vehicles.

DESIGNING FOR MULTIMODAL NETWORKS AND COMPLETE STREETS

Traditional roadway design in the United States has historically prioritized automobile traffic, often relegating pedestrians, cyclists, and transit users to secondary consideration. This vehicle-centric approach has contributed to environments where pedestrians face significant safety risks. In recent years, however, the concept of Complete Streets and the development of multimodal transportation networks have emerged as guiding frameworks for creating safer, more inclusive, and more efficient roadway systems. This chapter explores the principles of multimodal design and how they can be applied to reduce pedestrian fatalities.

Principles of Complete Streets

The Complete Streets philosophy is rooted in the idea that roadways should be designed to safely accommodate all users, regardless of age, ability, or mode of travel. Table 23 highlights how a Complete Street integrates physical and operational elements to create a balanced and inclusive roadway system.

Rather than focusing narrowly on maximizing vehicular flow, Complete Streets integrate sidewalks, crosswalks, bicycle facilities, transit stops, and traffic-calming features into a unified design. This holistic approach not only enhances safety but also supports community health, economic vitality, and environmental sustainability.

Table 23: Core Elements of a Complete Street

Element	Description	Primary Safety Benefit
Sidewalks	Continuous pedestrian pathways	Reduces walking in traffic lanes
Protected bike lanes	Separated cycling infrastructure	Reduces vehicle-bicycle conflicts
Crosswalks	Marked, visible pedestrian crossings	Improves driver yielding behavior
Transit stops	Sheltered and accessible passenger zones	Enhances safe pedestrian access
Traffic calming	Speed-reducing street geometry	Lowers vehicle impact severity

Connectivity and Network Integration

One of the key features of multimodal networks is connectivity. A safe pedestrian network must provide continuous sidewalks, safe crossings, and direct access to destinations such as schools, transit hubs, and commercial centers. In many U.S. communities, sidewalks end abruptly or fail to connect across intersections, forcing pedestrians into hazardous conditions. Engineers can address this by ensuring that pedestrian and bicycle facilities are continuous and integrated into broader transportation planning.

Cross-Sectional Design and Space Reallocation

Cross-sectional design is also critical. Road diets, bike lanes, bus-only lanes, and curb extensions are examples of how space can be reallocated to serve multiple users. Table 24 shows how reallocating road space can directly translate into measurable safety gains for pedestrians and cyclists.

Narrowing vehicle lanes and providing buffer zones not only improve safety for non-motorized users but also encourage lower vehicle speeds. Transit integration further enhances pedestrian safety by providing accessible, well-designed stops with adequate lighting, shelter, and safe crossing opportunities nearby.

Table 24: Common Cross-Sectional Treatments and Safety Outcomes

Design Feature	Primary Function	Typical Crash Reduction
Road diet	Reduces lanes to lower speeds	25–35%
Protected bike lane	Separates bikes from vehicles	30–50%
Curb extension	Shortens crossing distance	20–40%
Bus-only lane	Prioritizes transit flow	Improves pedestrian visibility

Intersection Design for Multimodal Networks

Intersection design in multimodal networks requires careful attention. Protected intersections, which physically separate pedestrians and cyclists from turning vehicles using islands and setback crossings, provide significant safety benefits. These designs reduce conflict points and improve sightlines between vulnerable users and drivers. Additionally, advanced signal phasing, including Leading Pedestrian Intervals (LPIs) and transit signal priority, ensures that pedestrians and transit vehicles can move through intersections with minimal exposure to vehicle conflicts.

Context-Sensitive and Universal Design

The concept of context-sensitive design is central to multimodal planning. In dense urban centers, this may mean wide sidewalks, raised crosswalks, and frequent crossing opportunities. In suburban environments, safe mid-block crossings, shared-use paths, and transit-oriented development can create safer and more inviting walking conditions. Rural communities, though less dense, also benefit from multimodal considerations, such as paved shoulders, separated paths, and strategically placed pedestrian crossings near schools or community centers.

Complete Streets also incorporate universal design principles, ensuring accessibility for all users, including those with disabilities. This includes tactile paving, curb ramps, auditory crossing signals, and sufficient crossing times for slower pedestrians. By addressing the needs of vulnerable populations, engineers create networks that are both safer and more equitable. Table 25 underscores the importance of tailoring design interventions to match local land-use patterns and travel behavior.

Table 25: Context-Sensitive Design Strategies

Setting	Recommended Features	Key Objective
Urban	Wide sidewalks, LPIs, raised crossings	Encourage walking and transit
Suburban	Shared-use paths, mid-block crossings	Connect fragmented networks
Rural	Paved shoulders, refuge islands	Protect pedestrians near traffic

Cultural and Behavioral Shifts

Importantly, multimodal design not only reduces pedestrian fatalities but also shifts cultural expectations. By visibly prioritizing walking, biking, and transit alongside vehicles, communities foster an environment where drivers anticipate the presence of pedestrians and adjust behavior accordingly. The normalization of multimodal travel contributes to a feedback loop of safety, where infrastructure, culture, and driver behavior reinforce one another.

Implementation Challenges and Collaborative Planning

The transition to Complete Streets requires political will, funding, and collaboration among engineers, planners, and policymakers. While challenges exist, particularly in retrofitting existing auto-oriented corridors, the benefits are clear. Multimodal networks create safer, more resilient communities, reduce dependence on automobiles, and support the broader goal of reducing pedestrian deaths in the United States.

Table 26 identifies common challenges to implementation and corresponding strategies that facilitate progress toward multimodal safety goals.

Table 26: Common Barriers and Enablers for Complete Streets Implementation

Category	Challenge	Enabler
Institutional	Conflicting agency priorities	Unified planning frameworks
Financial	Limited funding for retrofits	Federal/state grants and incentives
Cultural	Driver resistance	Public engagement and education
Technical	Legacy infrastructure constraints	Phased implementation and pilot projects

CONCLUSION

Complete Streets and multimodal design represent a fundamental rethinking of transportation priorities. By integrating safe, connected infrastructure for pedestrians, cyclists, and transit users, engineers can create networks that protect all travelers while enhancing livability and sustainability. These approaches not only prevent pedestrian fatalities but also reshape communities into equitable, efficient, and resilient urban systems.

ENGINEERING APPLICATIONS OF DATA AND PREDICTIVE ANALYTICS

The increasing availability of transportation data has opened new opportunities for engineers to address pedestrian safety with greater precision and foresight. Traditional safety analysis often relied on historical crash records, which, while valuable, only revealed problems after fatalities or serious injuries had already occurred.

With advances in data collection and predictive analytics, transportation professionals can now identify risk factors proactively and apply interventions before tragedies happen. This chapter examines the role of data-driven methods in reducing pedestrian fatalities and improving roadway safety outcomes.

Predictive Methods and the Highway Safety Manual

One of the most widely used data tools in traffic safety is the Highway Safety Manual (HSM) and its predictive methods. These statistical models allow engineers to estimate expected crash frequencies for given roadway types, traffic volumes, and geometric configurations. By comparing predicted values with observed crash data, engineers can identify sites with elevated risks. The ability to quantify risk through predictive modeling enables more effective prioritization of limited safety resources, particularly in corridors where pedestrian exposure is high.

Near-Miss Data and Proactive Risk Identification

Near-miss data has emerged as a powerful complement to crash data. Traditional crash records capture only the most severe outcomes, but near-miss events, such as drivers braking hard to avoid a pedestrian, occur far more frequently and provide valuable insight into dangerous conditions.

Modern video analytics systems can automatically detect near misses at intersections and crosswalks, providing a much richer dataset for evaluating pedestrian risk. These proactive

indicators allow engineers to identify hazardous locations without waiting for fatalities to accumulate.

Machine Learning and Advanced Analytical Techniques

Advances in machine learning have further expanded analytical capabilities. Algorithms can process large datasets from traffic sensors, cameras, GPS traces, and mobile devices to identify patterns not easily detected through traditional methods. For example, machine learning models can predict pedestrian crossing behavior, assess the impact of land use changes on pedestrian flows, and estimate the likelihood of conflicts at complex intersections. These insights allow for tailored engineering solutions, such as adaptive signal control or targeted crosswalk enhancements.

Geographic Information Systems (GIS) for Safety Mapping

Geographic Information Systems (GIS) play a crucial role in mapping and analyzing pedestrian safety data. By layering crash records, roadway characteristics, socioeconomic indicators, and pedestrian volume estimates, GIS tools allow engineers to visualize spatial patterns of risk. This integration is particularly valuable in identifying systemic issues, such as corridors with recurring pedestrian fatalities or communities disproportionately affected by unsafe roadway conditions.

Real-Time Data Integration and Connected Systems

Another promising field is the use of real-time data integration. Connected vehicles, smartphones, and wearable devices can transmit location and movement information that, when aggregated, provides real-time insights into pedestrian activity. This data can inform dynamic signal timing, activate warning systems, or even communicate directly with vehicles through Vehicle-to-Pedestrian (V2P) technology. While still in early stages, such systems hold significant potential for reducing collisions in rapidly changing urban environments.

Performance Evaluation and Continuous Improvement

Performance evaluation is another key application of predictive analytics. Engineers can use before-and-after studies, informed by robust datasets, to measure the effectiveness of interventions such as road diets, refuge islands, or lighting upgrades. By quantifying reductions in crashes, near misses, or exposure risk, transportation agencies can refine best practices and allocate funding more effectively.

Data Quality, Integration, and Privacy Challenges

Challenges do remain in implementing data-driven safety approaches. Data quality and consistency vary widely across jurisdictions, and integrating datasets from different sources, police reports, hospital records, sensor networks, and private mobility providers, can be complex.

Privacy concerns must also be carefully managed, particularly when using mobile or video data. Engineers must therefore balance the promise of predictive analytics with the need to protect personal information and ensure transparency in how data is used. Table 27 identifies key data management and ethical issues and summarizes best-practice responses for mitigation.

Table 27: Common Challenges in Data-Driven Safety Implementation

Challenge Category	Example Issue	Engineering Response
Data quality	Inconsistent coding of crash types	Standardize data formats
Integration	Disconnected systems across agencies	Centralized data platforms
Privacy	Use of personally identifiable data	Data anonymization and ethics review
Resource limits	High cost of analysis tools	Public-private partnerships

CONCLUSION

The shift toward data-driven decision-making represents a significant evolution in pedestrian safety engineering. Rather than reacting to past tragedies, engineers now have tools to anticipate risks and apply interventions where they will be most effective. This proactive approach embodies the Safe System philosophy, reinforcing the principle that no loss of life is acceptable and that technology and data should be leveraged to prevent fatalities before they occur.

EVALUATING COUNTERMEASURE EFFECTIVENESS THROUGH METRICS

For transportation engineers, the implementation of safety countermeasures must be accompanied by systematic evaluation. Without measurable outcomes, it is difficult to determine whether interventions are achieving their intended goals or whether resources are being used efficiently.

In pedestrian safety, evaluation is particularly important because fatalities are influenced by multiple interacting factors, including roadway design, driver behavior, vehicle characteristics, and land use. This chapter explores the metrics and methodologies used to assess the effectiveness of engineering countermeasures aimed at reducing pedestrian fatalities.

Crash Frequency and Severity Analysis

The most direct measure of effectiveness is the change in pedestrian crash frequency and severity. Before-and-after studies compare collision data prior to the installation of a countermeasure with data collected after implementation.

A reduction in pedestrian fatalities or serious injuries is the most compelling evidence of success. However, because pedestrian crashes are relatively rare events compared to vehicle-vehicle collisions, a sufficient period of post-implementation observation is necessary to yield statistically significant results. To supplement crash data, engineers often use surrogate measures that capture broader patterns of safety.

Pedestrian Exposure and Normalized Safety Indicators

One such surrogate measure is the Pedestrian Exposure Index, which accounts for the number of pedestrians crossing a given roadway segment relative to the traffic volume. This allows safety performance to be normalized for changes in pedestrian activity. For instance, if a new mid-block crossing results in increased pedestrian use but a reduction in collision rate per crossing, the measure demonstrates safety improvement even if the absolute number of pedestrians involved in crashes remains constant.

Driver Yielding Behavior as a Performance Metric

Driver yielding rates are another valuable performance metric. At unsignalized crosswalks, the percentage of drivers who yield to pedestrians provides a direct measure of the countermeasure's effectiveness in altering driver behavior. High-visibility crosswalk markings, flashing beacons, and curb extensions often show significant improvements in yielding behavior when evaluated systematically. Observational studies conducted shortly after installation can provide early indications of effectiveness before long-term crash data are available.

Speed Management and Compliance Metrics

Metrics also extend to speed management outcomes. Average operating speeds, 85th-percentile speeds, and speed compliance rates provide insight into whether traffic calming or roadway redesign measures are achieving the intended reductions. Because speed is such a critical factor in pedestrian survivability, even modest reductions can translate into meaningful safety improvements. Engineers can use radar measurements, automated speed cameras, or connected vehicle data to monitor these outcomes.

Conflict Analysis and Near-Miss Observation

Conflict analysis represents another emerging evaluation technique. Using video analytics or field observation, engineers can track near misses or conflicts between vehicles and pedestrians. These events occur more frequently than crashes and can provide earlier feedback about the effectiveness of interventions. For example, the installation of a Leading Pedestrian Interval (LPI) at an intersection may be shown to reduce pedestrian-vehicle conflicts significantly, even before crash statistics can confirm a reduction in injuries or deaths.

Equity-Based Evaluation Metrics

Evaluation also includes equity-based metrics. Given that pedestrian fatalities disproportionately affect low-income and minority communities, engineers must assess whether safety interventions are equitably distributed. Metrics such as the percentage of safety funds allocated to high-risk neighborhoods, improvements in sidewalk continuity, or reductions in nighttime fatalities in underserved areas provide important insights into whether pedestrian safety gains are being shared across populations.

Cost-Effectiveness and Benefit-Cost Analysis

Another layer of evaluation involves cost-effectiveness analysis. Transportation agencies often operate under budget constraints, making it essential to compare the safety benefits of interventions relative to their costs. Benefit-cost ratios, net present value analyses, and life-cycle

cost evaluations allow agencies to prioritize projects that deliver the greatest safety impact per dollar invested. This approach ensures that limited resources are directed to measures with the highest potential to save lives.

Continuous Monitoring and Adaptive Management

Finally, evaluation requires long-term monitoring and feedback loops. Countermeasures must be revisited periodically to confirm that benefits are sustained over time. Changes in traffic volumes, land use, or driver behavior may reduce the effectiveness of an intervention, necessitating adjustments or supplemental treatments. Institutionalizing evaluation as an ongoing process, rather than a one-time activity, helps ensure that pedestrian safety strategies remain adaptive and evidence-based.

CONCLUSION

By employing robust metrics and methodologies, engineers can demonstrate the value of pedestrian safety interventions and refine their approaches for maximum impact. In doing so, they not only provide accountability to the public and policymakers but also advance the broader goal of creating safer, more equitable transportation systems.

POLICY, STANDARDS, AND ENGINEERING GUIDELINES

Engineering solutions to pedestrian safety challenges are most effective when supported by sound policy frameworks, consistent standards, and well-established guidelines. While transportation engineers apply technical expertise to design and implement countermeasures, the adoption, funding, and enforcement of these solutions often depend on regulatory and institutional structures.

This chapter examines the policies, standards, and guidelines that shape pedestrian safety practice in the United States and highlights areas where alignment with engineering needs can be improved.

Federal Standards and the MUTCD

At the federal level, the Manual on Uniform Traffic Control Devices (MUTCD) is the foundational document governing traffic control measures, including pedestrian facilities. The MUTCD sets national standards for crosswalk markings, pedestrian signals, signage, and roadway treatments. Table 28 summarizes how the MUTCD provides baseline consistency but can constrain innovation when overly vehicle-focused.

Consistency in these standards ensures that pedestrians and drivers encounter familiar cues across jurisdictions, reducing confusion and promoting predictable behavior. However, critics argue that the MUTCD has historically prioritized vehicle movement over pedestrian safety, and ongoing revisions aim to better reflect multimodal needs.

Table 28: Key MUTCD Provisions Affecting Pedestrian Design

Element	MUTCD Specification	Design Implication
Crosswalk markings	Standardized widths and color contrast	Enhances visibility and driver awareness
Pedestrian signal timing	Minimum walk and clearance intervals	Determines crossing feasibility for vulnerable users
Signage	Uniform shape and placement	Promotes consistency across states
Curb ramps and accessibility	Referenced through ADA integration	Ensures universal access compliance

Accessibility Standards and the Americans with Disabilities Act (ADA)

The Americans with Disabilities Act (ADA) establishes critical accessibility requirements that directly affect pedestrian infrastructure. ADA compliance mandates features such as curb ramps, tactile warning surfaces, and adequate crossing times for individuals with mobility impairments. These standards ensure not only equity but also safety by accommodating slower or less visible pedestrians who might otherwise face disproportionate risks. Engineers must incorporate ADA standards into all roadway projects to ensure universal accessibility and compliance with federal law.

State and Local Design Manuals and Policies

State and local governments also issue design manuals and roadway standards that supplement federal guidelines. Many states have adopted Complete Streets policies, requiring transportation agencies to consider the needs of all roadway users in project planning and implementation. These policies institutionalize the principle that pedestrian safety is not optional but a core design responsibility.

Local jurisdictions may go further, implementing zoning codes and development requirements that mandate sidewalk construction, pedestrian-oriented site design, and traffic calming in new

developments. Table 29 shows how states and municipalities tailor national guidance to address local pedestrian safety priorities.

Table 29: Examples of State and Local Pedestrian Policy Instruments

Policy Type	Governing Level	Objective	Example
Design manual	State DOT	Provide standardized design templates	Caltrans Highway Design Manual
Complete Streets policy	State or municipal	Integrate all users in roadway planning	Massachusetts DOT Complete Streets Program
Local ordinance	City/county	Mandate pedestrian infrastructure in new developments	Portland, OR zoning code

Funding and Prioritization Frameworks

Funding policies are another decisive factor. Federal programs such as the Highway Safety Improvement Program (HSIP) allocate resources to projects that demonstrate measurable safety benefits. Pedestrian-focused projects often compete with vehicle-centric safety initiatives, making data-driven justifications essential. States and metropolitan planning organizations (MPOs) play a key role in prioritizing which projects receive funding, and engineers must align proposals with established performance measures to secure support.

Enforcement and Legal Frameworks

Enforcement policies also influence pedestrian safety outcomes. Speed limits, impaired driving laws, and yielding requirements for crosswalks form the legal framework within which engineers operate. However, without consistent enforcement, even well-designed infrastructure may fail to achieve its potential. Automated enforcement tools such as speed cameras and red-light cameras can enhance compliance, though their adoption varies widely by jurisdiction due to legal, political, or public acceptance barriers.

International Policy Comparisons

International policy comparisons reveal opportunities for improvement in the United States. In Europe, for example, pedestrian safety is integrated into vehicle safety standards through pedestrian impact testing, something not yet mandated domestically. Similarly, countries that adopt Vision Zero policies establish a national-level commitment to eliminating traffic fatalities, supported by legislation, funding, and accountability measures. The U.S. has seen local adoption of Vision Zero in cities such as New York, Los Angeles, and Washington, D.C., but there is no unified federal mandate.

Professional Guidelines and Industry Leadership

Professional organizations provide additional guidance. The American Association of State Highway and Transportation Officials (AASHTO) publishes design guides that set recommended practices for roadway and pedestrian infrastructure. The Institute of Transportation Engineers (ITE) and the National Association of City Transportation Officials (NACTO) have also issued pedestrian safety guides that promote innovative treatments, including protected intersections and context-sensitive street designs. These resources expand the toolbox available to engineers, encouraging designs that go beyond the minimum standards in the MUTCD.

Integrating Policy, Standards, and Engineering Practice

Ultimately, the alignment of policy, standards, and engineering guidelines determines the scale and pace of pedestrian safety improvements. Engineers must work within existing frameworks but also advocate for reforms where standards are outdated or insufficient. By leveraging data, evaluation metrics, and case studies, engineers can influence policymakers to adopt more progressive standards that prioritize pedestrian life. The integration of policy and practice is not merely procedural; it is a vital link in the chain of responsibility that ensures safety is embedded into every stage of transportation system design.

CONCLUSION

Policy and standards provide the framework within which engineering solutions are conceived and executed. When aligned with safety objectives and supported by robust enforcement and funding, they enable engineers to deliver infrastructure that protects all users equitably. Continued collaboration between policymakers, professional bodies, and engineers will be essential to achieving a future where pedestrian fatalities are no longer accepted as inevitable.

FUTURE DIRECTIONS IN PEDESTRIAN SAFETY ENGINEERING

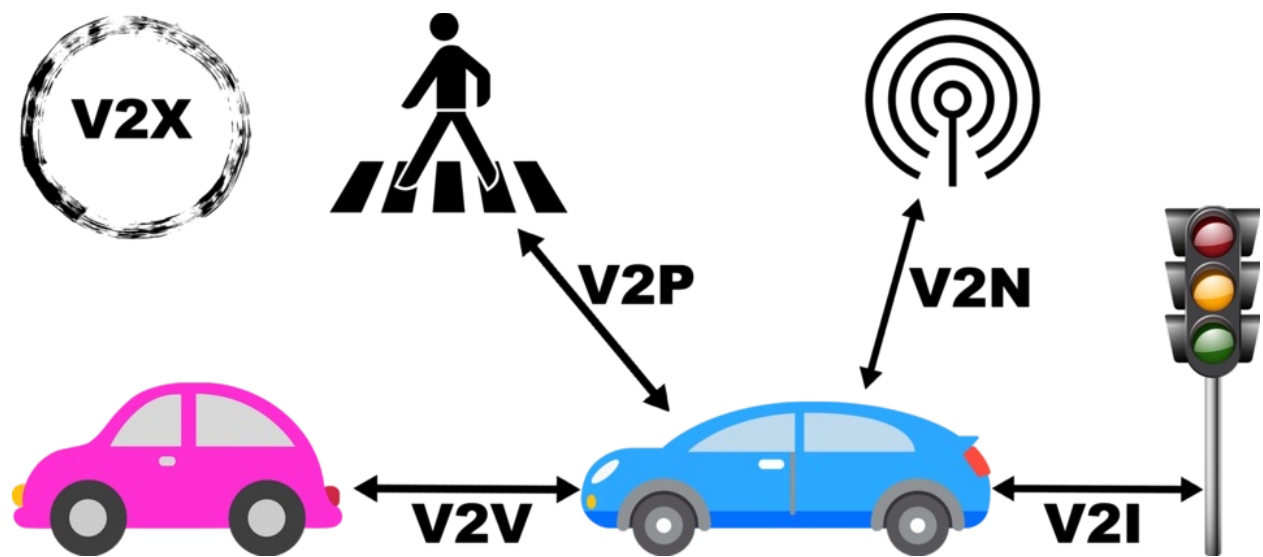


Figure 10: Future cellular V2X technology: Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P), Vehicle-to-Network (V2N), Vehicle-to-Infrastructure (V2I).

Credit: Vehicular Communication, via Wikimedia Commons

As transportation systems evolve, the strategies for protecting pedestrians must also adapt. While the rising number of pedestrian fatalities in recent decades represents a serious public health and engineering challenge, advances in design, policy, and technology present opportunities for meaningful improvement.

This chapter examines emerging directions in pedestrian safety engineering and considers how future developments can be aligned with the goal of reducing and ultimately eliminating pedestrian deaths.

Expansion of Vision Zero and Safe System Frameworks

One of the most significant trends is the expansion of Vision Zero and Safe System frameworks. Increasingly, cities and states in the United States are adopting policies that explicitly reject traffic fatalities as an acceptable outcome. These frameworks shift responsibility away from individual road users alone and place greater accountability on system designers, policymakers, and engineers. This cultural and professional shift is likely to accelerate as public demand grows for safer streets and as funding mechanisms increasingly reward data-driven safety initiatives.

Automation, Connectivity, and Vehicle-to-Pedestrian Technology

Integration of automated and connected vehicles will also transform the pedestrian safety landscape. Autonomous driving systems, though still in development, promise to reduce collisions by eliminating human error in areas such as distraction, fatigue, and impaired driving.

Vehicle-to-Pedestrian (V2P) communication, in which vehicles receive signals from smartphones or wearable devices carried by pedestrians, may provide additional layers of protection by allowing vehicles to detect pedestrians who are out of sight. While challenges such as privacy, infrastructure compatibility, and consumer adoption remain, these technologies have the potential to reduce many of the risks associated with human drivers.

Artificial Intelligence and Predictive Data Systems

The growing use of data analytics and artificial intelligence will continue to advance proactive safety management. Table 2 summarizes how AI technologies can transform reactive engineering practices into proactive safety management systems.

Predictive models can identify emerging risk factors before fatalities occur, while AI-powered signal systems can optimize crossings dynamically based on real-time pedestrian activity. The integration of large-scale datasets from connected vehicles, mobile devices, and sensor networks will allow engineers to target interventions more precisely and evaluate their impact more effectively.

Table 30: Emerging AI Applications in Pedestrian Safety Engineering

Application Area	Description	Example Implementation
Predictive modeling	Identifies locations of future risk	Machine learning algorithms using crash and traffic data
Dynamic signal control	Adjusts signal timing in real time	AI-controlled pedestrian phases
Anomaly detection	Recognizes abnormal vehicle behavior	Intelligent camera networks
Exposure estimation	Tracks pedestrian movement via aggregated mobile data	Citywide safety mapping tools

Retrofitting Suburban Arterials and High-Risk Corridors

Another direction is the redesign of suburban arterials and retrofitting of auto-centric corridors. Many of the highest-risk pedestrian environments in the United States are found in sprawling suburban areas where wide, high-speed roads intersect with pedestrian demand.

Future roadway projects are likely to place greater emphasis on road diets, mid-block crossings, refuge islands, and pedestrian-scale lighting in these environments. Federal and state funding priorities are expected to increasingly support such retrofits as part of broader safety performance goals.

Climate Change, Sustainability, and Active Mobility

Climate change and sustainability considerations are also influencing pedestrian safety. With growing emphasis on reducing vehicle emissions and promoting active transportation, more communities are investing in walkability and multimodal networks. These investments, when paired with safety-focused engineering, offer dual benefits of environmental and public health improvements. Green infrastructure, shaded walking paths, and resilient design features will likely become integral to pedestrian networks in the coming decades.

Equity and Inclusive Design Priorities

Equity will remain a central focus. As data continue to demonstrate that pedestrian fatalities disproportionately affect lower-income and minority communities, future engineering practices will need to address these disparities directly. This may include prioritizing safety projects in underserved areas, adopting inclusive design practices, and ensuring that technology deployment does not exacerbate inequities. Pedestrian safety cannot be considered fully achieved until it is shared equitably across all populations.

Interdisciplinary and Ethical Collaboration in Engineering Practice

Finally, the profession itself is evolving toward a more interdisciplinary approach. Engineers are increasingly collaborating with urban planners, public health professionals, behavioral scientists, and technology developers to create holistic safety solutions. Table 31 demonstrates how multiple disciplines combine to deliver comprehensive, systems-based pedestrian safety solutions.

This blending of expertise reflects the complexity of pedestrian safety, which cannot be solved by engineering alone. Future training, professional development, and CE requirements for transportation engineers will likely place greater emphasis on systems thinking, cross-disciplinary collaboration, and ethical decision-making.

Table 31: Interdisciplinary Roles in Future Pedestrian Safety Practice

Discipline	Primary Contribution	Example Role
Transportation engineering	Infrastructure design and data analytics	Road diets, signal control
Urban planning	Land use and connectivity	Mixed-use zoning for walkability
Public health	Risk factor analysis	Injury prevention metrics
Behavioral science	Human factors insight	Designing intuitive crossings
Technology development	Automation and sensing systems	AI-driven detection tools

CONCLUSION

The direction of pedestrian safety engineering is clear: it is moving toward proactive, technology-enhanced, equity-centered, and system-based solutions. While the rise in fatalities over the past decade has revealed significant shortcomings, it has also galvanized momentum for change. Engineers of the future will play a decisive role in ensuring that roadways are no longer environments of risk for pedestrians but instead networks that protect life at every step.

CONCLUSIONS AND PROFESSIONAL RESPONSIBILITIES

The rise in pedestrian fatalities across the United States since 2009 represents a sobering reminder that progress in transportation safety is not guaranteed. Despite decades of improvements that once drove fatalities to historic lows, changing conditions—larger vehicles, roadway design practices, distracted driving, and sprawling development—have combined to create a reversal of this trend. For transportation engineers, the challenge is not only to understand the causes of this crisis but to accept the professional and ethical responsibility to apply solutions that prevent further loss of life.

Key Themes and Lessons Learned

Throughout this course, several themes have emerged. Vehicle design has shifted in ways that increase pedestrian vulnerability, emphasizing the need for both safer fleet standards and roadway countermeasures that account for modern vehicle characteristics. Roadway design continues to play a central role, with wide arterials, long crossing distances, and insufficient lighting creating hazardous conditions in many communities. Speed management and traffic calming have been shown to dramatically reduce pedestrian fatalities, yet their adoption remains inconsistent across jurisdictions.

The Role of Technology within Safe Systems

Technological innovations, including sensors, artificial intelligence, smart signals, and vehicle-based safety features, offer promising new tools to mitigate risk. However, these technologies are not substitutes for fundamental design improvements; they are most effective when layered upon safe roadway systems that anticipate human error. The Safe System framework provides an essential philosophy: assume mistakes will occur and design transportation networks to prevent those mistakes from becoming fatal.

The Power of Policy, Standards, and Advocacy

The role of policy and standards cannot be overstated. Federal guidelines such as the MUTCD, state-level design manuals, and local ordinances collectively shape the scope of engineering practice. Where these standards fall short, engineers must advocate for revisions that place pedestrian safety at the forefront. Funding priorities and enforcement strategies likewise influence the pace of change, and engineers must work with policymakers to ensure that resources are directed toward interventions with the greatest potential to save lives.

Table 32 highlights how engineers influence safety outcomes through collaboration with policy and governance systems.

Table 32: Policy and Practice Levers for Advancing Pedestrian Safety

Policy Area	Key Influence	Engineering Role
Federal standards (MUTCD)	Defines national design and signalization rules	Support revisions emphasizing multimodal safety
State design manuals	Determine roadway configuration and criteria	Integrate pedestrian safety into all roadway classes
Local ordinances	Govern zoning, sidewalk continuity, and crossings	Advocate for walkability requirements
Funding mechanisms	Allocate resources for safety programs	Provide data-driven justification for projects
Enforcement	Ensures compliance with speed and yielding laws	Collaborate with law enforcement and planners

Equity and Ethical Imperatives in Design

A recurring theme is equity. Pedestrian fatalities disproportionately affect low-income communities, racial and ethnic minorities, older adults, and individuals with disabilities. These populations are often underserved by existing infrastructure, and their safety needs are too often overlooked in roadway design. Professional engineers carry a duty to address these disparities, ensuring that safety is not a privilege but a right enjoyed by all members of society.

The Engineer's Call to Leadership and Accountability

Ultimately, the profession must embrace a proactive and holistic approach. No single countermeasure will eliminate pedestrian fatalities, but the combined application of roadway redesign, technological innovation, policy reform, and community engagement can create environments where walking is safe, dignified, and accessible. As guardians of public welfare, transportation engineers must uphold the ethical principle that every life matters and that fatalities are not inevitable but preventable. Table 33 outlines how ethical, leadership, and professional obligations align with the duty to safeguard pedestrian life.

Table 33: Professional Responsibilities in Pedestrian Safety

Responsibility Area	Description	Ethical Imperative
Design accountability	Ensure all roadway projects consider pedestrian safety	Protect life through informed design choices
Advocacy	Support data-driven policies and funding	Promote public good beyond technical compliance
Education and leadership	Mentor new engineers and influence industry standards	Uphold ethical practice and continuous learning
Community engagement	Include residents in planning processes	Build trust and ensure equitable representation

CONCLUSION

The conclusion of this course is not the end of the discussion but a call to action. The tools, strategies, and philosophies described herein provide a foundation, but their effectiveness depends on consistent application, evaluation, and refinement. By integrating engineering expertise with a commitment to safety and equity, the profession can reverse the current trajectory and restore the long-term trend toward safer streets for all.

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