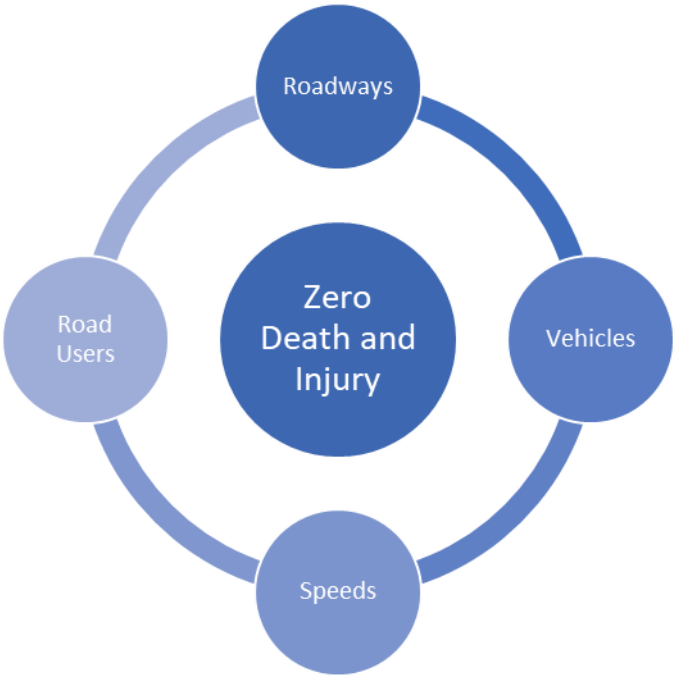
Safe Systems Synthesis: An International Scan for Domestic Application

Final Report



Prepared by:

Kari Signor
Wes Kumfer
Seth LaJeunesse
Daniel Carter
UNC Highway Safety Research Center

Prepared for:

Warren Smith, Mark Scaringelli, and Stacey Deans
Highway Safety Specialists
North Carolina Governor's Highway Safety Program

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INTRODUCTION

This report transmits the results of a wide-ranging literature and policy scan of international practices that fall under the scope of Safe Systems. Safe Systems, though difficult to define, is generally regarded as a framing philosophy of roadway transportation that entails the needs and efforts of all involved stakeholders in promoting a safe and healthy transportation system. Although the focus of Safe Systems is generally a reduction-to-zero of fatal and injury crashes, a more general reduction of total crashes and an overall improvement of health are in view. In this report, we document how we arrived at this general understanding of Safe Systems, and the practices that inform such an approach to road safety. It is our hope that this report contributes a much-needed meta-analysis to the transportation safety field and informs future policy decisions at all levels of government.

Nature of the Problem

According to the World Health Organization, road traffic crashes claim the lives of more than 1.25 million people around the world annually and are the leading cause of death in young people between the ages of 15 and 29 years old [1]. In addition, the economic and societal costs from these incidents are tremendous. In the United States in 2016, The National Safety Council estimated that the costs of road trauma (deaths, injuries, and property damage) were $432.5 billion [2]. Great improvements in road safety have been achieved over the last few decades from advancements in vehicle safety, road design, and safety education; however, the number of traffic-related fatalities and injuries is still significant. In recent years, these numbers have increased in countries of all economic backgrounds, including the U.S. [3].

This global epidemic has prompted local and national governments and road safety practitioners to seek out new strategies to address the increasing risks on our roadways. In 2010, The United Nations General Assembly proclaimed 2011 to 2020 the “Decade for Action for Road Safety.” Co-sponsored by 100 countries and endorsed by leading institutions, including the World Bank and the World Health Organization, this declaration aims to “stabilize and then reduce the forecast level of road traffic fatalities around the world by increasing activities conducted at the national, regional and global levels” [4]. The overall goal is to prevent five million road traffic deaths and 50 million injuries worldwide by focusing on road safety management, road infrastructure, vehicle safety, road user behavior, road safety education, and crash response [5].

During the 1970s, the United States had the safest roads in the world; however, we now lag far behind when it comes to improving road safety outcomes. Leonard Evans, the president of Science Serving Society, compared traffic fatality trends in the U.S. to those of 25 other countries - that we once surpassed in safety - and found that all countries outperformed the U.S. in reducing fatalities since reaching their all-time highest death toll [6]. As an example, fatalities in Sweden and the U.S. both peaked in 1972, but by 2011 Sweden had reduced traffic fatalities by 81%, while road fatalities in the U.S. only declined 41%. Compared to the average traffic fatality reduction across three other similar countries, the difference in progress is equally

dramatic. Between 1979 and 2002, the average reduction across Great Britain, Canada, and Australia was 49%. In the U.S., our reduction was 16%, resulting in 200,000 more traffic deaths [6]. If the U.S. had kept pace with even the average rate of decline of all 25 comparison countries (1972-2011), over 16,330 deaths may have been prevented [6].

More recent data show that circumstances are worsening. The road toll in the U.S. increased more than 8% between 2014 and 2015 (2,741 additional deaths) and another 5.5% in 2016. Compared to five years ago, the increase is nearly 10% [7]. In 2015, crashes were the leading cause of death for those between the ages of 17 and 23 [8]. According to official data released by the U.S. Department of Transportation, deaths related to drunk driving, speed, and failing to use a restraint all increased in 2016, as did pedestrian and bicyclist deaths. Official data for 2017 have not yet been released, but early estimates from the first nine months of 2017 suggest fatalities will be similar to 2016 [9].

North Carolina data are equally alarming. Traffic fatalities have risen every year over the last five years and follow the national trends in 2015 and 2016, with fatalities being the fifth highest among all states in 2016 [10]. Injuries and crashes have also increased. According to an analysis using National Highway Safety Traffic Administration fatality data in five different categories, North Carolina tied Delaware as the eighth worst in driving failures resulting in traffic death and injury last year [11]. One possible explanation for this high rate may be a boom in population. The U.S. Census Bureau reports growth of almost 8% in North Carolina since 2010 [12]. With increased population comes increased exposure, and, statistically, more cars lead to more conflicts on the road.

What are the primary driving behaviors associated with these fatalities? Over a 10-year period, speeding was a factor in 31% of all traffic deaths nationwide [13] and nearly half of all occupants who were killed were not wearing seatbelts [14]. About 28% of fatal accidents involved drivers with a blood alcohol content (BAC) greater than 0.08 g/100ml [15]. Speeding, alcohol, and failure to use a restraint were factors in a similar portion of North Carolina fatalities during 2016, with lane departure also reported as a contributing factor in over half of all fatalities [16].

A Potential Solution

Despite these major concerns regarding traffic safety in the United States, significant progress in highway safety has been made over the last few decades. In 1965, 40,000 people were killed in motor vehicle accidents at a time when many fewer cars were on the road and no governing road safety body existed [17]. However, in 1966 a new era of road safety emerged when the National Traffic and Motor Vehicle Safety Act and Highway Safety Act were passed.

According to then-President Lyndon B. Johnson, almost three times the number of Americans had died since the turn of the century as a result of road crashes than had died in all previous wars. This was seen as a crisis that called for immediate government action, and new laws put a number of provisions in place to address occupant protection, vehicle safety, and roadway design [18]. Since this time, numerous actions have contributed greatly to reducing the road toll. Some

notable measures included airbags, integrated seat belt and shoulder harnesses, child restraint systems, advanced vehicle crashworthiness and vehicle ratings (5-Star Safety Ratings Program), and various regulations limiting driver behavior such as the graduated driver licensing and Zero Tolerance Laws for drivers under the age of 21.

Although the road toll in the U.S. has declined, overall, since its peak in the 1970s, our progress has slowed dramatically and may even be reversing. Public safety experts agree that preventing road deaths and serious injuries can be achieved, but this requires a fundamental shift in how we think about and manage our road transportation systems; it is no longer sufficient to merely address driver behavior [19] [20]. Other developed countries have demonstrated that significant progress can be made with strong leadership and system-wide accountability [21]. Clearly much more can and must be done in the U.S. to reduce our increasing road toll, and trends indicate that actions must be directed toward every aspect of the transportation system [20].

Traditionally, mobility within the transport system has been prioritized over safety, and road users have been viewed as the "problem" [19]. Efforts to improve road safety have generally focused on crash reduction and adapting drivers to the road transport system [22] [23]. By definition, the cost-benefit framework suggests that there is an optimum number of fatalities and that safety is an inherent trade-off in the transportation system [23]. However, experts and the public view this as an antiquated and unproductive way of thinking about road safety.

A number of countries that have experienced the greatest improvements in road safety have incorporated a Safe Systems approach into their strategies [24]. A Safe Systems approach challenges traditional ideas by asserting that no one should be killed or seriously injured from using the road network. This assertion is a moral imperative; transportation systems must be healthy and accommodating to all road users [19]. Safe Systems is a holistic, long-term vision that deaths and injuries are preventable, not inevitable. This concept was first adopted by Sweden and the Netherlands as part of their innovative road safety strategies, *Vision Zero* and *Sustainable Safety.*

The Safe System focuses attention on specific elements of the road transportation system - safe roads and roadsides, safe speeds, safe vehicles, and safe road use. More recently, the United Nations has expanded this to include post-crash response [25]. The Safe System is also defined by four core principles [25]:

- Humans are fallible, but no reasonable mistake should lead to death or serious injury.
- The road system should be designed around the capacity of the human body to tolerate external forces.
- The responsibility for road safety should be shared by all parties, including road users and system designers.
- All parts of the system must be strengthened to multiply their effects.

As stated in the first core principal of *Vision Zero*, human beings make mistakes, and even small mistakes within the road transport system can lead to disastrous consequences. Instead of

conforming human behavior to the design of the road system, engineers and road safety practitioners should adapt the system to road-user behavior. Second, crashes should be expected, but the kinetic energy of collisions should be managed such that crash energy does not exceed the human tolerances to those forces [26]. Third, maintaining a safe transport system should not be the sole responsibility of drivers [21]. Finally, all components of the road transport system must be enhanced to ensure that road users are protected in the event one part of the system fails.

Sweden demonstrated that incorporating the fundamental principles of the Safe System can have a profound positive impact on road safety outcomes. Other countries - including Australia, New Zealand, and the Netherlands - have recognized the need to explore more effective ways to mitigate the road safety crisis and have modeled their road safety programs after *Vison Zero*.

In the U.S., a number of cities and states have also begun to adopt the Safe Systems principles, including New York City, San Francisco, Chicago, Portland, and Minnesota. Since launching *Vision Zero* in 2014, New York City has achieved four straight years of traffic fatality decline and now reports 2017 as the safest year on record [27]. Last year, San Francisco also recorded the fewest traffic deaths in over 100 years [28]. Road traffic fatalities in Minnesota dropped by 40% over 10 years after implementing Safe Systems [29].

Report Overview

In this Synthesis, we examine four countries that have the most well-established Safe Systems programs: Sweden, the Netherlands, Australia, and New Zealand. Each of these countries have structured their approaches to road safety around the Safe Systems core principles and implemented innovative measures to address their specific priorities. We framed our examination by answering five questions for each of the representative nations:

1. What was the motivation for implementing a Safe Systems program?
2. What exactly was implemented to improve road safety?
3. What challenges did the nation face in its implementation?
4. How effective was the implementation?
5. What recommendations, if any, does this nation have for others seeking road safety improvements?

This report is not an exhaustive review of every action undertaken under these strategies but an overview of what led to each Safe Systems approach, the general areas of concern in each country, and a summary of proposed actions and measures implemented to address these road safety concerns. Information about their effects on improving road safety is limited, but findings are included where possible. We also briefly document three other nations with Safe Systems-adjacent programs that advocate many of the same principles. Some traffic safety measures, such as speed reduction, traffic calming, and stronger enforcement, have already been shown to be successful here in the U.S. Other countermeasures show great promise but may need to be assessed further to be effective in the physical and cultural context of the U.S.

INTERNATIONAL STUDY

Sweden

Motivation and Trends

Sweden is generally credited, along with the Netherlands, with initiating the Safe Systems approach to roadway safety [30] through its careful and rigorous approach to reorganizing the top-down structures responsible for transportation safety management [25]. Sweden has a reputation for excellence in road traffic safety and has been praised for its leadership and success in managing road safety issues for decades. Overall, road deaths in Sweden have declined sharply since the 1970s, despite a growing population and a steady increase in traffic volume. In 2016, Sweden had the fewest number of road fatalities on record (254) and still maintains the lowest road traffic fatality rate worldwide with approximately 2.9 deaths per 100,000 people [31].

Sweden has the lowest road fatality rate in the world with approximately 2.9 deaths per 100,000 people.

This was not always the case. Annual road deaths in Sweden peaked at close to 1,300 in the late 1970s then steadily declined in the years that followed until the late-1980s, when numbers plateaued, hovering at about 500 deaths per year [32]. The road transport system carried a considerably higher risk level than other modes of transport [22]. This reality was completely unacceptable to road safety practitioners. Around this same time (1994) the lives of over 500 Swedish citizens were lost in one of the worst maritime disasters in modern times when a ferry carrying over 800 passengers sank in the Baltic Sea. This tragedy, along with diminishing gains in the road toll, strengthened interest in improving public transport safety and set the stage for Sweden's comprehensive road safety strategy, *Vision Zero* [33].

Developed by the Director of the Swedish National Road Administration, Claes Tingvall, and the Minister of Transport, Ines Usmann, *Vision Zero* aimed to address this road safety problem using a comprehensive Safe Systems approach. With strong support across all party lines, the concept was written into law by Swedish Parliament in 1997 and proposed that "no-one shall be killed or seriously injured as a consequence of the transportation system" [22] [33].

Based on Safe Systems principles, *Vision Zero* emphasized that the responsibility for road safety should be shared by both designers and road users [33]:

1. The designers of the system are always ultimately responsible for the design, operations and use of the road transport system, and are thereby responsible for the level of safety within the entire system.
2. Road users are responsible for following the rules for using the road transport system set by the system designers.

3. If road users fail to obey these rules due to a lack of knowledge, acceptance or ability, or if injuries occur, the system designers are required to take the necessary steps to counteract potential death or serious injury.

Policies and Implementation

Following the *Vision Zero* legislation, the Swedish Government launched a short-term action plan that proposed 11 priority areas. These priorities included focusing on the most dangerous roads, improving traffic safety in built-up areas, and placing more emphasis on the responsibilities of road users and transport system designers (Figure 1).

1. A focus on the most dangerous roads (e.g. priority for installing centre-guardrails for eliminating head-on collisions, removing obstacles next to roads, etc.)
2. Safer traffic in build-up areas (e.g. a safety analysis of street networks in 102 municipalities led to reconstruction of streets; the efforts are continuing.)
3. Emphasis on the responsibilities of road users (e.g. creating more respect of traffic rules in particular with regard to speed limits, seat belt use, and intoxicated driving.)
4. Safe bicycle traffic (e.g. campaign for using bicycle helmets, a voluntary bicycle safety standard.)
5. Quality assurance in transport work (e.g. public agencies with large transportation needs will receive traffic safety [and environmental impact] instructions on how to assure the quality of their own transportation services and those procured from outside firms.)
6. Winter tyre replacement (e.g. a new law mandating specific tyres under winter road conditions.)
7. Making better use of Swedish technology (e.g. promoting the introduction of technology—available or to be developed—the relatively soon can be applied, such as seat belt reminders, in-car speed adaptation systems [ISA], alcohol ignition interlocks for preventing drinking and driving, and electronic driver licenses.)
8. Responsibilities of road transport system designers (e.g. establishment of an independent organization for road traffic inspection is proposed by a commission of inquiry on the responsibilities of the public sector and the business community for safe road traffic.)
9. Public responses to traffic violations (e.g. a commission of inquiry is reviewing existing traffic violation rules in the light of the Vision Zero principles and of ensuring due process of the law.)
10. The role of voluntary organizations (e.g. the government is evaluating the road safety work of the "Nationalföreningen för trafiksäkerhetens främjande" [National Society for Road Safety or NTF] and its use of state funds.)
11. Alternative forms of financing new roads (e.g. possibilities are studied for other forms of supplementing public financing of major road projects.)

Figure 1: Priority Areas for Vision Zero [33]

A number of key transportation experts also outlined specific ways to mitigate Sweden's road safety problem. Tingvall and Monash University Accident Research Centre's Narelle Haworth proposed several strategies that they believed could easily be adopted independent of any political sphere [34]:

- gradually aligning vehicle speed to the inherent safety of the system by rating roadways according to their infrastructure;
- improving vehicles to address driver behavior issues by incorporating seat belt interlocks, alcohol interlocks, and intelligent speed limiters; and
- motivating the community to use the system in a safer way.

Mobility cannot exist at the expense of life and health.

They also emphasized that societal benefits, such as mobility within the transportation system, should never be prioritized at the expense of life and health, and when a death or serious injury occurs, steps must be taken to prevent a similar event [34].

Roger Johansson of the Swedish Road Administration also summarized how incompatible traffic elements should be separated, including diverse road users, based on human tolerances to physical violence, as shown in Figure 2 [35]. He emphasized that when separation of road users was warranted, this separation should always be by physical means, such as a barrier. This approach to design places a greater emphasis on more rigid stratification of functional use for roadways; roadways with high mobility demands should not create situations through open access that expose road users to excess risk.

1. Vulnerable road users should not be exposed to motorised vehicles at speeds exceeding 30 km/h.

2. If 1. cannot be satisfied then separate or reduce the vehicle speed to 30 km/h.

3. Car occupants should not be exposed to other motorised vehicles at speeds exceeding 50 km/h in 90 crossings.

4. If 3. cannot be satisfied then separate, or reduce the angle, or reduce the speed to 50 km/h.

5. Car occupants should not be exposed to oncoming traffic (other vehicles of approximately same weight) at speeds exceeding 70 km/h or 50 km/h if oncoming vehicles are of considerably different weight (Fig. 3).

6. If 5. cannot be satisfied then separate, homogenize weights or reduce speeds to 70 (50) km/h.

7. Car occupants should not be exposed to the road side at speeds exceeding 70 km/h, or 50 km/h if the road side contains trees or other narrow objects (Fig. 4).

8. If 7. cannot be satisfied separate or reduce speed to 70 (50) km/ h.

Figure 2: Human tolerance to speed exposure [35]

Drawing upon these guiding principles of road user separation and speed reduction, Sweden implemented multiple roadway measures to improve safety for all users. In application, *Vision Zero* primarily focused on speed limit reductions, road design improvements, and extensive data analysis and monitoring [36].

Transportation agencies implemented Large-scale speed limit reduction to 30 km/h (19 mph) in many urban areas which previously had default speeds of 50 km/h (31 mph) [37] [38]. Beginning in 2008, they also implemented speed limit reductions of 10-20 km/h (6-12 mph) on several rural road types with pre-existing speed limits of between 90-110 km/h (56-68 mph), shown in Table 1 [36]. These reductions purportedly reduced deaths from 41% to 14%, although no significant change in serious injuries was observed [39]. A large-scale road safety camera program was also implemented in 2006 to encourage drivers to comply with posted speed limits. Adherence to speed limits improved from 50% in the 1990s to more than 80% across Sweden and 95% at camera sites as of 2014 [40].

Table 1: Speed limit changes in Sweden [36]

Type of Road	Description
1. Motorways, 110 → 120 km/h	Motorways where the speed limit increased from 110 to 120 km/h
2. 2+1 roads, 90 → 100 km/h	A continuous three-lane road with alternating passing lanes and the two directions of travel separated by a median barrier
3. 2+1 roads, 110 → 100 km/h	A continuous three-lane road with alternating passing lanes and the two directions of travel separated by a median barrier
4. Rural roads, 110 → 100 km/h	Two-lane rural roads
5. Rural roads, 70 → 80 km/h	Two-lane rural roads
6. Rural roads, 90 → 80 km/h	Two-lane rural roads
7. Rural roads, 90 → 70 km/h	Two-lane rural roads

Transportation agencies also made Structural improvements to roads and roadsides. Efforts included constructing center median wire rope barriers and roadside barriers to roadways as well as removing dangerous objects from roadsides [36]. Another effort was the conversion of three-lane undivided roads to a "2+1" road configuration. In a "2+1" design, a continuous flexible center barrier separates opposing lanes of traffic, but the presence of a second lane alternates from one direction of travel to the other as the location of the barrier shifts toward or away from the single lane. It is estimated that fatalities on these roadways have been reduced by up to 90% [41].

Multiple actions pertaining to vehicle safety were also implemented. The use of winter tires became mandatory in 1999. Beginning in 2005, laws required 70% of new cars to have seat-belt reminders [35]. Following this policy, the seat-belt wearing rate increased from 92% to 99%. Cycle helmets became mandatory for those aged 15 years and younger [42].

To assess these gains in safety and to ensure that countermeasures were properly evaluated, Swedish authorities also established a rigorous data collection and safety measurement program. Since 1997, Sweden has conducted individual investigations of every fatal car crash to separate which factors contributed to the crash and which contributed to the fatality. Based on these factors and what aspect of road safety failed, crashes fall into one of three groups: "excessive force," "excessive risk," and "beyond system recommendations" [33].

Road safety professionals in Sweden also monitor numerous other metrics related to roadway safety, including drunk driving, speeding, seatbelt use, cyclist helmet use, emergency services rescue times, and motor vehicle crashworthiness [36]. Analysts combine hospital data with

police reports and regularly review and share injury reports at national conferences each year. In addition, agencies routinely identify locations on roadways that share similar attributes to problematic locations on roadways to apply safety measures before road safety issues develop.

Efficacy of the Solutions

Sweden reports 95% compliance with red-light cameras.

Given the number of factors that can influence a system**,** it can be difficult to attribute road safety trends to any one specific cause. However, several positive trends have been observed in Sweden since *Vision Zero* was implemented. Fatalities declined by 50% between 2000 and 2014, and pedestrian fatalities, specifically, declined by 50% between 2009 and 2014 [43]. Fatalities of children seven years of age and younger also plummeted, from 58 in 1970 to one in 2012 [44].

Other road safety improvements, as mentioned, include:

- Reduction of 90% of fatal crashes on three-lane undivided roads [41]
- Seat-belt compliance at 99% [42]
- 95% compliance with red-light cameras at enforcement sites [40]

Sweden had 254 road fatalities in 2017, a slight decline from 2016 and its lowest number ever recorded. Despite this achievement, significant drops in fatalities have stagnated over the last several years (Figure 3). The majority of these deaths were motorists and motorcyclists (67%) while approximately one-fourth of deaths were of pedestrians and cyclists (17). These stagnations are not themselves indications of failure but highlight many of the difficulties and challenges still faced by countries that have adopted Safe Systems approaches. These challenges, and the potential opportunities for improvement they invite, are discussed in the next subsection [31].

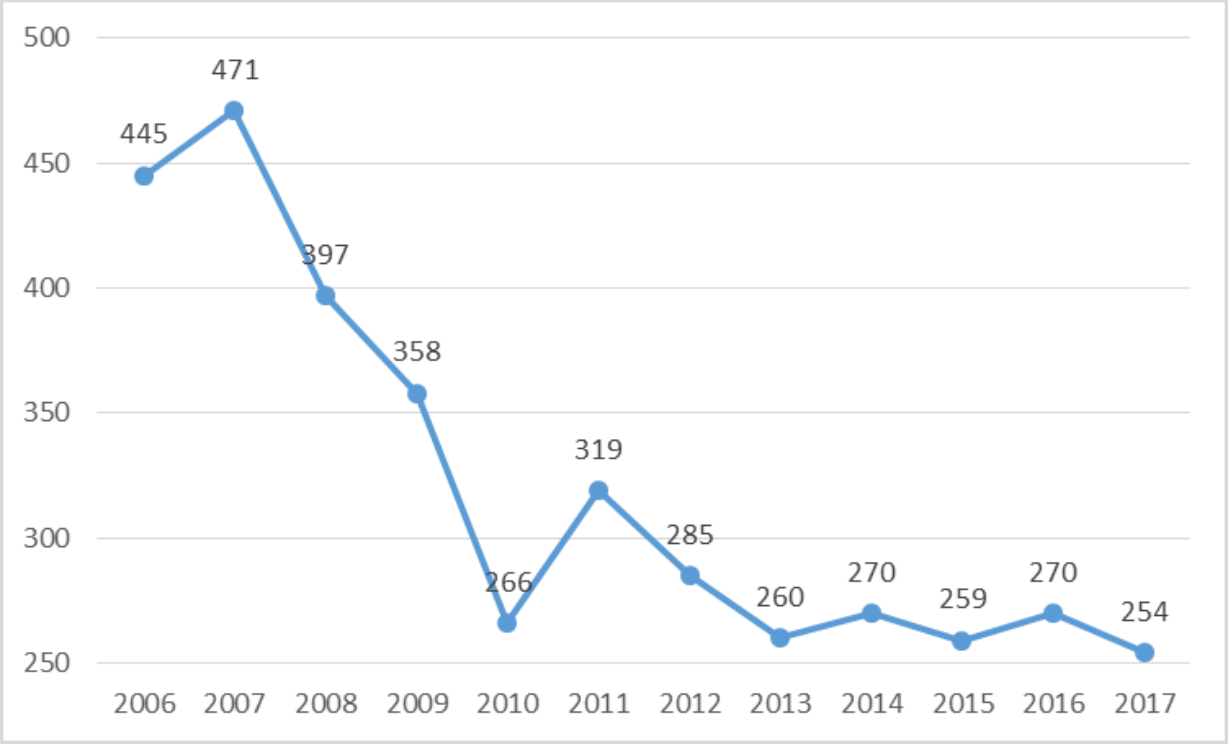

Figure 3: Road traffic fatalities in Sweden 2006-2017

Challenges and Opportunities

Despite widespread support of Sweden's *Vision Zero*, there was some early opposition from industry experts. Matts-Åke Belin, a *Vision Zero* architect and road safety strategist with the Swedish Transport Administration, has said that the one of the main challenges of implementing the strategy was shifting system stakeholders' mindsets from "cost-benefit" to "Safe Systems," i.e., placing a greater emphasis on health and autonomy [37]. In addition, since traditional approaches focused on changing human behavior, road engineers were reluctant to accept shared responsibility for roadway safety. However, in an interview with the ITE Transportation Podcast, Belin emphasized how critical a role traffic engineers play in enhancing safety by comparing the consequences of a crash at a 4-lane intersection with a traffic light to a crash at an intersection controlled by a roundabout [23].

For example, Belin illustrated that at an intersection controlled with a traffic light, the total number of conflicts will be reduced, but any crashes that occur will likely be severe due to the high speed and high-energy transfer of those impacts. At a roundabout, traveling speeds are reduced by design and crashes will inherently be much less severe. These aspects could literally mean the difference between life and death. Since road engineers make these determinations of roadway design, they ultimately bear the responsibility for the safety of the road user. For this reason, Belin believes it is essential for road engineers to understand the *Vision Zero* philosophy and to shift their mindsets dramatically to implement new road safety solutions [23].

Although it may be initially difficult to encourage transportation engineers to adopt Safe Systems principles, especially at the cost of mobility, reframing the argument beyond a simple cost-benefit analysis and instilling a moral imperative for promoting safety and health may encourage buy-in from these key stakeholders. An approach Sweden took early on to shift the paradigm was to reorganize their road safety management structure from the ground up, so as to not promote the idea that road safety is a process isolated from society, rather one that integrates stakeholders from a wide variety of disciplines, including engineering [25].

Matts-Åke Belin believes that an approach like *Vision Zero* is transferable to road systems around the world, but he emphasizes that strong political support is essential [23]. He also emphasized that it is important to understand that the mechanical, scientific basis of *Vision Zero* remains constant and is relevant in any system. Critics often cite a lack of accountability for risk in Safe Systems approaches [45], but the data management and evaluation process implemented by Sweden highlights a dedicated approach to measuring safety improvements and scientifically responding to risks in the system. Human tolerances to violence and crash energies remain the same. The approaches to resolving these problems, however, will be different because traffic dynamics and aggregations of road users will vary from one locality to the next.

The motivation for Safe Systems must be an ethical imperative to mitigate death and serious injury.

Belin also suggested that road safety practitioners focus on unprotected road users when designing transportation systems, as they will set the standard for safety. Since North American society is more dependent upon motor vehicles, adapting the U.S. system to vulnerable road users like pedestrians and cyclists will pose a greater challenge than for those regions with more diverse transportation systems [22].

Most importantly, Belin believes that the motivation must come from the ethical imperative that fatalities and serious injuries in the transport system are unacceptable.

New Zealand

Motivation and Trends

Like Sweden, New Zealand traffic safety has improved dramatically over the last several decades. Despite an increase in traffic volume, road deaths have declined by 50% since 1970 [46]. Between 1990 and 2000, road deaths and serious injuries attributed to drug and alcohol use also declined significantly.

However, this progress was beginning to stabilize, and in 2007 New Zealand still had one of the highest rates of road fatalities per capita in the developed world (about 10 per 100,000 residents) [47]. New Zealand acknowledged that it would not meet 2010 targets to reduce deaths and serious injuries under the status quo of road safety management. Other factors that had great potential to influence the safety of road users were also emerging, including a growing and aging

population, an increase in motorcycle use and overall traffic volume, and novel illegal drugs. To address these road safety challenges, new strategies were needed.

In 2009, the New Zealand National Road Safety Committee (NRSC) proposed *The Safer Journeys Strategy*, which was based on Safe Systems and envisioned "A safe road system that is increasingly free of road deaths and serious injuries." NRSC members included the Ministry of Transport, the New Zealand Transport Agency, the New Zealand Police, the Accident Compensation Corporation, and Local Government New Zealand, but many other supporting members also played important roles [46] [47].

As part of this strategy, The New Zealand Minister of Transport, Hon Steven Joyce, released a discussion document to the general public. The document outlined New Zealand's achievements in road safety, the proposed *Safer Journeys* vision and approach, and proposed over 60 possible road safety initiatives under consideration. Many more initiatives were proposed than the government expected to fund; however, this was intentional and provided a platform for public discussion [46] [47].

These initiatives were placed into 13 priority areas broken into three groups: areas of high concern, areas of medium concern, and areas for continued focus and emerging issues (Figure 4). It was explained that high concern areas were those most likely to result in the greatest road safety improvement. The five areas of highest concern included reducing alcohol/drug impaired driving, increasing the safety of young drivers, safer roads and roadsides, safer speeds, and increasing the safety of motorcycling. Some specific initiatives proposed to address high priorities included reducing the legal adult blood alcohol limit from 0.08 to 0.05 g/100mL, raising the driving age to 16 or 17, adopting lower speed limits in urban areas, and improving motorcycle riding training [46] [47].

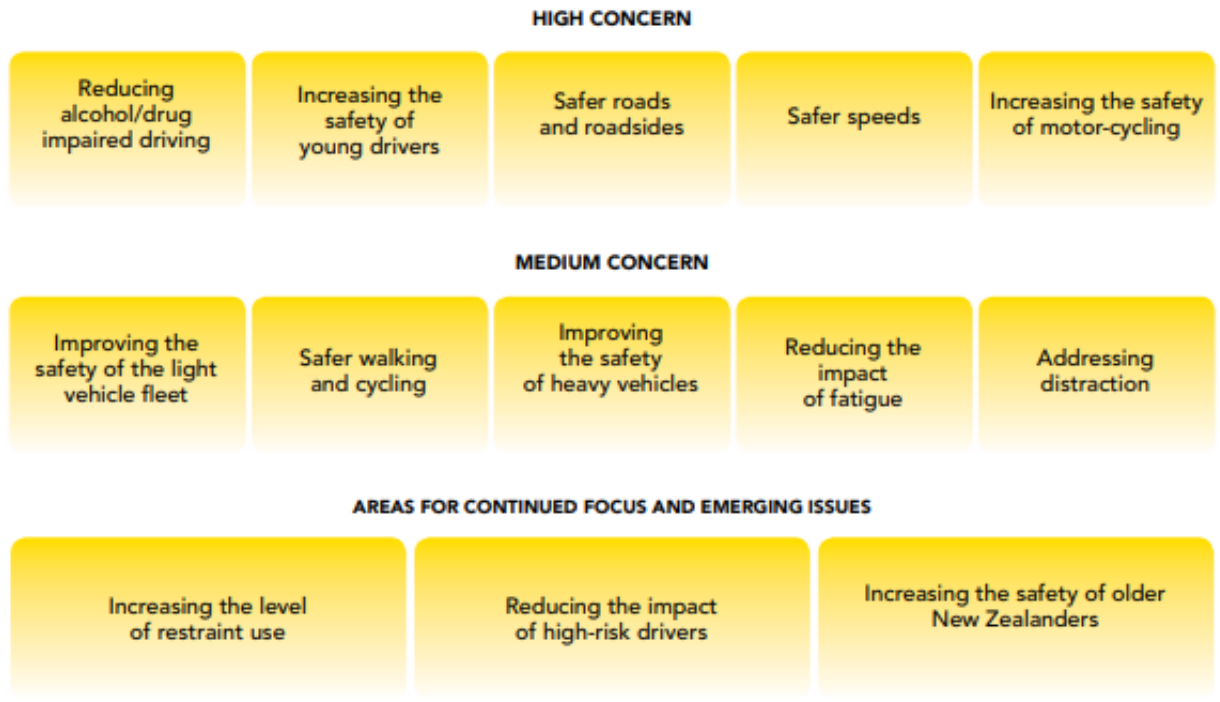

Figure 4: New Zealand 'Safer Journeys Strategy Discussion Document' priority areas [47]

The document explained the relevance and scientific merit of each priority area, presented relevant trends and statistics, and discussed various aspects of the proposed initiatives, including benefits and limitations. During a two-month public consultation period, citizens were asked to submit their choices for the top 10 or 20 initiatives and share general thoughts about how to improve outcomes in each priority area [46] [47].

Overall, New Zealanders responded favorably to the Discussion Document and provided over 1,500 submissions to the Ministry of Transport. The public strongly supported most priority areas but expressed interest in improving a few specific areas, shown in Table 2 [46] [47].

Table 2: Public support of "The Safer Journeys Strategy Discussion Document" priority areas [46] [47]

Initiatives with strong public support	Public desired more focus on
• Lowering legal BAC limits • Raising driving age • Changing 'give-way' rules • Improving walking/cycling infrastructure	• Enforcement and compliance in all areas • Drivers and road users • Stronger penalties for repeat drug/alcohol offenses

Citizens felt that the most emphasis should be placed on initiatives aimed at road users (one of the four elements of a Safe System). Since submissions were disproportionately focused on this one element, with less focus on safe speeds, roads, and vehicles, the Ministry of Transport questioned whether the public fully understood the overall premise of the Safe Systems approach. Not all issues that received strong support from the public were actually backed by evidence, i.e., mandatory third party insurance was a popular proposed policy, but given that the rate of insurance was already high, this policy would not have significantly improved road safety *[46] [47]*.

Using input received from the public, as well as research and experience from other countries that implemented Safe Systems approaches, New Zealand developed the *Safer Journeys Strategy 2010-2020.* The strategy was led by the NRSC, but other partners included the New Zealand Police, the New Zealand Transport Agency, the Accident Compensation Corporation (ACC), and Local Government New Zealand [46] [47].

Over the long-term, the goal of the strategy was to, "Improve the safety of our roads and roadsides to significantly reduce the likelihood of crashes occurring and to minimize the consequences of those crashes that do occur," but it was designed to be implemented through a series of smaller Action Plans (2011-2012, 2013-2015, and 2016-2020) and tailored to address individual community needs [46] [47].

Policies and Implementation

The first Action Plan 2011-2012 focused on advancing the Safe Systems approach, addressing the areas of high and medium concern with initiatives that could most greatly reduce the road toll. Some specific goals included [46] [47]:

- targeting high-risk rural roads and high-risk urban intersections;
- improving speed management through public campaigns, safer speeds, and expanding the use of safety cameras;
- generating consumer demand for safe vehicles and improving child restraint use;
- increasing the safety of motorcycling through training, road treatments, and enforcement;
- reducing alcohol/drug impaired driving through regulations, education, and enforcement;
- increasing the safety of young drivers through regulations, education, and enforcement;
- reducing the impact of high-risk drivers through rehabilitation, regulations, and enforcement;
- improving pedestrian and cyclist safety through education and safer infrastructure; and
- reducing the impact of distraction and fatigue through education and road infrastructure.

Road safety stakeholders should generate consumer demand for safe vehicles.

The second Action Plan 2013-2015 consolidated efforts from 2011-2012 but laid out specific goals for each element of the Safe System. Some of these goals included identifying the 100 highest-risk intersections and implementing improvements for a subset of 20, developing a consistent and effective national speed management program, accelerating the removal of less safe vehicles from the roads, and strengthening drug-driving enforcement. The plan also focused on demonstrating the effectiveness of the Safe Systems approach by launching two new initiatives, the Safe System Signature Programme and the Safe System Partnership Programme [48] [49].

The Safe System Signature Programme sought to identify specific projects that had the potential to collectively reduce the road toll for all road users by using innovative approaches. Specific projects included: the Future Streets Project to improve pedestrian and cyclist safety on urban streets; Behind the Wheel, which supported young learning drivers in the community of Mangere; and the Visiting Drivers Project, aimed at improving road safety for visiting tourists [48]. The Safe System Partnership Programme created new initiatives with partners to demonstrate the effectiveness of collaboration in reducing road trauma [49].

The third and final Action Plan 2016-2020 focuses on the use of current and emerging technologies and on areas of road safety that relate to disproportionate road toll. The plan aims to [46] [47]:

- Enable smart and safe choices on the road by using technology to provide real-time safety information to road users.
- Make motorcycling safer by increasing rider awareness and training, encouraging use of motorcycle technologies, and improving protective clothing.
- Ensure safer roads and roadsides on urban arterial routes and increase low-cost safety improvements on high-risk rural routes.
- Encourage safe vehicles through the uptake of vehicle safety technologies into the vehicle fleet.

Efficacy of the Solutions

In the few years immediately following the introduction of the strategy, three-fourths of actions proposed in the first action plan were completed, and various road safety outcomes were drastically improved. Between 2009 and 2012, road deaths declined 20%, and 284 fatalities in 2011 marked the lowest road toll since 1952. Deaths of young drivers (ages 15-24) decreased 38%. Alcohol-related crashes with fatal and serious injuries also declined significantly [50].

The New Zealand Ministry of Transport also implemented several other actions to promote safe and healthy use of the roadway in each of the priority areas. Some of these actions included [50]:

- Raising the minimum driver age from 15 to 16;
- Implementing stricter child restraint regulations and BAC limits; and

- Enhancing speed management with red light and speed cameras.

A more comprehensive list of actions implemented in *Safer Journeys* is presented in Table 3. More recently, 5-star vehicle ratings for new light cars entering New Zealand roads increased from 51% (2009) to 95% (2016). There are also ongoing efforts to install rumble strips and safety barriers, widen shoulders, improve signage, and implement more appropriate speed limits [46] [47].

Challenges and Opportunities

Despite achieving great improvements in road safety since implementing *Safer Journeys*, some areas still need improvement. Motorcycle deaths and serious injuries have risen since 2013 [49], and road fatalities overall have risen over the last several years (Figure 5). Fatalities from failing to use seatbelts doubled between 2014 and 2016, which also correlates with drunk driving among male drivers. During this same time, the number of high-risk drivers (e.g., repeat offenders and disqualified and unlicensed drivers) involved in fatal or serious injury crashes increased dramatically, from 183 in 2014 to 346 in 2016. Crash deaths per 100,000 among 15- to 24-year-olds has increased slightly since 2012. Alcohol or drug-related fatalities or serious injuries per 100,000 also increased slightly during 2014-2016, as did motorcycling entitlement claims. Overall, since 2013, the fatality rate has steadily increased, and 2017 may have reached the highest total since 2010 [46]. Although New Zealand still faces a number of challenges, particularly those that require enforcement of traffic laws, researchers like Bambach and Mitchell believe a holistic approach that integrates design, enforcement, and education, may provide substantial reductions to road tolls, particularly for vulnerable road users, in countries with Safe Systems programs [51].

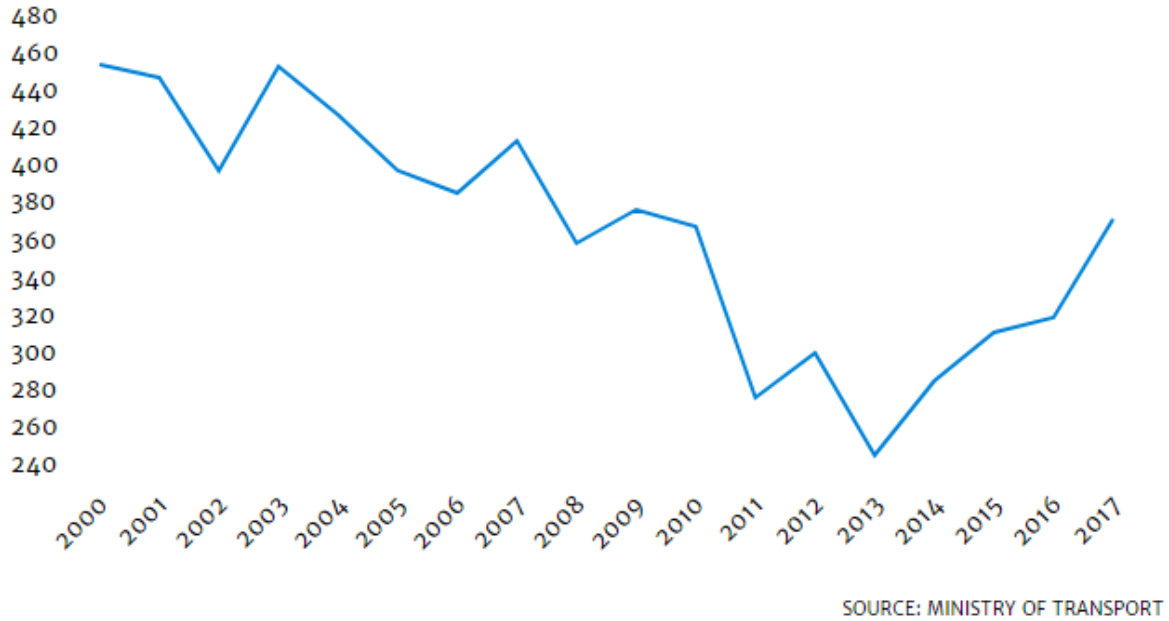

Figure 5: New Zealand road traffic fatalities [49]

Table 3: Actions implemented in "Safer Journeys 2010-2020" [46] [47]

Priority Area	Action Implemented
Young Drivers	• Raised minimum driving age from 15 to 16 • Implemented zero BAC for drivers <20 years old • Strengthened Restricted Driver License Test • Introduced Community Driver Mentor Programme • Launched online interactive website "Drive" for learner drivers • Produced road safety resources that supported school curriculum
Drink Driving	• Implemented zero BAC for drivers <20 years old • Lowered BAC to .05 for drivers >20 years old • Focused on reducing drink driving through the "Legend Campaign" • Implemented Alcohol Interlock Programme
Motorcycling	• Introduced power-to-weight restriction for novice riders • Introduced Competency-based Motorcycling License Testing • Increased numbers of motorcyclists trained in Ride Forever Program • Updated *Safer Journeys* for motorcycling on New Zealand roads
Drug Driving	• Raised awareness of the risks posed by drug driving (TV ads)
Restraint Use	• Increased age of compulsory child restrain use to 7 years of age
Safe Speeds	• Published a Speed Management Guide • Developed resources for Road Controlling Authorities to facilitate better road risk conversations with communities/stakeholders • Developed new geospatial tool to identify where to target roads to best reduce deaths and serious injuries for all crashes
Safe Vehicles	• Developed Vehicle Standards Map to identify new vehicle technologies • Promoted and expanded vehicle safety information with RightCar • Mandated Electronic Stability Control for new light vehicles • Adjusted motor vehicle levies to reflect vehicle safety • Increased 5-star vehicle ratings for new light cars entering NZ roads

Australia

Motivation and Trends

As in the U.S. and Sweden, Australia has halved the death toll from road traffic crashes since the 1970s when road fatalities were at their peak (Figure 6). Much of this decline can be attributed to a road safety countermeasure program that was progressively implemented over the years [52]. Some measures put in place included graduated driver licensing, roundabouts, mandatory seat belt laws (1973) and bicycle helmet use (1990), random breathalyzer testing (1976 in Victoria), and speed camera programs [53].

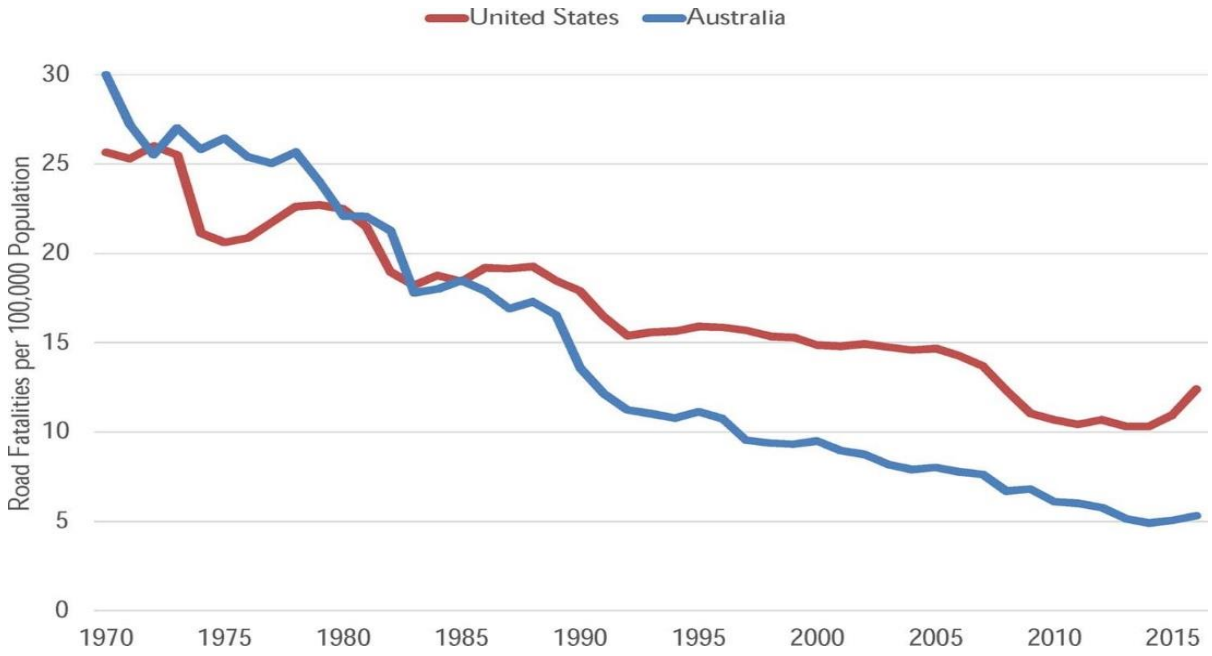

Figure 6: Comparison of road fatalities per 10,000 people between the United States and Australia [54]

Additionally, the Motor Vehicles Standards Act of 1989 introduced strict safety standards for all vehicles entering the Australian market. In 1990, the Australian Government implemented a Black Spot Program to target specific road segments and locations with a proven crash history or significant crash potential [55]. The National Road Safety Strategy of 1992-2001 marked Australia's first collaborative effort to improve road safety. Significant reductions in the road toll were achieved but the rate of improvement gradually slowed and remained relatively constant.

Tingvall and Haworth together advocated for a *Vision Zero* Safe Systems approach in Australia, starting with the state of Victoria [34]. Their recommendations focused on infrastructure improvements and speed management, citing that the most important aspect of *Vision Zero* centered around the human body's biomechanical tolerance to an external force. Specifically, they proposed that speed limits be reduced to levels more appropriate for the road infrastructure and significant separation should exist between road users on roads where speed exceeded 60-70 km/h (37-43 mph). Further, where conflicts between vehicles and pedestrians occurred, speed

limits should be no more than 30 km/h (19 mph). Otherwise, vehicles and pedestrians should be physically separated [34]. These recommendations are highlighted in Table 4.

Table 4: Long-term travel speeds based on best-practice vehicle design [34]

Type of infrastructure and traffic	Possible travel speed (km/h)
Locations with possible conflicts between pedestrians and cars	30
Intersections with possible side impacts between cars	50
Roads with possible frontal impacts between cars	70
Roads with no possibility of a side impact or frontal impact (only impact with the infrastructure)	100+

Policies and Implementation

Recognizing the need for stronger measures, the Australian Transport Council formally adopted Safe Systems principles in the subsequent National Road Safety Strategy 2001-2010 [56]. This effort aimed to reduce the rate of road fatalities by 40% by 2010 (equivalent to a 30% reduction in the number of fatalities). The Strategy proposed a number of Strategic Objectives to be implemented through a series of two-year Action Plans. Proposed initiatives included improving road user behavior, occupant protection, emergency response, and reducing human error through the use of technology. Some Strategic Objectives for the National Road Safety Strategy are summarized in Table 5.

The National Road Safety Strategy 2011-2020, still in progress, expanded this vision by setting a goal for reducing serious roadway injuries as well as fatalities. The Strategy aimed to reduce both the number of deaths *and* serious injuries by at least 30% by 2020 using evidence-based safety countermeasures [57].

At the time that this strategy was launched (the 2011-2020 Strategy), several trends were apparent. Speeding accounted for the greatest proportion of deaths and serious injuries on the country's roadways, followed by drunk driving and fatigue (in fatalities only). The majority of fatalities and serious injuries occurred in regional areas (65% and 59%, respectively), and fatalities per capita (per 100,000 residents) increase dramatically the more remote and further a region was from a major city. Traffic-related deaths were three times higher for indigenous people than non-indigenous people. Three crash types also dominated Australian roadways: intersection, single vehicle run-off-the-road, and head-on crashes [57].

To address these challenges, interventions were proposed around four "cornerstone areas" that aligned with the Safe Systems approach: *safe roads, safe speeds, safe vehicles, and safe people.* Specific actions that were to be implemented in the first three years of the strategy are outlined below [57].

The primary *safe road* objective was to design all new roads and upgrades to reflect Safe Systems principles. Other steps included ensuring that roads were "self-explanatory" to reduce the risk of crashes and injury, and designing infrastructure treatments to target intersection, run-off-road, and head-on casualty crashes, and addressing the safety of vulnerable road users [57].

The Australian Safe Systems Approach is centered on four cornerstone areas: safe roads, safe speeds, safe vehicles, and safe people.

Speed limits should be adapted to the risks of the road environment such that crash impact forces do not exceed human tolerance. Several studies demonstrated that 10 km/h (6 mph) speed reductions on 110 km/h (68 mph) roadways in Victoria, South Australia, and New South Wales all resulted in 20% or more reductions in fatal crashes. The National Road Strategy managers also pointed out that point-to-point camera systems have also been proven to be effective in reducing driver speeds in the UK and Europe. These systems track speed over a longer distance, rather than clocking speed momentarily at one location. In justifying their use, the Australian Transport Council highlighted that Northamptonshire, England experienced a 78% -85% reduction in fatal and serious injuries on two different routes within five years using this point-to-point speed camera system. In the 2011-2020 Strategy. The Council proposed to develop national speed limit guidelines and to improve speed compliance by implementing tougher penalties and using the illustrated speed camera technologies [57].

The Australian Transport Council proposed numerous vehicle safety countermeasures, including improving new vehicle safety standards, reducing the average vehicle fleet age, and using intelligent technology systems, such as advanced seatbelt reminders, lane departure warning systems, and brake assist systems [57].

The overall objective within this area is to encourage people to maintain consistent and compliant behavior within the road system. Specific measures include improving the graduated driver and motorcycle rider licensing programs and introducing programs that focus on the road safety of the indigenous community and disadvantaged groups. Additional measures focus on irresponsible road users and include lowering BAC limits, expanding the use of alcohol interlocks, and increasing penalties for repeat drink and drug-driving offenders [57].

Interventions are also designed with the expectation that they be customized to local and regional differences across Australia. A diverse National Road Safety Strategy Panel provided guidance on all aspects of the Strategy implementation, and strategies are assessed through systematic reporting on the progress of Targets, Strategic Objectives, and Action Plans at annual meetings [57].

Efficacy of the Solutions

During the first National Road Safety Strategy, a number of measures were implemented, many of which demonstrably reduced the road toll. The introduction of a 50 km/h (31 mph) urban default speed limit was linked to a greater than 20% reduction in serious injury and fatality crashes. Safety outcomes were also improved by implementing 40 km/h (25 mph) and lower speed limits in school zones and high-risk pedestrian areas. When the state of Victoria adopted School Speed Zones, pedestrian and bicycle crashes decreased by 24% [57].

Australia introduced alcohol-interlock programs for repeat drink-driving offenders and roadside drug testing programs were implemented in most states, producing high detection rates. While no

specific safety assessment has been conducted on these programs, they have the potential to contribute to road safety efforts by increasing overall awareness of drug-driving [57].

A number of actions pertaining to vehicle safety were implemented. Three-point seatbelts mandated for all new passenger car models, new standards for front and side impact protection for new vehicles were put in place, and consumer ratings programs including the Australasian New Car Assessment Program (ANCAP) were developed to promote vehicle safety [57].

Table 5: Strategic Objectives outlined in Australia's National Road Safety Strategy 2001-2010.

Objective	Proposed Strategies and Focus Areas
Improve Road User Behavior	• Educate young road users responsible road safety behavior • Driver Training & Licensing – Improve competence and attitudes • Enhance police enforcement using targeted campaigns
Improve the safety of roads	• Improve crash cost estimates • Conduct widespread road safety audits of improvement projects • Conduct safety investigations on existing road network (prioritize sites with a crash history) • Create safer environments for pedestrians, cyclist, and motorcyclists through road design and traffic engineering
Improve vehicle compatibility and occupant protection	• Improve vehicle safety standards and vehicle design • Provide consumers with information on relative safety of vehicles
Use new technology to reduce human error	• Incorporate Intelligent Transport Systems into vehicles and roads
Improve equity among road users	• Implement programs that target vulnerable road users
Improve trauma, medical and retrieval services	• Systematically link crash types with injury and treatment outcomes • Improve all components of trauma management systems reduce deaths and serious injuries for all crashes
Improve road safety programs and policy through research of safety outcomes	• Collect and analyze evidence from road safety outcomes • Improve learning and communication processes across local and international governments
Encourage alternatives to motor vehicle use	• Land-use planning and transport planning • Expansion of telecommuting • Promoting benefits of public transport, walking and cycling

While the National Road Safety Strategies have been implemented on a national scale, individual states also developed their own Safe Systems strategies, including Victoria, New South Wales, and Western Australia [58]. In 2000, Victoria implemented a speed camera program that included strengthening speed enforcement and extensive public campaigns about speeding. After four years, fatal crashes declined by 27% and injury crashes declined by 10%, clearly demonstrating that comprehensive speed management programs can improve road user safety.

Outcomes may vary from state to state.

The 2001-2010 strategy resulted in a 34% reduction in the rate of road fatalities nationally but fell short of the 40% target. In general, however, programs targeting high-risk behaviors such as driver impairment, seatbelt wearing, and speeding made substantial improvements. Outcomes varied across states and territories, with the greatest 10-year reduction in road fatalities (per 100,000) occurring in Tasmania (47.5%) while the Northern Territory experienced the least overall reduction (16.1%) [57].

Challenges and Opportunities

According to annual road trauma summary reports, total road deaths in Australia have declined by 20% overall and an average of 3% each year over the last decade. However, in 2015 and 2016, the death toll increased by approximately 6%. Researchers have projected that at the current rate, Australia will not reach its 2020 goal of reducing annual numbers of deaths and serious injuries by 30% [59].

In response, the government has launched a comprehensive review of the National Road Safety Strategy. Leading road safety expert and chair of the Royal Australasian College of Surgeons' Trauma Committee, Dr. John Crozier, and the director of the Centre for Automotive Safety Research at the University of Adelaide, Jeremy Woolley, have been appointed to conduct the review [59].

Dr. Crozier strongly criticized Australia's Black Spot Program in early 2018. He suggested that proactively improving entire road corridors, rather than high crash-prone areas, would be much more effective at addressing road safety issues. He also recommended coordinating road safety legislation across all states and strengthening Australia's speed camera program [59].

It is difficult to predict road trauma levels due to the range of factors that influence road safety outcomes. Since Australia has enacted policies similar to Safe Systems measures for decades, it is difficult to parse out which specific gains can be attributed to Australia's broad Safe Systems approach [54]. However, by monitoring strategy implementation, evaluating safety outcomes, and periodically reviewing and revising safety-oriented actions, municipalities can adjust their road safety strategies as needed.

The Netherlands

Motivation and Trends

While Sweden may be better-known for being the first nation to adopt the Safe Systems approach, the Netherlands was the first country to construct quantitative road safety targets [60]. In the 1980s, the Dutch Government introduced several road safety plans that set long-term road safety policy goals. The *Meerjarenplannen Verkeersveiligheid* (MPV-I) set a goal of a 25% reduction in the number of injury crashes from 1985 to 2000. To meet this goal, the Dutch Government aimed to reclassify roadways and set focus areas targeting alcohol, speed, hazardous locations, children, elderly, and safety devices [61]. An updated road safety plan, the MPV-II, was adopted in 1989 and highlighted the importance of incorporating road authorities and stakeholders into the policy process.

The second Structure Plan for Traffic and Transport (SVV-II) of 1990 set a goal for a 50% reduction in fatalities and a 40% reduction in injury crashes by 2010 [61]. Doubt arose as to whether these goals could be met because, while the focus areas were well documented, they did not address the root of the manifested safety problems. There were reductions in the number of injury crashes, but there were also large discrepancies between different road classes that were unaddressed, specifically with arterials. The high crash rates occurring on arterials ultimately led to the *Sustainable Safety Program*.

Policies and Implementation

The *Sustainable Safety Program* was a proactive approach that aimed to prevent serious crashes and to eliminate the risk of severe roadway injury [62]. The program was built around the idea that the majority of road accidents can be attributed to the limitations and the unpredictable nature of humans. Recognizing that behavior modification was unsustainable over the long term, *Sustainable Safety* was based on the interactions between all elements of the transportation system (driver, vehicle, road design, regulations, usage, intended function) [61] and included five guiding principles: the functionality of roads, the homogeneity of traffic, a predictable road design, a forgiving environment, and road user awareness (Table 6).

Table 6: The five Sustainable Safety principles [61].

Sustainable Safety principle	Description
Functionality of roads	Monofunctionality of roads as either through roads, distributor roads, or access roads in a hierarchically structured road network
Homogeneity of mass and/or speed and direction	Equality of speed, direction, and mass at moderate and high speeds
Predictability of road course and road user behavior by a recognizable road design	Road environment and road user behavior that support road user expectations through consistency and continuity of road design
Forgivingness of the environment and of road users	Injury limitation through a forgiving road environment and anticipation of road user behavior
State awareness by the road user	Ability to assess one's capability to handle the driving task

The program was implemented in two phases to meet crash reduction goals. Phase 1 (1998-2002) was outlined in the 1997 document "Start-up programme – Sustainable Safety" [61] and targeted sections of the road network that were considered dangerous or potentially dangerous. A number of short-term action plans were established and formal agreements between the Central Government and other major stakeholders (Association of Dutch Local Authorities, Union of Water Management Authorities, Interprovincial Consultation Body) were reached.

Proposed measures included establishing a general urban speed limit of 30 km/h (19 mph), expanding 60 km/h (37 mph) zones in rural areas, and classifying the road network into three functional categories: through function (involving rapid vehicle movements), distributor function (to disperse traffic), and access function (providing access to homes, shops, and offices). Priorities were also aimed at law enforcement and information campaigns to educate road users about the new initiatives [61].

Phase 2 (2002-2010) focused on ensuring that the new road categorization plans were implemented and securing new funding to support the proposed actions. Specific proposed measures included expanding the urban and rural speed limits to other areas, as well as setting target speeds in areas where pedestrians and bicyclists interact with traffic and where motor vehicles have greater potential to interact (Table 7) [61]. The program was updated in 2005, putting more emphasis on education, regulations, enforcement, and technological developments. It also recommended establishing a system of quality assurance and highlighted the importance of integrating road safety with other policy areas [62].

Table 7: Sustainable Safety Phase 2 Target Speeds [63].

Location	**Target (Maximum) Speed**	**Application Areas**
1. Where pedestrians cross the road 2. Where bikes are in mixed traffic	20 mph	1. Local streets 2. Crossings
Where vehicles meet at a 90-degree angle	30 mph	Intersections, signalized and unsignalized
Where vehicles pass in opposite directions	40-45 mph	Undivided highways

Efficacy of the Solutions

Initial road efforts under *Sustainable Safety* were projected to produce a wide range of benefits [61], including:

- Crash reductions up to 10% by assigning priority with better traffic control at intersections
- Crash reductions up to 20% from speed management efforts
- Uniformity of roundabouts
- Improved safety for other traffic modes
- Increased compliance with seat-belt and helmet regulations

Although some of these benefits are difficult to evaluate quantitatively, researchers did note a general sense of compliance and security among the traveling population due to the programmatic improvements [64]. In practice, the *Sustainable Safety* efforts did produce quantifiable gains in safety. Fred Wegman of the SWOV Institute for Road Safety Research reported a direct effect of infrastructure change amounting to a 6% reduction in all fatalities and serious road injuries during the 1997-2002 period. By 2007, road traffic fatalities had been reduced by 30% but there was not any significant reduction in serious road injuries [64]. According to civil engineering professor Peter Furth, 70% of urban roads are now in 20 mph zones [63].

The most important aspect of the *Sustainable Safety* approach, however, was self-categorization of roadways. With roadways that promote healthy flow by either prioritizing mobility or access, but not both, the Netherlands was able to create shared spaces for road users where high speeds do not prevail. Where high speeds are needed, such as outside cities, conflicts are reduced by strictly adhering to access limitations [64].

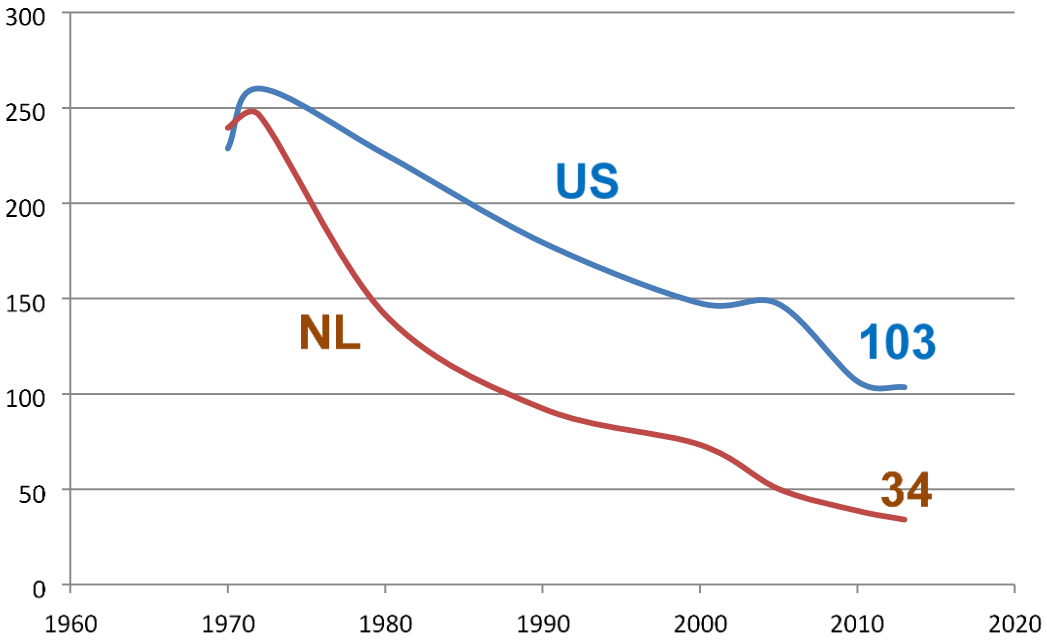

Figure 7: A comparison between traffic deaths in the United States and the Netherlands per million population [63]

Challenges and Opportunities

As with other strategies, the Netherlands's *Sustainable Safety* encountered a few challenges. There were difficulties implementing some of the proposed measures. Initial subsidies under Phase 1 were not sufficient to expand 30-km/h (19 mph) zones to all desired areas due to the cost of signing and control. Some local authorities did not comply with recommended infrastructure changes to accommodate moped users on 80 km/h (50 mph) roadways, perhaps indicating resistance to the new measure. There was some concern that implementing countermeasures at a large-scale would be too time consuming to be effective and would be better coordinated at the regional level. Some road authorities resisted initial safety diagnoses, such as road safety audits, citing the auditing process as a difficult and unnecessary planning step [61].

Since the implementation of *Sustainable Safety*, it seems issues relating to bicycle-only crashes have come to the forefront in light of infrastructure changes [62]. Other outcomes of *Sustainable Safety* included an increase in elderly cyclist injuries, a lack of appropriate countermeasures for e-bikes, decentralization of planning, budget cuts, and competition among policy domains [65]. Researcher van der Knaap also cited a need for more evidence through more countermeasure evaluation, especially pertaining to education, and a need for smart enforcement [65].

Jurisdictions should make better use of ITS devices for data-driven safety improvements.

The National Institute for Road Safety Research believes an extensive look at the relationships between infrastructure and bicycle crashes could be beneficial and could lead to further infrastructure changes. They also recommend investigating other Safe Systems practices and guidelines to enhance their own policies, better incorporation of intelligent transportation system (ITS) devices, and more cooperation and shared responsibilities between involved parties. Including education and enforcement as initial steps rather than through a slow integration may have been beneficial as well [64].

Similar International Programs

The four nations we outlined above each adopted some form of a Safe Systems program in response to national road toll trends. However, these nations are not alone in their pursuit of more holistic or systemic road safety programs. Government agencies in England, Ireland, and Northern Ireland have in recent years adopted programs that share some similarities to Safe Systems or worked actively toward the adoption of a Safe Systems program. While we do not believe these programs illustrate optimal deployment of Safe Systems principles, they do support the suggestions and findings produced by the four countries previously examined.

England

Great Britain has a strong record of road safety; in 2017, the Department for Transport reported only 1800 traffic fatalities for the previous year [66]. Between 2005 and 2014, road deaths in England dropped 45%. England also had its lowest recorded number of road deaths in 2013. The Secretary of State for Transport attributes these gains in road safety to a number of factors, including safer infrastructure, stronger enforcement, new vehicle technologies, and improved trauma care [67].

The Department for Transport in England has not formally adopted a comprehensive Safe Systems approach as a national policy but recognizes this strategy as a best practice in road safety. The Department for Transport listed Safe Systems as a top priority and established Highways England to implement a Safe Systems approach across the strategic road network over a 5-year period, beginning in 2015. With an investment of £11 billion, Highways England aims to reduce deaths and serious injuries on the strategic road network by 40% by 2020 and will strive to approach zero deaths and serious injuries by 2040 [67].

As part of their road safety strategy, the Department for Transport outlined a number of priorities. These objectives directly targeting road users included road safety education and training opportunities for children and vulnerable road users, improving licensing and testing, increasing road user awareness through targeted campaigns, encouraging the use of safer vehicles and equipment, improving motor vehicle insurance, and providing more effective enforcement. They also specified additional areas of focus, including investing in safer infrastructure, enhancing emergency services, and partnering with local authorities and the road safety community [67].

Further, Highways England outlined numerous national actions as part of their strategy to improve road safety. These actions included improving air quality through monitoring and research activities, engaging in noise mitigation programs across the road network, improving pedestrian and cyclist facilities, and enhancing economic growth [68]. These actions are noteworthy because they express a national interest in promoting healthy transport in England that extends beyond simply reducing crashes.

Overall, the government believes that local authorities are best equipped to manage road safety measures according to local needs, as local roads comprise 98% of England's road network. However, road authorities initiated some initiatives on a national scale. Community Speedwatch developed a program to reduce vehicle speed and increase public awareness of speed. Trained volunteers are equipped with speed detection devices and cooperate with local police to monitor vehicle speeds in their communities. Live data from monitoring activities are accessible to police through an online platform, Community Speedwatch Online, and the organization tracks a number of metrics, including cases of repeat and excessive speeding offences, allowing authorities to target their enforcement activities [69].

Another novel initiative is Bikeability cycle training for school children. This program educates children on road cycling skills and road awareness; The Secretary of State for Transport reports that the program improves child perception of road hazards [67]. Again, programs like Community Speedwatch Online and Bikeability indicate the Department for Transport's interest in promoting more than crash reduction. The Department is using or intends to use education, enforcement, and policy to comprehensively improve transportation safety and healthy transport, and this vision is comparable to that of Safe Systems.

Several local municipalities have already adopted a Safe Systems strategy. The Bristol City Council incorporated this approach in a 10-year road safety plan for 2015-2024. In Bristol, pedestrians and cyclists incur over half of all road deaths and serious injuries. Further, the two age groups that are projected to experience the largest increases in population are also the most vulnerable to pedestrian injuries (ages 0-15 and 65-74). The City Council designated improving walkability and pedestrian safety top priorities. Targets proposed for 2020 included a 30-50% reduction in deaths and serious injuries and 20% of the mode of transport to work occurring by bike, as well as 30% by foot by 2021. Specific actions implemented by the Bristol City Council included 20 mph speed limits across all residential streets (and some local streets), cyclist safety improvements at intersections with records of cyclist deaths or serious injury, and a number of projects to train and educate the general public and high-risk road users (children, pre-drivers, young male drivers) on road safety [70].

Ireland

Similar to England, Ireland has a strong road safety record. Following the first Road Safety Strategy in 1997 [71], total road fatalities in Ireland dropped 65.7% during the period of 1997-2012. The Louth County Council attributes this reduction in part to more compliant road user behavior, such as wearing seatbelts, adhering to speed limits, and fewer alcohol-related offenses.

Additional legislative actions through The Road Traffic Act have also contributed to improved road safety. Some measures that were introduced by road authorities in Ireland include checkpoints for mandatory alcohol and intoxication testing, stronger penalties for vehicle offenses, road network upgrades, and safety cameras.

Following the safest year on record in 2015, Ireland ranked seventh (out of 28 EU countries) for fewest road deaths per million inhabitants [71]. Despite this achievement, Ireland's Road Safety Authority recognized the need to incorporate a Safe Systems approach in the National Road Safety Strategy 2013-2020, stating, "There is a cause for every collision, fatality and injury. Collisions are avoidable. They are not accidents" [72].

The National Roads Authority's specific targets are to reduce road fatalities to no more than 25 deaths per million population, a target set by the European Union, and to reduce serious injuries to 330 by 2020. One particular emphasis in the strategy is improving roadside safety, one of the major tenets of a Safe Systems approach. The National Roads Authority developed the Forgiving Roadsides program to improve the outcomes of run-off-the-road crashes by removing and relocating obstacles, modifying roadside elements, and shielding obstacles [73].

Several cities and counties in Ireland have also developed road safety strategies that align with the National Road Safety Strategy and the Safe Systems approach, including the Louth County Council, the Dublin City Council [74], and the Dún Laoghaire-Rathdown County Council [75]. These agencies adopted a shared focus on education, engineering, enforcement and evaluation to reduce road collisions. The Louth County Council identified mobile phone distraction, fatigue, speeding, drink and drug driving, and failure to wear a seat belt as specific challenges that must be addressed [71]. Addressing these issues comprehensively indicates a move toward a more holistic approach to traffic safety in line with many of the tenets of Safe Systems.

Northern Ireland

Northern Ireland has adopted the Safe Systems approach in the country's Road Safety Strategy to 2020. While Northern Ireland experienced a rapid decline in fatal road collisions during the ten-year period between 2003 and 2013, road fatalities increased significantly in 2014 for unknown reasons [76]. To implement the strategy to reduce fatalities, The Northern Ireland Assembly and system stakeholders developed a Road Safety Partnership that includes members of the Department of Environment, Transport Northern Ireland, the Police Service of Northern Ireland, the Northern Ireland Courts and Tribunal Service, and the Department of Justice. Specific objectives of the Partnership include delivering educational campaigns, using safety cameras to reduce speeding and collisions through targeted enforcement, and focuses on protection for children under 15 years of age and young adults (16-24 years old), also Northern Ireland's most vulnerable road user group [76]. The Northern Ireland Assembly's comprehensive approach of education, enforcement, and engineering aligns well with Safe Systems principles, and its desire to protect vulnerable road users highlights the importance of promoting a healthy transportation system for all road users.

Applications for the United States

Given the complexity of the road transport system, it can be difficult to fully understand specific causes of road casualties or measures that will be effective across a system. Crash analysis methods, data collection, and data reporting are often inconsistent. Crashes may be caused by multiple factors, and interactions between these factors are poorly understood. Population demographics, economic conditions, driver behavior, and road and vehicle characteristics all contribute to road safety outcomes. For these reasons, comparing strategies from one location to the next is challenging. Still, in reviewing the Safe Systems approaches in Sweden, the Netherlands, New Zealand, and Australia, as well as England, Ireland, and Northern Ireland, some overall trends emerge, and general conclusions about the applicability of Safe Systems in the U.S. can be made. These trends, and how they can be applied to the United States broadly and to North Carolina specifically include:

1. **Speed Management** – The relationship between speed and safety has been consistently evidenced throughout this report, and we believe that speed management should be one of the first steps taken in the United States to improve road safety [26] [19]. Since the repeal of the National maximum speed limit in the United States, there has been at least a 3.2% increase in road fatalities attributable to raised speed limits across functional road classifications [77]. However, since the repeal, states now have sovereignty to raise and lower speed limits as they deem appropriate. We encourage the State of North Carolina (and the communities that have statutory jurisdiction over most roadways in the state) to consider lower speed limits to mitigate the severity of high-speed crashes on vehicle occupants and other road users. There is some concern that the traditional approach to setting speed limits may no longer be the most effective approach. Most speed limits are based on the "85th percentile speed," the maximum speed at which 85% of drivers travel on a given road segment but are often set lower [78]. In recent years, the National Transportation Safety Board has recommended that road safety practitioners revise the current speed standards to incorporate crash history and the safety of vulnerable road users [13]. Tools, such as USLIMITS2 may facilitate adjusting speed limits [79]. This tool generates an appropriate maximum speed limit for a particular section of road based on its roadway characteristics, crash history, and prevailing speed trends.
2. **Functional Classification** – In addition to controlling speed, we encourage the State of North Carolina to adopt and promote policies of improved separation and access control, especially on roadways where road user mobility is prioritized. All of the nations surveyed in this document promote road user safety by limiting the potential conflicts among different road user groups on high-speed roadways. They tend to do this by separating different road user groups (e.g., pedestrians and bicyclists from drivers of motor vehicles) and limiting road users' access to certain higher speed roadway types.
3. **Intersection Design** – Just as North Carolina should adopt policies that promote limited conflicts on roadways, engineers employed by the State should also design safer intersections. All of the surveyed nations advocated for the use of roundabouts as

alternatives to signal-controlled intersections to mitigate the effects of speed and sharp-angle collisions. There are other intersection types – such as cut-throughs, elevated stoplines, raised intersections, or intersection with green light speeds – that researchers recommend to better integrate Safe Systems principles with our existing infrastructure [26] [19] [80]. The State of North Carolina should also be prescriptive in approaching alternative intersection promotion since the public is often reticent to accept non-traditional designs; careful crash data collection and proactive communication with the public may assuage some of these concerns.

4. **Enforcement** – Since driver behavior is still an issue even when safe designs are implemented, the State of North Carolina should consider increasing enforcement of both speeding and red-light-running, particularly at high risk intersections, segments, and corridors.
5. **Moral Imperative to Improve Safety** – When developing and implementing the country's Safe Systems approach, Swedish leaders recognized that the country's transportation system should not operate separately from the diverse stakeholder groups who design, plan, enforce, and use the system. Thus, in finding common ground among all transportation stakeholder groups, the Safe Systems approach satisfies the basic safety needs of road users prior to addressing other system contributions (e.g., access, aesthetics, and mobility). These approaches are philosophically and ethically distinct from cost-benefit frameworks, which reduce traffic considerations to trade-offs among project costs, high-speed mobility, and road user safety.

Although these five principles are not novel, they do distill the combined wisdom of years of Safe Systems practice throughout the world. However, it should also be noted that Safe Systems itself entails far more than simply improving engineering and enforcement. The State of North Carolina should consider more visible public outreach programs and cooperation with the state's *Vision Zero* initiative [81] to ensure that all stakeholders of the system, particularly auto groups and road users, are involved in policy creation.

However, as this document clearly indicates, there are a number of challenges and new issues that arise from Safe Systems implementation. This literature search consistently highlighted three specific concerns that any entity seeking to implement Safe Systems should consider.

1. **Vulnerable Road Users** – The exact reasons why pedestrian and bicyclist injuries and fatalities continue to rise in the surveyed nations are not clear, but plausible contributors to the rise are two-fold. First, in locations like New Zealand, the rising number of at-risk vulnerable road users may simply reflect changes in population demographics and in travel behavior, whereby the population is aging and a growing number of people walk, bike, or drive to get around [47]. Second, it may also be a symptom of infrastructural changes that encourage use of increasingly larger motor vehicles (e.g., Sport Utility Vehicles), thereby increasing the exposure of vulnerable road users to risk [64]. Whatever the contributing factors, the gains in safety for motor vehicle users but less substantial

improvements for other road users highlights the need for more targeted focus on vulnerable road user safety in Safe Systems planning. With pedestrian fatalities on the rise in the United States, this consideration is critical [82].

2. **Structural Organization** – The exact structure for implementation of Safe Systems varies from location and should be a response to local conditions. In the Netherlands, a top-down management structure that ultimately enabled local municipalities to take ownership of their own goals through decentralization worked best [61]. In Sweden, a bottom-up reorganization was necessary to get buy-in from different stakeholders [25]. Due to the differences between these nations and the United States, the exact nature of Safe Systems implementation domestically is difficult to predict. However, as reported in the introduction, we have seen substantial gains at the city and state level in the United States. Therefore, this path, starting with the North Carolina *Vision Zero* initiative and working with *Vision Zero*-adopting North Carolina municipalities may be the best approach for the State, especially if local and state actions can be buttressed by national initiatives like the National Safety Council's *Road to Zero* campaign [83]. Whatever the exact organizational structure may be, researchers like Salmon and Lenné [21] and Scott-Parker et al. [20] emphasize that vertical integration between stakeholders at all levels of government is key to the success of a Safe Systems program.
3. **Integrated Approach to Education and Enforcement** – Evaluations of the Netherlands' *Sustainable Safety* program highlighted that Safe Systems efforts could have benefitted from a better initial integration of education and enforcement from the program's inception rather than a gradual deployment of these strategies [64]. Education and enforcement themselves may be effective depending on the way they are employed, but a true Safe Systems approach should seek to combine these efforts with engineering and emergency response to truly produce a holistic plan to improve road users' health and safety. One model that that may be considered here in the United States and specifically in North Carolina is an initial public feedback program such as that conducted in New Zealand [47]. For example, North Carolina *Vision Zero* could solicit stakeholders' thoughts on proposed actions to ensure that specific groups are not neglected when any systemic treatments are applied.

These three concerns may present unique challenges in the United States generally and in North Carolina specifically. As Wesley E. Marshall, a traffic safety researcher from the University of Colorado Denver, noted, the U.S. differs from Australia in several ways, not the least of which is simply the prevailing transportation paradigm [54]. Our land use patterns and speed limits distinguish us from the other industrialized nations in this survey, and measures that work in other industrialized nations may not automatically succeed here.

However, the Safe Systems paradigm, as defined and characterized in this report, is both robust and flexible. With proper leadership, an evidence-based approach to evaluation and treatment, and a moral imperative to not just reduce crashes but to promote healthy use of our roadways (by protecting and encouraging vulnerable users), the key strategies outlined here – speed

management, functional classification, intersection design, and enforcement – have the potential to produce significant change on our highways and streets. For this reason, we encourage the United States and the State of North Carolina to adopt Safe Systems—a multidisciplinary approach to safety that meets the needs of the many stakeholders.

North Carolina's long history of integrating education and enforcement efforts into roadway safety programs align with this Safe Systems vision. Both the Graduated Drivers Licensing Program [84] and the Click-It-Or-Ticket campaign [85] were born in North Carolina and demonstrate the State's capability for approaching roadway safety holistically. These programs could easily integrate into newer, more systematic approaches to identifying risk in order to promote the health and wellbeing of all road users throughout the state.

Only by adopting a true Safe Systems approach, one in which all of the system shareholders – engineers, planners, public health agents, emergency respondents, manufacturers, policymakers, and road users – are allowed to have their voices heard in policy, can the true road toll be reduced.

With proper leadership, an evidence-based approach to evaluation and treatment, and a moral imperative to not just reduce crashes but to promote life and healthy use of our roadways (by protecting and encouraging vulnerable users), the key strategies outlined here – speed management, functional classification, intersection design, and enforcement – have the potential to produce significant change on our highways and streets.

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