Moving Beyond the Vision Zero Slogan

Ge Shi
Department of Civil and Environmental Engineering
University of Connecticut, Storrs, Connecticut, 06269
Email: ge.shi@uconn.edu

Vannesa Methoxha
Transportation Engineer
Howard Stein Hudson
Boston, MA, 02108
Email: vmethoxha@hshassoc.com

Dr. Carol Atkinson-Palombo
Department of Geography
University of Connecticut, Storrs, Connecticut, 06269
Email: carol.atkinson-palombo@uconn.edu

Dr. Norman Garrick
Department of Civil and Environmental Engineering
University of Connecticut, Storrs, Connecticut, 06269
Email: norman.garrick@uconn.edu

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ABSTRACT

Safe system is a holistic way of managing traffic safety based on all components within that system including road environments, speed regimes, vehicle safety and post-crash intervention. The ultimate goal is to achieve zero road death and serious injury. Safe system was pioneered in the Netherlands and in Sweden in the 1990s and gradually began to influence traffic safety management in other countries, including the U.S. Our research shows that since the adoption of safe system in the Netherlands and in Sweden, the risk of fatality has decreased at a rate far outpacing that in the U.S. The improvements have been particularly impressive when it comes to pedestrians and bicyclists who now have fatality risks that are as low as that of people in cars. Our paper outlines details of the Dutch and Swedish approach to safe system that is associated with their tremendous success in reducing traffic fatality. The synthesis suggests that to embrace safe system approach, we need a paradigm shift that puts safety and quality of life at the forefront of our thinking about transportation planning, design, and implementation. We argue that there is a need for a broader dissemination, understanding, and adoption of the underlying principles of sustainable safety, and recommend that universities improve engineering and planning education with more sustainable safety thinking. We also argue for greater coordination between federal, state, and municipal agencies, and move away from victim blaming towards the achievable goal of zero road deaths through the adoption of sustainable safety approaches.

Keywords: Road Safety, Walking, Cycling, Vision Zero, Sustainable Safety, Safe System Approach

INTRODUCTION

In the 1990s, Sweden and the Netherlands radically changed national traffic safety policy by independently developing their own systems-based approaches, named Vision Zero and Sustainable Safety respectively (*1*, *2*). In both cases, the results have been overwhelmingly successful. In a previous paper, our research team documented the fact that in the Netherlands, the risk of dying in a traffic crash for a pedestrian is now the same as that for a vehicle occupant (*3*). This was not always the case: thirty years ago, a pedestrian had a risk 52% higher than that of a vehicle occupant. This is just one measure of the success of the sustainable safety approach which challenges the traditional approach to traffic safety that puts much of the onus on the role of human errors in the occurrences of traffic crashes. Instead, Sustainable Safety in the Netherlands, as well as Vision Zero in Sweden, changes the focus by first explicitly recognizing the fallibility of humans and then developing a system that is designed to mitigate these human fallibilities.

The success in Sweden in reducing traffic trauma parallels that in the Netherlands. The difference is that Sweden's Vision Zero concept has been far most successful at capturing the imagination of policymakers all over the world. A report supported by National Cooperative Highway Research Program (NCHRP) from 2016 revealed that in most places in the U.S., policy makers have endorsed the terminology of Vision Zero without actually applying its underlying principles (*4*). But the tide may be turning, as the ideas behind a sustainable approach to traffic safety is beginning to gain traction in the US and elsewhere (*5*). However, detailed information on the principles of safety system is just beginning to be explored in the academic literature.

This paper builds on our research team's previous work in which we assessed the evolution of traffic safety in the Netherlands spotlighting, in particular, on the progress that has been made to safeguard non-motorized road users (*3*). We begin with a literature review of how road safety management has evolved over time. We then provide some context by comparing the evolution in fatality records in the US versus the Netherlands and Sweden, two early adopters of safe system approaches. Finally, we provide a synthesis of safe systems approach as practiced in Sweden and the Netherlands. Our hope is that by articulating the details of the system-based methods, we can illuminate which aspects of this approach might aid policy makers in the U.S. and other countries with high rates of traffic causality to succeed in their quest for vision zero.

LITERATURE REVIEW

The approach for road safety management evolved over several decades. In 2009, Bliss and Breen divided the evolution of road safety management thinking into four chronological stages (*6*): Phase I- Focus on Human Factor; Phase II- The Three E's Approach (Engineering, Education, and Enforcement); Phase III- Institutional Goal Setting; and Phase IV- Safe System Approach in Practice. In this section of the paper, we conduct a review of the state-of-art academic research on road safety management thinking at each stage. We recognize that the four phases are not entirely distinct, but this way of compartmentalizing time serves as a good starting point for organizing this discussion. In addition, avant-garde approaches from academic research get translated into practice at different rates in different places all over the world. Some places are still stuck with older ways of thinking while others have continually pushed the envelope. In the case of systems-based approach to safety management, policies in the most innovative countries have in some ways moved ahead of academic research. Details of this evolution are discussed below.

Phase I: Focus on Human Factor.

Before the 1970s, a focus on human factors prevailed in road safety research. For instance, in 1954, Chapman stated that in order to devise a comprehensive traffic crash strategy, many questions regarding drivers' behaviors needed to be studied (*7*). In 1961, Gibson built a driver behavioral framework and concluded that the misperception of danger, inappropriate reaction, and motivation could be the reasons for "accidents" (sic) (*8*). In 1979, Treat et al. suggested that human factors contribute to 90% of road crashes (*9*). The literature focused on road safety prevention in terms of human factor issues such as the law enforcement and education of drivers. Researchers tried to find screening methods to identify "accident-prone" drivers (*10*). These "who" type studies can be considered as an important step forward as crashes were no longer deemed as just “unlucky” events as they were in the early stage of motorization. However, this “accident-prone” research had some clear flaws. Researchers soon realized that it was difficult to identify so called “accident-prone” drivers because there was no obvious way to measure proneness (*11*).

One of the byproducts of focusing on human factors as the primary cause of traffic crashes is that we ended up with a ‘blame the victim’ approach in attempting to solve the problem, especially when it came to crashes affecting pedestrians and bicyclists. This is a legacy that continues to this day in many contexts in the U.S. and other countries. Today, this is seen, for example, in imbalanced editorial and linguistic patterns that contributes to victim-blaming (*12*). Moreover, ‘blaming the victim’ tends to ignore the fallibility of humans and shifts the focus from other aspects of the system that need to be addressed. A particular pernicious aspect of ‘victim blaming’ is that it exacerbates issues of societal inequality in mobility, such as the over policing of pedestrians and cyclists, especially racial minorities (*13*).

Phase II: The Three E’s Approach (Engineering, Education, and Enforcement).

Between the 1970s and the 1980s, the emphasis in traffic safety management shifted from a primary focus on human errors to a broader range of issues. Researchers started to pay more attention to the safety of vehicles and roads under a framework that became known as the three E’s (Engineering, Education, and Enforcement) approach to traffic safety. In 1968, American epidemiologist William Haddon developed a systematic framework for road safety investment based on a matrix model that encompassed infrastructure, vehicles and users in the pre-crash, in-crash and post-crash stages (*14*). This work expanded our ability to study the complexity of crashes through a more systematic lens.

In 1975, Agent and Deen summarized the number of crashes and severity on each highway type and found that the severity of crashes was related to the types of crashes, the type of highways, and the type of traffic control, as well as to safety belt use (*15*). In 1976, Fell created a driver-vehicle-environment information flow with a cause-and-effect relationship in driving tasks (*16*). Although this was still a human-focused approach, this model contained the prototype for more systemwide interventions. In 1985, Björnstig employed Haddon’s theories to study snowmobile, motorcycle and moose-car “accidents” and provided some pre-crash and post-crash measures with the consideration of energy transfer in a collision (*17*). Vehicle design was another important area in road safety field during this phase. In 1966, William Haddon, who was the administrator of the National Highway Traffic Safety Administration (NHTSA), promoted the setting of the first Federal Motor Vehicles Safety Standards for vehicle production (*18*).

Although the three E’s approach expanded our understanding of the causes it fell short of being a real systems approach since it omitted any consideration of institutional responsibility and the need for a proactive process to safeguard fallible road users.

Phase III: Institutional Goal Setting.

By the early 1990s, leaders in the transportation safety realm had started to focus on the institutional responsibilities for road safety issue by facilitating funding allocation processes and optimizing the organizational coordination between agencies. What is more, they had embedded numerical outcome targets in their longer-term road safety plans and strategies. These quantitative targets not only showed their ambition for road safety improvement but also helped these countries evaluate and monitor intermediate progress towards zero road death. For example, in 1987 the UK set a national target to reduce casualties by one third by 2000 based on the average for 1981-85. Although the overall target was not achieved due to increase in minor injuries, deaths declined by 39% and serious injuries by 49% (*19*).

More evidence-based research came from interdisciplinary approaches. In 1990, Reason created the “Swiss Cheese” model of injury causation showing that the failure of all latent errors and unsafe actions in the system can lead to a crash (*20*). It has had some influence on Safe System thinking as it addressed different roles including planning, design, construction, and maintenance. In 1993, Elvik found that countries with numerical targets succeeded in reducing the accident rate per kilometer of travel more than those that did not (*21*). They further suggested that countries adopting quantifiable road safety targets differed systematically from those that did not.

Phase IV: Safe System Approach in Practice.

Sweden and Netherlands were two early leaders in developing a prototype safe system approach - Vision Zero implemented in 1997 in Sweden, and Sustainable Safety implemented in 1998 in the Netherlands (*1*, *2*). Although their policies differed in operational details, they both stressed the need for institutional responsibility from the myriad institutions involved in funding, planning, building, managing, and regulating a transportation system that catered to human limits and tolerance. The paradigm of safe system as practiced in both countries marked a crucial shift from focusing on the vulnerability of road users as the cause of crashes to understanding how this inherent vulnerability should be taken into account to develop a road environment that reduces the risk of fatality and injury (*22*). The positive outcomes in both countries demonstrate the effectiveness of safe system approach. In Sweden, the number of road deaths was halved and the number of deaths for car occupants decreased by 60% during 2000–2010 (*23*). In the Netherlands, Sustainable Safety Vision has been credited with a 30% decrease in road deaths from 1998 to 2007 (*24*).

Since the inauguration of Vision Zero and Sustainable Safety both systems have been the subject of numerous studies, primarily in Europe. In 2006, Fahlquist found that the distribution of responsibility introduced by Vision Zero could be an efficient tool in reducing traffic fatalities (*25*). In 2007, Rosencrantz et.al analyzed the criticisms regarding the rationality of a zero road death goal by evaluating the precision, evaluability, approachability and motive of Vision Zero Planning (*26*). They stated that Vision Zero is a rational goal that has led to many interventions and subsequent reduction in road death in Sweden. In 2009, Johansson outlined the safety philosophy inherent in present road and street design, and presented the framework for a new design of streets and roads based on principles in Vision Zero (*27*). In 2016, Fleisher et.al created a comprehensive matrix, including specific measures referenced from the safety documents in some American cities, and Sweden, Netherlands, and London (*28*). They used the matrix to determine which measures were widely adopted, partially implemented, or minimally utilized in selected cities/countries.

In 2011, Weijermars and Wegman investigated numerous Dutch traffic safety measures implemented from 1998 through 2007 (*24*). They found that the measures prevented 300 to 400 fatalities with a cost–benefit ratio of 4:1. In 2017, Knaap discussed the possibilities of a positive, success-oriented evaluation approach, taking the ‘Sustainable Road Safety’ program of The Netherlands as an example (*29*). They found that sustainable safety marked a definite change from a reactive, ‘accidents-oriented’ approach to proactive preventative method linked to ‘predictable road-user behavior’. In 2017, Wegman stated that compared with safe system approach, the traditional policies have become less effective and efficient because the inherent unsafe conditions in road traffic remained untouched. They also suggested that Safe System principles are not universal and the transformation from principles need to be fine-tuned based on local context (*30*).

The extensive body of work in Sweden and the Netherlands from academics, policy makers and transportation safety advocates show how the concept of safe systems has evolved over time and provide a rich background for the specific changes that have been made to the transportation design, planning, and provision. The remainder this paper goes into more detail on these issues with the goal of explaining how these changes can be more widely adopted in the U.S.

SYSTEM SAFETY AND PROGRESS TOWARDS

It has been almost 35 years since the safe system policy was implemented in the Netherlands and Sweden. While Vision Zero has not been adopted at the federal level, many U.S. jurisdictions have either embraced the concept in theory or expressed interest in doing so. In this section, we compare road safety performance of the U.S. to Sweden and the Netherlands since the diversion in policy to conceptualize our study.

To make a meaning comparison by transportation mode, we rely on the user-based exposure matrix developed in our previous work (*3*). This metric is used to estimate fatality risk by dividing the number of fatalities by the numbers of road users. The numbers of users by mode were estimated through the method ascribed to Marshall and Garrick (*31*). For example, the number of bicycle riders was estimated by multiplying the total population by the bicycle mode share. Because the differences in the bike share of trips roughly parallel differences in the average distance cycled per person per day, bike share becomes an reliable alternative of measuring cycling levels among countries (*32*). To control for annual variations, we used three-year averages for 1989–1991, 2008–2010, and 2016–2018. For Sweden, we were only able to obtain the mode share for 2005, 2019, and 2020 from the Swedish national travel survey, so this metric is missing for 1989-1991.

The police-registered fatality data are used to represent the adverse events in our evaluation. The population data is collected from Statistics Netherlands, Statistics Sweden, and U.S. Census Bureau. Mode share data are collected from the national travel survey conducted in each country. We made some necessary adjustments to keep consistency in the compiled dataset. For example, we re-classified the categorization of vehicles so that they are consistent across countries.

Figures 1 shows that overall road fatalities per one million population decreased in the U.S., the Netherlands, and Sweden from 1985 to 2010. However, road fatalities in both safe system countries declined much more rapidly than the United States. Even though those two countries started with fatality rates of half the level of the U.S. in 1985, they still managed to reduce the fatality rate per capita by 64% for the Netherlands, and by 78% for Sweden, compared to a 40% decline in the U.S. To further investigate the underlying factors for this disparity, we calculated fatality risk per one million road users for three separate classes of road users: vehicle occupants, pedestrians, and bicyclists **as shown in Figure 2.**

Figure 2(a) shows the risk of fatality for pedestrians based on mode share-based risk measure. The U.S. started with a much higher risk of fatalities for pedestrians than for car occupants in 1989–1991, this gap had since not closed significantly. Based on raw numbers, there was a 51% increase in pedestrian fatalities from 2009 to 2019, signaling a deteriorating environment for pedestrians in the U.S. in recent years.

The pattern for the bicyclists is shown in **Figure 2(b)**. In the U.S., the safety condition for bicyclists has improved overall, perhaps as a result of efforts in many cities to construct biking infrastructure. However, in more recent years biking fatality rates have seen a spike albeit not as large as the one for pedestrian fatalities. The implementation of the safe system approach in the Netherlands coincided with a decrease in fatality rates of 78% for pedestrians and 62% for bicyclists compared to the rate in 1989–1991. For Sweden, we observe a similarly low fatality rates for pedestrians and cyclists in recent years although we do not have the fatality rates for 1989–1991. The fatality rate for pedestrians and bicyclists are now only 14% and 8% of those in the U.S. respectively. It is also startling to note that in both countries, the rates of fatalities for these non-motorized users are significantly lower than that for car occupants in the U.S.

Figure 2(c) shows the risk of fatality for car occupants based on mode share-based risk measure. We notice that although the fatality rates are higher in the U.S., the difference between the U.S. and the other two countries are much smaller than for the non-motorized modes. In addition, the trend in the U.S. shows a very steady decline in the fatality risk for car occupants. However, there are still a growing gap for car occupants between the U.S. and countries with safe systems. The fatality rates in the U.S. were more than 1.5 times that in the Netherlands in 1989–1991. After twenty-five years, the fatality rates in the U.S. are now more than 3 times that in the Netherlands. This indicates that although the U.S. has managed to reduce the fatality risk for car occupants, the rate of decrease is much slower than in the safe systems countries.

Overall, the results suggest that the Sustainable Safety in the Netherlands and Vision Zero in Sweden have coincided with significant road safety improvement. What is more interesting is that the so-called "vulnerable road users" in the Netherlands and in Sweden are now as safe as the protected motorized users in their respective countries and much safer than motorized users in the U.S., as shown in **Figures 3**.

This discrepancy can be explained by safer people, safer roads, safer vehicle, safer speeds, better post-crash care in these better performing countries. For example, there is evidence showing that the popularity of light trucks on US roads is responsible for a large number of pedestrian deaths (*33*). But as of yet, no updated Federal safety standards for passenger vehicles have included pedestrians into vehicle safety ratings. In contrast, European Union has implemented strict regulation concerning pedestrian safety in car design and assessment of the pedestrian protection performance (*34*). Another important difference is the adoption of widespread traffic calming such as 30km/h (18.8 mi/h) zones on local streets in these countries. More than 75% of all local streets in the Netherlands had speed limits of 30 km/h or less in 2017 (*35*). Lower impact speeds have given non-motorized users a higher change of surviving on the road. In the next sections, we discuss the principles of the safe systems that have guided the implementation of some of these initiatives.

[insert Figure 1]

[insert Figure 2 (a), 2 (b), and 2 (c)]

[insert Figure 3]

SUSTAINABLE SAFETY PRINCIPLES AND OTHER KEY COMPONENTS IN SAFE SYSTEMS

In 1998, the Netherlands began to implement Sustainable Safety with some start-up programs (see our previous study for a more detailed description) (*3*). Campaigns and protests by parents in 1970s raised political awareness of the deteriorated situation for pedestrians and bicyclists and created room for planners and engineers to implement designs to protect active road users. This in turn led to innovations in policy and infrastructure, which formed the building blocks of Sustainable Safety. The name "Sustainable Safety", which originated from the concept of sustainable development in the Brundtland report from the United Nations (*36*), stood for inherently safe design in traffic system and land use that can be sustained for future development. The start-up program introduced measures such as the implementation of 30 km/h and 60 km/h speed zones in urban areas and rural areas respectively, better cycling facilities, the construction of roundabouts, and permanent road user education. The first version of Sustainable Safety has been updated twice, in 2003 and 2018, with each update new principles have been added including institutional responsibility and iteratively learning (*36*, *37*).

In 1997, the Swedish Parliament also adopted a safe system strategy called Vision Zero. It unambiguously declared non-tolerance for road causalities by stating that: ‘‘Vision Zero means that eventually no one will be killed or seriously injured within the road transport system" (*27*). The basic principles in Vision Zero include preventability of traffic deaths; focusing on system failure rather than human error; change in thinking from collision reduction to injury prevention; data-driven decisions; shared responsibility between system and design; stimulating the automotive industry to build safer vehicles; and the acknowledgement that "saving lives is cheap and achievable" (*38*).

These two visions of safe systems share similar goals but also have different points of emphasis. In this discussion we follow a framework of five road safety principles developed by the Dutch Sustainable Safety, which is functionality of roads; (bio)mechanics; psychologics; responsibility; and learning and innovating. The first three principles stress design thinking and the last two principle focus on organizational functions. Following this overview of these five elements, additional elements that are more explicitly expressed in the Sweden approach are discussed, including the "zero death goal" and the concept that saving life is cheap.

Principle 1: Functionality of roads.

The basis of this principle is that road sections and intersections should ideally have only one function for all modes of transport, either a traffic flow function or an exchange function. There are three categories of roads in a hierarchical structure according to the definitions from Sustainable Safety. Through-roads are the main roads for vehicular movements. Distributor roads are roads between the residential streets and through-roads which provide access points at the intersections. Access roads are the local roads mainly for exchange function in built-up areas. Each road and street should not have a mixed function of both accessibility and mobility, such as a local street with design features that support higher speed and mobility of vehicles. Sustainable Safety recognizes that there are some drawbacks to this principle. First, this road classification presents a single-functional hierarchical road structure that might impede network connectivity. Second, the functionality of the road is primarily from the perspective of vehicular traffic. Therefore, this principle is more applicable to non-urban settings. In an urban context, so-called "grey-roads" have multiple functions. In this case, the top priority is the safety of unprotected non-motorized road users. A safe speed should be defined by the street design characteristics that are reflected in the second principle (see below).

In the US a hybrid version of street and highways, or "Stroads", are ubiquitous (*39*). Based on the first principle of Sustainable Safety this type of design would be considered inherently unsafe for all, especially for non-motorized road users. This type of design tries to provide accessibility with design features that favor high traffic speed. Fixing "Stroads" would seem to be a priority for addressing traffic safety at numerous locations in the US. This principle of road functionality was not explicitly addressed in the Swedish Vision Zero approach.

Principle 2: (Bio)mechanics.

Principle 2 requires that traffic flows and transport modes are compatible with respect to speed, direction, mass, size and degree of protection. This harmony is enabled by methods of road environment design, vehicle design, and additional protective devices. This principle of Sustainable Safety emphasizes designing in concert with the tolerance of the human body in order to diminish the possibility of a crash and mitigate the severity of the crash if one cannot be prevented. It has been shown that the impact speed of vehicle has a significant impact on the likelihood of fatality for all road user (*40*). More kinetic energy is transferred to the human body upon collision when the impact speed is higher and therefore road users are exposed to a higher risk of severe injuries (*41*).

An interesting illustration from the Swedish Road Administration makes this point by suggesting that unprotected users negotiating spaces with high-speed vehicle is akin to a person walking at the edge of cliff – if a mishap occur, the consequences can be catastrophic. Therefore, one important principle in safe system approach is that the presence of non-motorized users should govern design speed. For instance, in the Netherlands the safe speed should be 15 km/h (9.3 mile/h) where the conflicts are highly likely with vulnerable road users as in local streets. The safe speed should be 30 km/h (18.6 mile/h) where possible conflicts with vulnerable road users on roads or at intersections are probable, including situation with bike lanes. One of the design innovations consistent with this principle is the Dutch "woonerfs" ("living yard" in English) that was introduced in 1976 and has since been promoted nationwide by Sustainable Safety for traffic calming. Woonerfs are shared spaces in residential areas where street narrowing and the adding of landscape in the carriageway and street furniture serve to slow speed to a crawl.

Wherever the criteria for speed, mass, size and road user protection are not satisfied, extra safety measures should be provided. These include physical separation between the motorized and non-motorized users. It is noteworthy that only setting speed limits without changing the actual street designs can be very limited in effectively controlling the speed. With this in mind, street designers in the Netherlands have developed the concept of self-explaining roads that is defined as roads where the design features of the road clearly convey how the road should be used.

In the Swedish Vision Zero approach, this principle is referred to as "Integration and Separation", and states that kinetic energy is managed by integrating compatible traffic elements and by separating incompatible ones (*38*). Therefore, non-motorized road users should not be exposed to motorized vehicles speeds exceeding 30 km/h. If this cannot be satisfied, then separate or reduce the vehicle speed to 30 km/h.

Principle 3: Psychologics.

This principle states that the design of the traffic system should be aligned with the competencies and expectations of all the road users so that the information is perceivable, understandable ("self-explaining"), and credible. The underlying philosophy is that road users' behavior is more dependent on the road system, including the road environment, vehicle, and traffic information, rather than on individual ability and choice. Instead of relying on intense regulation and enforcement, roads system should provide a self-guided, self-explaining environment where the road users are aided and motivated to behave safely. The whole road system should cater to road users' errors by understanding fallibility and the providing a forgiving environment. This principle implies that the most vulnerable road users, e.g. senior bicyclists, are the "design individual". In other words, the street design should be consistent with the needs and behaviors of these most vulnerable road users in order to achieve the maximum safety (*36*).

This approach is in stark contrast to that in the U.S. where design speeds, and hence, design are determined based on the "85th percentile speed" or the speed at which 85% of drivers are expected to travel on a given street type. Allowing vehicle behavior to dictate road design violates this basic principle of Sustainable Safety. Therefore, a target speed approach, that is gaining favor in some parts of the U.S., is more aligned with this principle.

In Vision Zero, this principle is stated as "through designing and constructing roads, vehicles and transport services, the level of violence that can be tolerated by the human being is not exceeded" (*38*). The following story is an illustration of how this is converted into practice. When speed cameras first came to Sweden, they were commonly referred to as "sheet metal cops", as the residents in communities didn't like the grey boxes with a round hole and a black camera lens that seemed to stare at the drivers (*42*). Since 2003, cameras have been redesigned to remind road users to reduce speeds for safety, providing information rather than penalizing people. The design was modified to align with this new function. The holes were removed, and the hoods were painted blue to match traffic information signs. The locations of installation are explicitly shared with citizens through the media. After the transformation, speed decreased significantly (*42*).

Principle 4: Responsibility.

The overarching point behind this principle is the idea of shared responsibility of engineers, planners, enforcement officers, educators, lawmakers and others. Traditionally, road users have been assigned much of the responsibility for road crashes. The safe system approach, on the other hand, focuses more on the shared responsibilities from each role in the whole system. In other words, engineers and planners should plan and design roads that minimize the risk and severity of road crashes; vehicle manufacturers should produce safer vehicles for all road users; and the public health sector should provide better post-crash care and trauma response to avoid road deaths. All these efforts should be coordinated to create a holistic traffic safety system that can cater to different classes of road users. In the Netherlands, the specific responsibilities for road safety are spelled out for each party. For example, the national government is responsible for designing the overall strategies and intermediate and long-term goals for road safety; road safety authorities take operational responsibility for designing and maintaining safe environments for road users; car manufacturers are required to produce vehicles that ensure the safety of people within vehicles as well as for non-motorized users.

In Vision Zero, this principle was stated as "responsibility is shared both by the system designers and the road user" (*38*). We notice that Swedish vision zero also emphasizes the responsibilities of road users in a more systematic way. In other words, it strived to create a safety culture that gives more respect to traffic rules. For example, In Sweden about 50% of all school buses have alcohol interlocks to check if the driver is sober (*27*).

Sustainable Safety also requires a change in understanding the 'responsibility' for traffic safety. In the US, the common narrative still revolves around blaming the victim (especially when the victim is not in a vehicle) or perhaps even worst, not assigning blame at all by referring to the crash as an 'accident'. Under this approach, essential methods include engineering out the "dangerous" drivers, using enforcement to regulate them, and educate them to be converted into "safe" divers. Sustainable Safety forces us to consider that a huge number of agents are involved in determining whether a crash occurs and the ultimate outcome of that crash. By calling out all the potential responsible parties this encourages a rethinking of things like street design policies and puts the onus on various agencies to develop and innovate. For example, in the U.S. we have seen innovation in many municipalities that adopted policy such as 'complete streets' policy or 'target speed' approach to setting design speeds. However, these efforts are often overruled by state agencies that are more focused on moving traffic rather than on safety. A sustainable safety approach at the state level would start to get state agencies to think more systematically about safety by aligning their design and planning with the principles of Sustainable Safety.

Principle 5: Learning and innovating.

This principle stresses the need for road safety professionals and researchers to continually examine the true causes of crashes and improving road safety polices. The process of learning and innovating follows a Plan-Do-Check-Act cycle: a safety measure is planned based on the research on the most severe crashes (Plan); implementation of the policy or measure (Do); evaluation of the safety performance and outcomes (Check); improvement of the policy based on feedback (Act). This process is repeated continuously to reduce the numbers of road causalities.

This principle is also expressed in Sweden approach which states that a data-driven approach should be employed to study the causes of fatal and severe injury crashes. Sweden designated intermediate or long-term national targets that can help track and advance the process each year. The analysis is shared at annual conferences attended by stakeholders (*43*). Another lesson from these countries comes from their setbacks in pursuing a vision of zero road death. The Netherlands has successful reduced traffic fatalities by 65% from 1986 to 2017. However, recent trends show that progress has slowed, and the number of traffic deaths has decreased more sharply among motorists than among cyclists over the past two decades, perhaps because of more e-bike use by older bikers (*44*). This is a reminder that striving for vision zero is a continuous process rather than an end state.

The foundation of Learning and innovating is good quality data, that is used in an effective manner. One way that the Dutch have improved their data assessment is by developing appropriate surrogate safety measures such as the "doctor" (Dutch objective conflict technique for operation and research) (*45*). Using such surrogate safety measure enable the researchers to evaluate the effects of policies, even before the actual crashes happen.

In the US, one fundamental and ongoing issue relates to the lack of available exposure data for pedestrians and bicyclists in most cities and states. Also although the National Automotive Sampling System's General Estimates System (NASS-GES) provides limited sources for non-fatal crashes, there is no complete nationwide database for road injury crashes (*46*). The insufficiency of reliable and robust data source is potentially one of the largest obstacles for professionals to examine appropriate policies and countermeasures (*47*). For example, when road safety practitioners examine the causes of fatal bike crashes and all injury bike crashes, limited data may lead to misunderstandings about the key mechanisms.

Overall, the literature shows that improving road safety can be cost-effective and the vision for zero death is achievable. Vision Zero defines the maximum acceptable number of road deaths and severe injuries as zero as the ultimate goal. There was a long history when traffic crashes were referred to "accidents" with the implication that traffic injuries and deaths were inevitable. Eventually both academics and practitioners started to realize that these injuries and deaths on road were, in fact, preventable. An ambitious goal of zero road death has also been recognized as rational, approachable and motivational (*26*). The concept of eliminating road injuries and deaths has social and economic benefits that are sometimes under-appreciated. Recognition of these benefits is a necessary step that can stimulate places to fully adopt the principles and measures of safe system approach.

Among many inexpensive options in road safety measures, tactical urbanism is one such method. Tactical urbanism also known as Do-It-Yourself (DIY) urbanism, uses low-cost, short-term interventions to catalyze long-term goals and improvements in road safety (*48*). It provides communities with affordable ways to reimage the use of public space and improve the road safety for cyclists and pedestrians in particular.

CONCLUSIONS: OPPORTUNITIES AND CHALLENGES FOR THE US

It has been almost a decade since the first group of jurisdictions in the U.S. officially adopted vision zero policy. Now more than 40 cities have committed to Vision Zero across the country (*49*). However, the U.S. pathway towards safe systems is complicated by this country's long history of automobile dependence where planning has prioritized cars and largely ignored non-motorized users' need for safe facilities, as Handy, Ahangari and other scholars have suggested (*50*, *51*). One encouraging sign is that in November 2020, the USDOT Pedestrian Safety Action Plan addressed needed actions for pedestrian safety under a safe system approach (*52*). In January 2022, the USDOT announced a Department-wide adoption of the Safe System Approach in National Roadway Safety Strategy (*53*).

Many of the interventions resulting from the Sustainable Safety principles are not new to the American context, but they have been implemented sparely or in a piecemeal fashion. The sustainable safety paradigm relies upon thinking about how these various policy, design and institutional considerations work together to create a holistic environment where each element complements and reinforces other elements to lessen the vulnerability of roads users of all types. Achieving vision zero in the US requires a paradigm shift away from current thinking about transportation towards a system where speed is less exalted and safety and placemaking are elevated. This conceptual shift is taking places at municipal level but still needs supports from state actors (*54*).

It must be emphasized that while this paradigm shift is motivated by improving safety, the initiatives also improve overall quality of life by, for example, reducing urban noise and the heat island effect (*55*). The changes resulting from Sustainable Safety create a virtuous cycle that reverberate throughout the transportation system by impacting a host of factors including greenhouse gas emissions. This comes about because, as we have seen in the Netherlands, making it safer to travel by foot or by bike means more people travelling by foot or bike thus reducing the need for vehicle travel (*32*).

Adoption of Sustainable Safety principles in the US would also stimulate a rethinking of how safety is taught in universities. In many instances, the three-E's still holds sway as the approach to traffic safety taught in universities. Engineers are traditionally taught that wider traffic lanes and greater sight distance is "better" even though both lead to greater traffic speeds and ultimately dangerous designs. Concepts such as traffic calming and bicycle design are treated as the exception that is grafted on to the conventional approach. This can have disastrous effects. Putting the Sustainable Safety principles upfront in engineering and planning education would change how we think about what is normative and what is considered to be the exception.

The results reported in this paper suggest that in order to pursue the goal of vision zero, the following should be prioritized:

- A paradigm shift from current thinking about transportation safety towards a systematic thinking of road system and crash factors is needed. This includes but not limited to diming the tendency of victim blaming in the media and improve engineering and planning education with more Sustainable Safety thinking.
- More reliable and consistent data bases must be developed across the country to help with the process of learning and innovating in road safety policy. The insufficiency of reliable and robust data source loams as one of the larger obstacles for professionals to examine appropriate policies and countermeasures (*47*).
- There is a need to promoting the organizational coordination between different disciplines and collaboration among federal, state, and municipal agencies.
- Work is needed to increase the confidence about the goal of zero road death through public communication.

Vision zero is an ambitious concept with a clear goal. No one should routinely run the risk of losing their life on the road going about their everyday business. The Dutch and Swedes have developed a sustainable system which forces us to reconsider our priority and develop specific principles for making progress towards this ambitious goal.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: N. Garrick; data collection: G. Shi, V. Methoxha; analysis and interpretation of results: G. Shi, N. Garrick, C. Atkinson, V. Methoxha; draft manuscript preparation: G. Shi, N. Garrick, C. Atkinson. All authors reviewed the results and approved the final version of the manuscript.

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FIGURE LEGENDS

Figure 1 Trends in Total Fatalities Per-capita Relative to 1985 in the USA Compared to the Netherlands, and Sweden. Data Sources: Statistics Netherlands, Statistics Sweden, and U.S. Census Bureau; SWOV (Institute for Road Safety Research), Transport Analysis; National Highway Traffic Safety Administration.

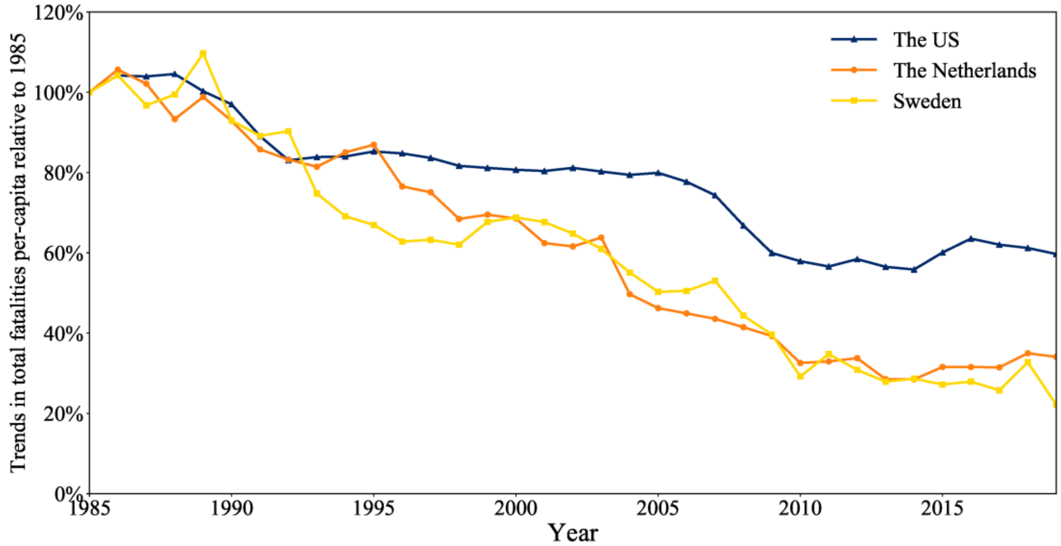

Figure 2 (a) Comparison of Pedestrian Fatalities per Million Road Users, 1990-2019;

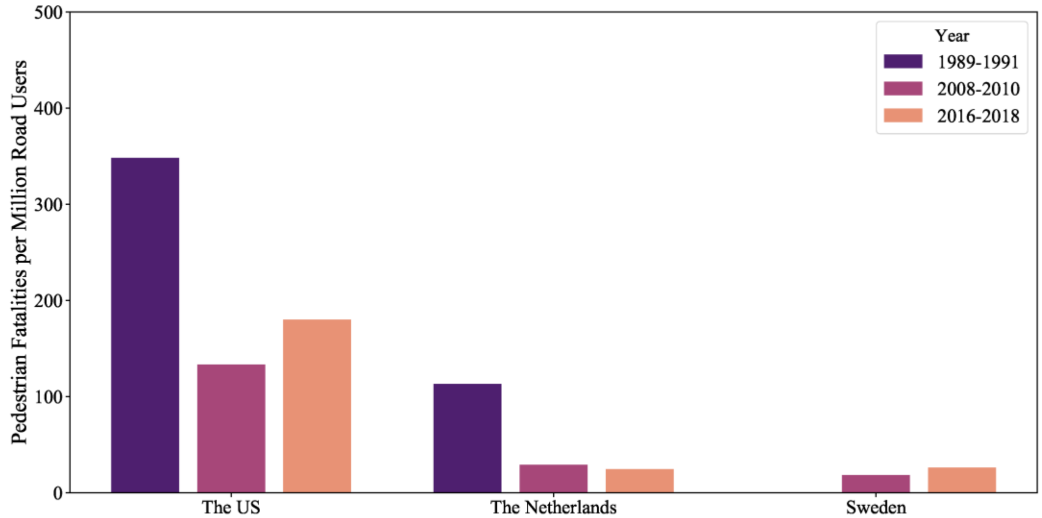

Figure 2 (b) Comparison of Bicyclist Fatalities per Million Road Users, 1990-2019;

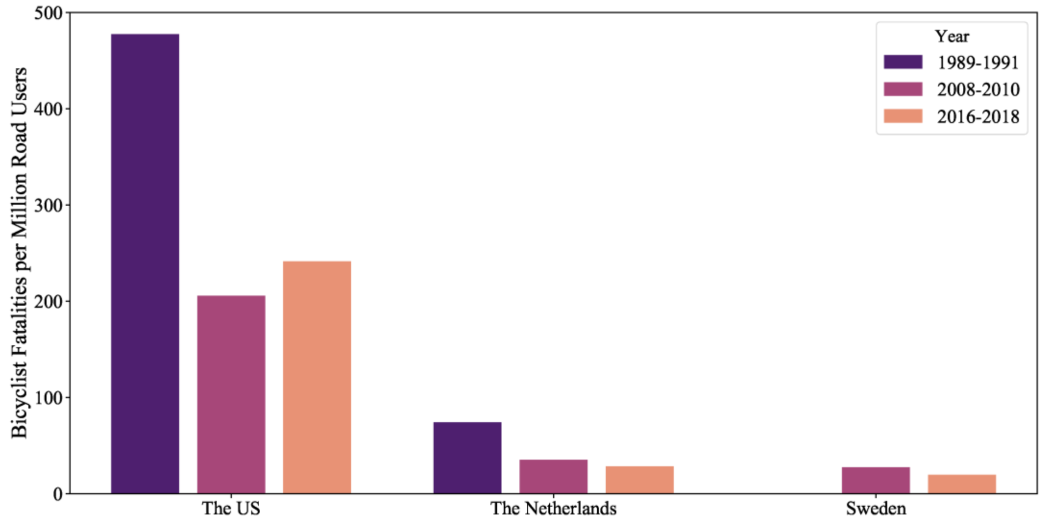

Figure 2 (c) Comparison of Vehicle Occupant Fatalities per Million Road Users, 1990-2019. Data Sources: Swedish national travel survey, the Dutch Travel Survey, and National Household Travel Survey

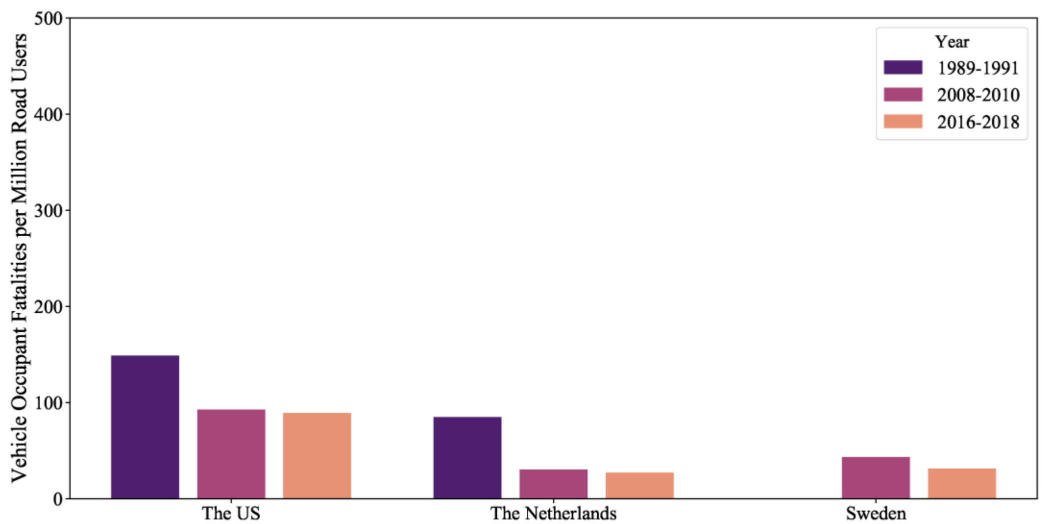

Figure 3 Comparison of Traffic Fatalities per Road Users for Different Types of Road Users in 2019.