Sustainable Safety in the Netherlands

Creating a Road Environment where People on Foot and on Bikes Are as Safe as People in Cars

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ABSTRACT

Road crashes claim over one million lives each year worldwide, overwhelmingly in low- and middle-income countries. A handful of higher income countries have made great progress in reducing traffic fatalities and are moving towards Vision Zero. The goal of this study is to evaluate how one such country, the Netherlands, has cut its traffic fatalities by over 90%. The results show that the Dutch have virtually eliminated the concept of "vulnerable road users" in that the risk of fatality for pedestrians, bicyclists and vehicle occupants have all converged at a low level. This is an amazing achievement especially when compared to countries like the US where the risk of fatality for non-vehicle occupants is 5 to 8 times that of vehicle occupants. In this paper, we assess the evolution of risk for different types of road users in the Netherlands since 1970. We also review critical events, advocacy, policies, and programs that were implemented in the Netherlands over the last five decades to address the issue of traffic safety. This analysis demonstrates that the Dutch used protests and advocacy campaigns to garner supports for policies and programs that promoted non-motorized transportation as routine mobility choice. Furthermore, the governing body for safety in the Netherlands was an early adopter (in the 1990s) of a systems-based approach to traffic safety called Sustainable Safety. A 2020 FHWA webinar highlights the fact that this systems-based approach is now beginning to take hold in the US.

Keywords: Road Safety, Exposure, Bicycle, Pedestrians, Vulnerable Road Users, Vision Zero, Sustainable Safety, Safe System Approach, International Road Safety

INTRODUCTION

According to the World Health Organization, road traffic deaths continue to climb, reaching a high of 1.35 million in 2016. In other words, almost 3700 people are killed by motor vehicles each and every day worldwide (*1*). To reduce the number of deaths happening on roads, the UN has embraced *the Sustainable Development Goal target 3.6* that aims for a 50% reduction in the numbers of global road traffic deaths. Many countries have also set a nationwide goal of zero road deaths by 2050 (*2*). In recent decades, a handful of developed countries have drastically reduced traffic fatalities, lending credence to the UN's goal. Although these countries have not quite attained their stated goal of zero fatalities their progress is noteworthy and could potentially serve as a template for other countries that are seeking to achieve similar outcomes.

The countries that lead the world in road safety are predominately clustered in northern and central Europe. This paper takes a closer look at the changes in traffic fatality in the Netherlands, one of the countries with the lowest level of traffic fatality with a rate of 3.39 per 100,000 persons in 2019. To put this rate into context, the US achieved a record low in its traffic fatality rate with 10.29 per 100,000 persons in 2014, 3 times more than that in the Netherlands. This discrepancy is striking when one considers that back around 1970 both countries had almost identical rates of traffic fatality per 100,000 persons and the US also had a much lower rate of fatality when measured in terms of fatalities per miles driven (*3*). In other words, in 1970 on the basis of miles driven the U.S. was much safer than the Netherlands. Today the opposite is true – the Netherlands is not only doing better on a per capita basis (which is partially a function of less dependency on vehicle travel) but is also significantly better based on fatality per miles.

How and why did these safety trajectories diverge? In this paper, we explore this question by analyzing the changes in traffic fatality experiences in the two countries over the last 45 years or so. We evaluate trends in traffic fatalities rates as a whole, and for three different classes of road users: pedestrians, bicyclists and vehicle occupants (*4*). We examine the extent to which the differences between the Netherlands and the U.S. is a function of differences in exposure or whether there is evidence of differences in objective safety. Finally, we outline key policy and design steps that have been taken in the Netherlands that correspond to the dramatic improvements.

LITERATURE REVIEW

A growing number of studies have compared road safety performance between countries. As this becomes more comprehensive, we are developing more accurate ways of assessing of an individual country's progress to extract lessons learned. In this section, we review the evolution in the approaches used to carry out the international comparison in road safety, summarize the results from this line of research, and discuss the implications of these results.

The first research on comparative international road safety was conducted by Smeed in 1949 (*5*). In this study, Smeed compared 20 developed countries and found a negative relationship between vehicle ownership (represented by registered vehicles per population) and road safety (represented by fatalities per vehicle). Smeed's statistical model was validated, further developed and utilized in a large number of studies since 1949 see (*6*–*9*) for examples. However, as these studies emphasize the relationship between the level of motorization and traffic fatality rate in modeling traffic safety, they are less useful for understanding situations in which there is substantial non-motorized travel.

Since 2000, research has moved beyond modelling fatality as a function primarily of motorization level. Methods such as factor analysis have been used to quantify the effect of multiple factors on the road fatality levels. Using this approach, in their study of 88 countries in 2005, Kopits and Cropper (*10*) found that traffic fatality risk starts to decline when income approaches the equivalent of $8,600 (1985 international prices). In a 2006 study of 23 Organisation for Economic Co-operation and Development (OECD) countries, Gerdtham and Ruhm found that traffic deaths were positively related to unemployment rates (*11*). One study in 2001 by Bester et.al. of 179 countries looked more broadly at multivariate factors, including infrastructure and socio-economic factors (*12*).

As more factors were found to explain road fatality rates and those factors were often correlated with one other, attempts have been made to develop comprehensive frameworks to better understand how various factors interact to influence road safety. One of the first frameworks from the World Health Organization in 2010, presented a comprehensive methodology for a global assessment of road safety (*13*). This conceptual framework emphasized institutional settings and policies, national legislation, vehicle and infrastructure standards, pre-hospital care, and alternative transportation. Building on this model, in 2014 Ahangari et.al developed a comprehensive framework for conducting international empirical studies of road safety (*14*). This conceptual framework is useful for the selection of variables in the empirical modeling of traffic fatalities for the purpose of cross country or cross state comparison. This approach has been used to model the impact of fluctuations in gasoline prices on road safety (*14*), and safety improvement for different age cohorts (*15*) in an international road safety comparison. Another example of comprehensive framework is Safe Road Transport System model, first developed by the Swedish Transport Agency and now adopted by the OECD (*16*). Marshall applied this model to qualitatively analyze some decisive factors leading to better road safety outcomes of Australia compared to the US (*17*). The results showed that Australia did a better job in decreasing mileage and encouraging alternative transportation modes by moving to a systems safety approach much earlier than the US.

Another important area of emerging research is a more detailed assessment of fatality rate trends by using the concepts of exposure and risk. Understanding which exposure is appropriate for a given situation is important in order to generate insightful comparisons between different types of users or between different states or countries. For example, Shen et.al illustrated this point by using three exposure measures—population, distance travelled, and the number of passenger cars—as inputs to assess national targets for fatality levels (*18*). In 2013, Nghiem et.al examined the trends of fatalities per population among 23 OECD countries and suggested that there was no evidence of a convergence of road fatality rates among these countries (*19*). In 2014, Evans compared the fatality rate trends in the U.S. with those in 25 other countries from 1970 to 2010 and found that all 25 countries were outpacing the US in terms of road safety improvements (*3*). In 2015 Brüde and Elvik demonstrated, by examining the fatality rate trends in 6 countries, that the turning point of traffic fatalities in 1970 resulted from the large decline rate of fatality per travel distances (*20*). In 2016, Oguchi compared the annual trends of fatality per population and fatality per vehicle in Japan with those of other developed countries. The results showed that over time Japan transitioned to becoming one of the world's safest countries (*21*). The author identified possible reasons by summarizing changes in the road traffic environment, law enforcement, education and advanced vehicle technologies. In 2020, Buehler and Pucher examined the growing difference in pedestrian and cyclist fatality rates between the US and the UK, Germany, Denmark, and the Netherlands, using population exposure and distance exposure. They identified some factors that might explain the huge and growing gap between the US and the better performing countries in Europe (*22*). These more recent studies show the importance of combining qualitative along with the more traditional, quantitative analyses if we are to make progress in understanding the factors that shape traffic safety improvements.

Most of the studies above have focused on overall fatality rates. Few studies have looked at the disparities in road safety between non-motorized and motorized road users at the scale of an international comparison due to the limited availability of exposure data. Given the growing significance of bike and pedestrian travel worldwide there is a crucial need for a better understanding of the disparate safety experience between non-motorized and motorized road users.

DATA

In this study, we relied on multiple sources of data to conduct a time-series comparison of the rate of traffic fatalities in the US and the Netherlands. The study was based on two main categories of data—traffic fatalities, and a variety of exposure data. The exposure data we looked at included population, travelled distance, the number of registered vehicles and mode share. We used police registered fatalities (*23*, *24*) to represent the adverse events in our risk evaluation. The number of total road fatalities and the number of fatalities for pedestrians, bicyclists, and car occupants are reliably available from 1950 to 2019 in the Netherlands based on the SWOV database (*23*). The number of fatalities by mode of travel in the US are available in 1965 and 1970, and on an annual basis from 1975 to 2019 (*24*, *25*). There are a number of inconsistences in the data between each country. For example, the categorization of vehicles for fatality data differ in the US and the Netherlands. This required us to re-classify the data to get a closer comparison between the two countries.

Within each country, we found several instances where the data collection methodology had evolved over time. For example, the mode share data in the Netherlands are available annually from the Dutch Travel Survey starting in 1978. In 2010, the methodology for collecting the data changed from a paper-based survey to a mixed-mode approach to obtain a more detailed understanding of travel behavior in the Netherlands. The data suggest that there is little or no discrepancy in the numbers before and after the change in methodology. Mode share data for the U.S. were from the decennial U.S. Census for 1970, 1980, 1990 and 2000 and from the American Community Survey (ACS) annually for 2003- 2019 (*26*). Straight line interpolation was used in those instances where annual data were not available. ACS data have been adjusted by removing the "working at home" category from the calculation to ensure consistency with the data for the Netherlands. It is also worth noting that the census data tends to underestimate the mode share of non-motorized modes, especially for walking, because it is restricted to commuting trips and it only counts the mode with the longest distance for each trip (*27*). However, at the national level, our analysis suggests that the census data provides a more consistent basis for comparing the trends of mode share over time. Total population in each year was from the US Census Bureau (Population Division) and from Statistics Netherlands (CBS) (*28*, *29*).

RESEARCH METHOD

In comparative research on international road safety, different exposure measures or estimation of exposures can be chosen according to the availability and purpose of the study (*30*). This section covers literature on the applications of exposure measures and the selection of appropriate exposure.

Hakkert and Baimaister defined the risk in road safety as the road safety outcomes (numerator) relative to the amount of exposure (denominator) (*31*). Different exposure measures can emphasize various aspects of road safety, and thus, tell a different story. For our study, choosing the appropriate risk metrics is a crucial component of the work. A growing body of research has addressed the question of which are the appropriate exposure measures for evaluating road safety in different contexts (*30*, *32*, *33*). Typically, distance-based exposures, such as vehicle miles traveled (VMT), have been used widely in the road safety domain partly because it is easily accessible. This risk measure is useful in many contexts, for example, when comparing streets or highways of the same type. However, when the goal is to compare streets of different speed profiles or to assess safety across modes or to compare the overall impact traffic fatalities on countries or states, a distance-based exposure measure is generally inappropriate. Compelling evidence suggests that distance-based exposures are confounded with speed, generating invalid results (*34*). Craig demonstrated that distance-based risk is confounded by the inclusion of speed in the calculation of risk, and is thus not suitable for use in situations where speeds vary significantly between the units being compared.

For international comparisons, population-based exposure is typically used in recognition of the fact that road fatalities should be treated as a public health issue akin to other epidemiological considerations (*4*). However, population-based exposure does not adequately address the challenges of comparing the risk between different modes. For this purpose, time-based exposures are commonly used in studies of non-motorized modes (*35*). Keall, for example, used two exposure measures— "time spent walking" and "numbers of roads crossed"—to estimate pedestrian risk. They found an elevated crash risk for the elderly by comparing the two measures of risk discussed above with crashes per population (*36*). Chu similarly proposes a time-based comparative approach to evaluate the fatality rate for pedestrians at the national scale in the US. (*37*).

Despite the benefits of using a time-based approach, data by mode are not readily available at the national scale. However, another potential metric to compare different modes is user-based exposure. This approach was used by Marshall and Garrick to evaluate bike safety in 24 California cities. The number of bicycle riders was estimated by multiplying the total population by the bicycle mode share (*38*).

Ideally in our study we would have liked to have used a time-based risk measure to compare the different modes of travel. However, we could not find the required data for the full time period for both countries. We were able to estimate number of users by mode using the method ascribed to Marshall and

Garrick. Our calculations show that both measures of risk track closely with each other for each class of users over the period of data we have (*39*). Based on this assessment we adopted the user-based exposure risk to compare the fatality risk of different type of road users in each country (shown in **Equation 1**).

$$user - based\ risk = \frac{fatalities}{estimated\ number\ of\ road\ users} = \frac{fatalities}{mode\ share * population} \quad (1)$$

RESULTS

Taking the long-term view, **Figure 1** shows that that fatality rates in both the Netherlands and the US peaked around 1970, with a fatality rate of 250 per one million population. The rapid growth in fatalities between 1950 and 1970 in the Netherlands was most likely a function of increasing car travel and car ownership and decreasing rates of cycling. This thesis is supported by the fact that Vehicle Kilometers Travelled increased seven-fold from 6,332 million kilometers (3,930 million miles) to 45,041 million kilometers (28,000 million miles) between 1950 and 1970. After the peak in the 1970s, both the US and the Netherlands experienced decreases in fatalities per capita. However, the average rate of decrease in the US was significantly lower than that in the Netherlands which accounts for the diverging trendlines. Another pattern observed in Figure 1 is that the US has experienced much more dramatic cyclical fluctuation in its fatality trend line. Hamed et. al. demonstrated that these cyclical fluctuations correspond almost exactly to fluctuations in macroeconomic conditions and gasoline prices (13). These patterns also hold for the Netherlands but with a much smaller amplitude of the cycle waves suggesting that fatality rates in the Netherlands are less sensitive to the vagaries of automobile usage patterns.

[insert Figure 1]

We calculated fatality risk per user for three separate classes of road users: vehicle occupants, pedestrians, and bicyclists. **Figure 2** shows that in 1970, both countries had a significant gap in fatality between modes, by 2019 the gap in the Netherlands had disappeared but it persisted in the US. Based on our estimate, the fatality rate for pedestrians in the US is more than 8 times that for car occupants. This gap overwhelms any error introduced by using the census data, which, as we discussed earlier underestimates walking mode share. It is generally believed that the walking mode share is 2 or 3 times more than that reflected in the census data.

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

To better illustrate these patterns, **Figure 3** shows the time series for the two countries for each mode separately. The first of these three graphs, **Figure 3a** shows the risk of fatality for vehicle occupants for the Netherlands versus that in the US. Both countries started with similar levels of fatality risk for vehicle occupants in 1970 with the Netherland at a slight advantage, 198 versus 243 fatalities per million road users. Over the years, both countries have experienced improvements but with the Netherlands outpacing the U.S. By 2019, the risk of fatality in the Netherlands fell to 33 per one million population compared to 80 in the US. Hamed et. al. have given evidence which suggests that much of these gains were associated with improvements in medical care, emergency response, and vehicle safety technology (*40*). In a further analysis, Hamed et.al. have also shown that suburbanization and street design likely played a role in retarding progress in the US. (*41*).

Figure 3b shows the risk of fatality for pedestrians based on mode share-based risk measure. In this case, the Netherlands started with at a more sizable advantage which has only increased over the years. In 1970, the risk of fatalities for pedestrians was 434 per one million pedestrians compared to 590 in the US. By 2019, the advantage for pedestrians had widened in the Netherlands with the risk being 22 per million pedestrians compared to 686 per million in the U.S. What is most striking is that there has been no improvement in the fatality risk to pedestrians in the U.S. over the last five decades. In fact, the number has actually gotten worse driven by a spike in pedestrian fatality rates since 2009. In raw numbers, in 2009 there were 4,109 pedestrian deaths and by 2019 this had risen to 6,205 with no corresponding increase in pedestrian mode share (*42*). Several hypotheses have been offered to explain the recent spike in pedestrian fatalities including distracted walking and driving and more dangerous vehicles (*43*).

Figure 3c shows the risk for bicyclists in the two countries. As with pedestrians, bicyclists are at significantly greater risk when traveling in the US than in the Netherlands in terms of fatalities per users. In 1970, the risk to bicyclists in the Netherlands was lower than those of both vehicle occupants and pedestrians and also significantly lower than that in the US. In that year, the risk for bicyclists was 148 per million users in the Netherland compared to 741 in the US. However, safety has steadily improved in the Netherlands since 1970. In the US, safety started to improve in the early 1990s corresponding to the first wave of biking infrastructure construction in cities like Portland and Cambridge (*44*). This trend continued until 2008 when fatality rates started to increase. This uptick started around the same time that pedestrian safety deteriorated and followed a similar pattern. However, the decline in bicyclist safety in the US was much more moderate than that experienced by pedestrians that occurred over the period starting in the late 2000s. By 2019 the risk for bicyclists in the Netherland had fallen to 33 per million users compared to 486 in the US. Notably, although the risk for bicyclists in the US in 2019 was still significantly higher than that in the Netherlands, this is the place where the US has managed to make marginal progress to protect a class of non-motorized road users. As mentioned earlier, this performance might be related to the nascent bicycling renaissance in the US which started in the 1990s and resulted in more bicycle infrastructure, more funds for bicycle projects, and more bicycle riders in cities across the country (*45*). This observation is consistent with the findings by a number of researchers that more biking facilities has a quantifiable impact on safety (*38*, *46*).

[insert Figure 3 (a), 3 (b) and 3 (c)]

DISCUSSION OF RESULTS

This comparison of the relative safety of vehicle occupants, pedestrians and bicyclists in the two countries suggests that the widening disparity in overall fatality rates between the Netherlands and the US resulted from an improvement in the risk profile of all three categories of users in the Netherlands that significantly outpaced the US. **Figure 2** presents a striking picture and truly a tale of two countries. On the one hand, in the US, we have a situation where the risk of fatality for vehicle occupants has steadily decreased over the last five decades, the risk for people on bicycles has decreased since the 1990s, and the risk for pedestrians has actually gotten worse. Nevertheless, despite fluctuations over the decades, two distinct class of road users remain: those in vehicles and those outside of them. The risk of fatality for non-vehicle occupants are still orders of magnitude greater than that for vehicle occupants. Non-vehicle occupants remain vulnerable road users. Conversely, in the Netherlands, we see that risk for bicycle riders started out as the lowest of the three groups of road users while pedestrians were the highest. Over time this risk has converged and now all these groups of road users have almost identical risk of fatalities.

In the 1960s, the British planner Stephen Plowden said that pedestrians and bicyclists were "vulnerable road users who takes to the street without armor" (*47*). When we look at the numbers in **Figure 2**, this description by Plowden still fits pedestrians and bicyclists in the US given their fatality risk profiles but it doubtful that this moniker can still be applied to pedestrians and bicyclists in the Netherlands. In fact, based on the numbers in **Figure 2** we would postulate that the Dutch have eliminated the concept of "vulnerable road users" by decreasing fatality rates for all categories of road users. Further the convergence of fatality rates indicates that people do not need armor to survive on the street (*39*). The Dutch have created a road environment where people on foot or on bike are as safe as people in cars. In the next section of this paper we will look at steps that the Dutch have adopted in an attempt to change the culture of safety on their streets. The above assessment largely focuses on the difference between the Netherlands and the US, but what is just as noteworthy are the changes that have occurred in the Netherlands over time. Focusing on the comparison between Netherlands and the US runs the risk of only attributing the current differences between the two countries to factors such as the density of urban area, and the transit system. However, shifting the focus to the temporal comparison tells a different story and places the attention on those factors that have changed in the two countries over the last 50 years. Factors such as terrain and climate have barely changed. In contrast, the pattern of urbanization has changed significantly in the US, while the Netherlands, able to control the city edges through the compact city policy, experienced less dramatic changes (*48*). That said, the most significant changes affecting road safety have been policy-related, specifically the systemic approach to road safety that has informed changes in street design in the Netherlands. This will be discussed in more details in the next section.

THE NETHERLANDS APPROACH TO SAFETY

In this section, we focus on the historical events, advocacy, policies, and programs that were carried out in the Netherlands over the last several decades to address the issue of traffic safety, and particularly, the safety of pedestrians and cyclists.

Pre- 1970s: increase in motorization level

After WWII there was a substantial increase in the distance travelled by cars in both the US and the Netherlands. In the US, more people were moving to increasingly far-flung suburbs far away from jobs. This resulted in longer commuting distances and greater automobile dependency. Other more traditional forms of commuting, including walking, biking and transit were increasingly being neglected—or, in some cases intentionally undermined/dismantled—in national policies (*39*). In the Netherlands, a similar but less muted pattern was playing out as residential areas expanded outwards. The decline of population density made bicycling less viable than automobile travel (*49*). But even in still dense cities, such as Amsterdam and Utrecht, biking was being displaced to make room for the increasing numbers of automobiles (*50*). Between 1945 and 1970, rapid motorization in the Netherlands led to relatively high automobile ownership rates, albeit only about half of car ownership per capita of that in the US (*51*). This unprecedented increase in motorization was accompanied by an equally rapid increase in traffic related fatalities (*23*).

1970s: Economic Turmoil and Protests

Traffic fatalities for both countries peaked in the early 1970s around the time the 1973 Oil Embargo had a short-term global impact on people's perception of automobile use (*39*). Facing reduced oil supplies, both countries implemented measures to reduce gas consumption. The US lowered the highway speed limit to 55mph, and rationed gas (*52*). The Netherlands introduced "Car-Free Sundays" that temporarily closed some streets to cars to deter gasoline use (*53*). The accompanying increases in gas prices helped to reduce traffic fatalities because, in addition to travelling less, people also drove more carefully (*14*). This crisis also provided a window to enact policies to promote cycling and other forms of greener mobility (*54*). Historical analysis suggests that in the Netherlands, advocates were able to parlay the crisis into deep and long-lasting reforms to transportation policy, in contrast to the US where changes were less drastic and less durable (*55*).

One of the most influential and memorable safety slogans in the Netherlands was "Stop de Kindermoord" (or "Stop the child murder"). This was the cry of children and parents fighting for the right to play on and in safe streets with minimal disturbance from automobiles. Protests such as these played an essential part in changing the views of politicians and enabled them to give transportation planners and engineers more room to innovate (*56*). This led to development of more infrastructure built during that period that prioritized people over vehicles. One early example of this change was the concept of traffic calming that was first promoted by citizen activists in the Netherlands in the 1960s and quickly permeated government policy (*57*).

In the US, there were also some environmental protests in the 1970s sought to regain street space for bicyclists and pedestrians. In February 1970, students from San Jose State College buried a newly bought Ford Maverick on campus in a 12-foot-deep hole (*58*). It was one of the protests that led to the inaugural Earth Day in 1970. During this time, bike sales boomed for a short period fueled by the trend of pursuing health and advances in bicycle design. However, faced with a lack of infrastructure to support biking, the boom soon fizzled. Unlike those in the Netherlands, protests in the US were unable to garner sufficient traction to result in meaningful policy reform to support active transportation (*56*).

1970s – 1990s: A Turn in Policy and Infrastructure

Before 1970, there were no formal policies directed at treating cycling and walking as forms of transportation in the Netherlands. The protests increased awareness of the disadvantaged status of active transportation, not just in terms of space but how it was treated in law, policy and design. This began to change with the national government implementing large-scale demonstration projects which would eventually inform policy making nationwide (*59*). During this period, two important initiatives were traffic calming and cycle network planning. To implement traffic calming or woonerf ("living yard" in English) design, the government started with demonstration projects in two cities in 1976. The research around these projects looked at traffic volumes, speed, and crash data, and concluded that adding slow zones within an area improved overall road safety. As a result of these projects, traffic calming spread to other locations in the Netherlands (*57*). In the same year, demonstration bicycle routes were implemented in The Hague and Tilburg and eventually in Delft to create a comprehensive bike network in that region of the country (*60*). Overall, these national government funded demonstration projects successfully simulated more innovative projects at the municipal level. These efforts were credited with helping the Netherlands to improve road safety nationwide (*55*).

In the US, prior to the 1990s, limited effort was directed towards improving road safety for bicyclists and pedestrians at the national level. This started to change in the early 1990s with the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), a true turning point in American transportation history. ISTEA made funding more flexible so that it could be used for a broad range of projects including bicycle and pedestrian facilities. The Congestion Mitigation and Air Quality Improvement Program of ISTEA also supported bicycle and pedestrian travel to improve air quality (*61*). During this period, fatality rates for bicyclists started to improve as shown in **Figure 3c**.

1990s – Present: Sustainable Safety

In the early 1990s, the Netherlands developed its so called "Sustainable Safety Vision" intended to create a traffic environment that can diminish the possibility of a crash and mitigate the severity of crash if a crash does occur. This approach is human-centric and is based on the following three considerations: (a) people are vulnerable; (b) people can be reckless and make mistakes; and (c) people do not always follow rules. The guiding philosophy was that the whole traffic safety system, including the road environment, vehicle technology, education, enforcement, should provide a reliable environment that caters to human behavior and shortcomings. It should have mechanisms to monitor if all road users behave safely and if traffic professionals adequately fulfill their roles. If tragedies do happen, trauma care should ensure fast and effective assistance (*62*). Sustainable Safety Vision marked a critical shift from a reactive safety approach to a more pro-active systems approach. It recognizes the vulnerability, fallibility, and unpredictability of all road users including active road users. Sustainable Safety Vision has been updated twice, in 2003 and 2018, and is now in its third iteration. The principles of Sustainable Safety Vision are as follows (the first three are design principles, the last two are organizational principles) (*62*):

1. Functionality of roads: a traffic flow function or an exchange function.
2. (Bio)mechanics: limiting differences in speed, direction, mass and size and protection of the road user.
3. Psychologics: aligning the traffic environment with road user competencies.
4. Responsibility: responsibilities are laid down unequivocally and are in line with the tasks of the parties involved.
5. Learning and innovating: traffic professionals continuously examine the causes of crashes and develop effective and preventive system innovations based on this research.

One of the applications of the Sustainable Safety Vision is shared space which slows the traffic by maximizing the interactions between road users. This measure makes motorized users aware of the existence of other road users through intensive interactions. It follows the Responsibility principles in that it is meant to heighten the social responsibilities of car drivers. Another important application is speed management. Considering the vulnerability of road users and kinetic energy transferred with high-speed collisions, speeds should be adapted to the most vulnerable transport modes in most urban streets. For higher speed roadways, it is recommended that a separated infrastructure is created for cyclists to remove potential conflict points with vehicular traffic (*39*).

The positive outcomes of Sustainable Safety Vision are enormous. It has been credited with a 30% decrease in road deaths from 1998 to 2007 compared to the number of road deaths that would have been expected if these measures not been taken (*63*). It is mostly likely a major factor contributing to the fact that non-motorized road users in the Netherlands have a risk of traffic fatality that is almost identical to motorized road users. The plan for Sustainable Safety Vision were credited with helping the Netherlands to achieve nationwide road fatality reduction goals (25% reduction by 2000 over 1985 levels, and 50% reduction by 2020 over 1986 levels) (55). Both goals were easily surpassed according to SWOV database- a reduction of 25% from 1985 to 2000 and 65% from 1986 to 2017 as shown in **Figure 1**.

CONCLUSIONS

Our results show that as a country with an almost identical rate of traffic fatality per 100,000 persons with the United States in 1970, the Netherlands has made significant progress in road safety. Fatality per users for all categories of road users have decreased significantly in the Netherlands. In 1970 fatality rate for pedestrians was relatively higher than other types of road users. Today all categories of road users in the Netherlands have similar level of fatalities per user. The Dutch have created a road environment where people on foot and on bike are as safe as people in cars. This progress can be partly attributed to 1970s' campaigns and protests that generated political and popular supports in favor of active modes of transportation in policy and infrastructure provision. The progress in the Netherlands resulted as much from infrastructure, policies and culture, as they did from a systems approach to safety.

Prior to the 1990s, before developing their Sustainable Safety Vision, the Netherlands approached traffic safety by treating high risk (or black spot) locations. Focusing on high risk locations is fundamentally a reactive approach (*64*). It was effective in the 1970s and 80s when there were a large number of crashes nationwide that showed up as clusters at select locations. As the crash numbers decreased, the Netherlands eventually realized that this approach would not contribute to making significant progress in road safety because high-risk locations were diminishing and becoming harder to identify. A new approach was needed and the Dutch turned to a systems approach Sustainable Safety Vision. With this new approach, they have continued to improve at a level that far outpaces most other countries. Today, the prevailing method of addressing road safety in the US remains reactive (*65*). This passive approach often credits crashes to human errors rather than the overall system itself. And in particular it overlooks the fact that humans are fallible, a fact that engineers need to accommodate in their design process.

The implications of our study are two-fold. First, the Netherlands' progress in road safety is largely based on improving conditions for non-motorized road users. This result implies that struggling countries should put more efforts into promoting the safety of non-vehicular road users. Second, addressing road safety needs to be a continuously evolving process that considers the road users, vehicles, road infrastructure, culture and society as an integrated system. To illustrate this point, some statistics show that progress in reducing bicyclists' fatalities in the Netherlands has slowed down over the last two decades (*66*). This is perhaps a function of conflicts relating to what types of vehicle should be allowed on biking infrastructure that has still not been resolved (*67*). This is a reminder that although the Netherlands is a good model for countries with less well-developed safety cultures, striving for vision zero is a continuous process rather than an end goal.

For the US, the path toward vison zero could be more challenging, because of much higher dependence on cars and more sprawls in suburb. People might even think that adopting the Sustainable Safety approach or more generally, systems-based approach, is not achievable in the US. However, looking at the case of Australia, a country with a similar level of car dependency and land use patterns, can provide some useful insights on this issue. As an early adopter of Safe System approach in the 2000s, Australia has decreased its fatality rate to 53 fatalities per one million population, less than half that in the US. To achieve such progress in the US, some critical steps include reinforcing the idea of shared responsibilities among all road users, vehicles, and the environments and enhancing the collaborations between jurisdictions in adopting systems-based approach. Furthermore, continued research focusing on the understanding of principles inherent in the safe system approach and the implementation of pertinent measures from these principles will be beneficial for a smooth transformation in the US.

This is already beginning to occur as transportation professionals are increasingly realizing the importance of embracing a system approach to road safety in the US (*68*). In July 2020, the US DOT hosted a "Pedestrian Safety Summit" which was designed to promote an open dialogue between diverse stakeholders to improve pedestrian safety. In the July 8th and 15th sessions, people from FHWA, ITE, NACTO, America Walks, Pedestrian and Bicycle Information Center stressed the importance of a systems-based approach to pedestrian safety (*69*) signaling an important shift to more systemic thinking about road safety. This paper is presented in the hope of furthering this nascent dialogue in the US and other places around the world.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: N. Garrick; data collection: V. Methoxha; analysis and interpretation of results: G. Shi, N. Garrick, C. Atkinson, V. Methoxha; draft manuscript preparation: G. Shi, N. Garrick, C. Atkinson, V. Methoxha. All authors reviewed the results and approved the final version of the manuscript.
The authors do not have any conflicts of interest to declare.

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FIGURE LEGENDS

Figure 1 Road fatalities per one million population in the U.S. and the Netherlands

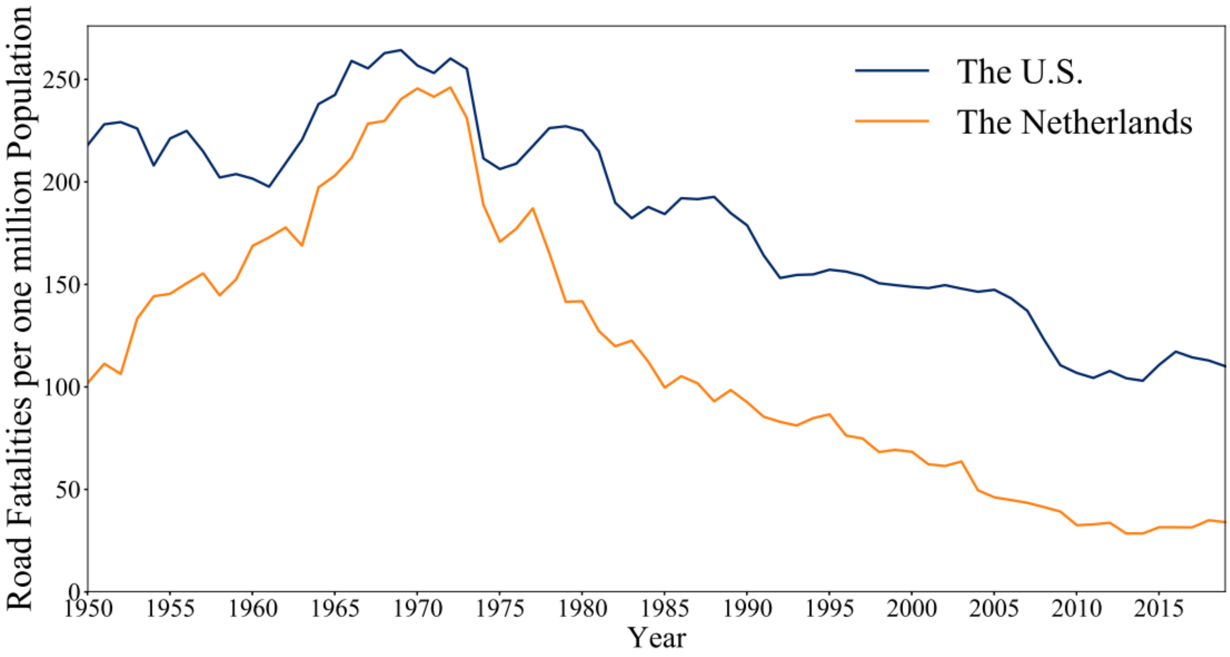

Figure 2 (a) Road fatalities per one million users by mode in the U.S.

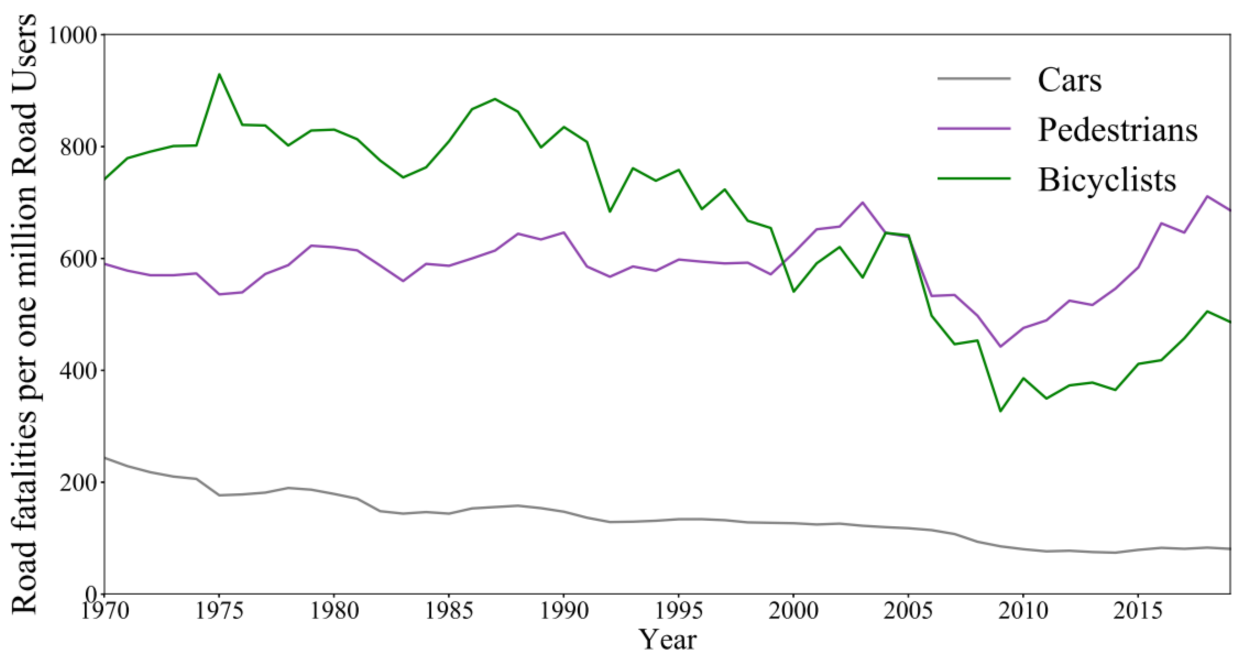

Figure 2 (b) Road fatalities per one million users by mode in the Netherlands

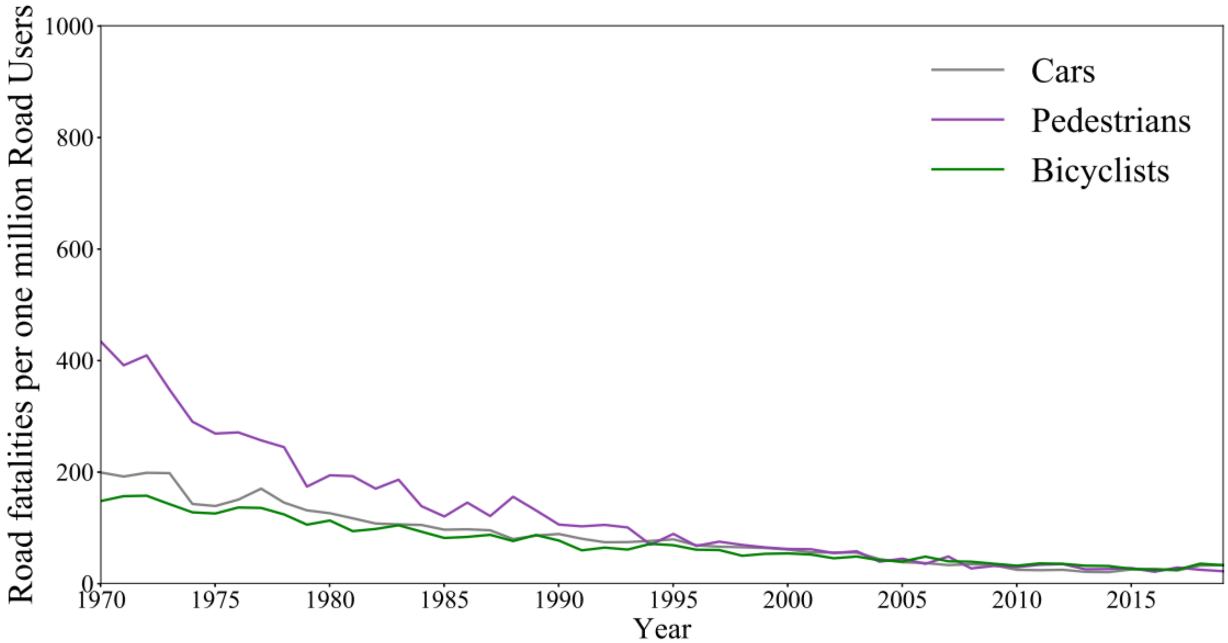

Figure 3 (a) Comparison of vehicle occupant fatalities per one million users in the U.S. and the Netherlands

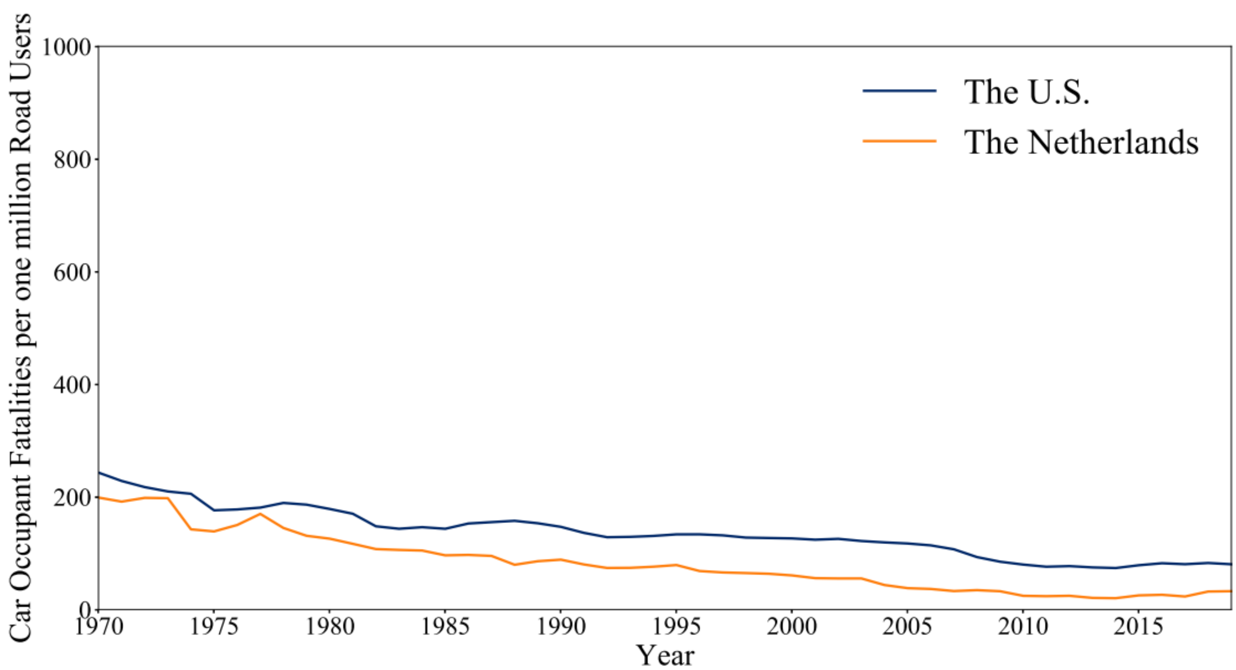

Figure 3 (b) Comparison of pedestrian fatalities per one million users in the U.S. and the Netherlands

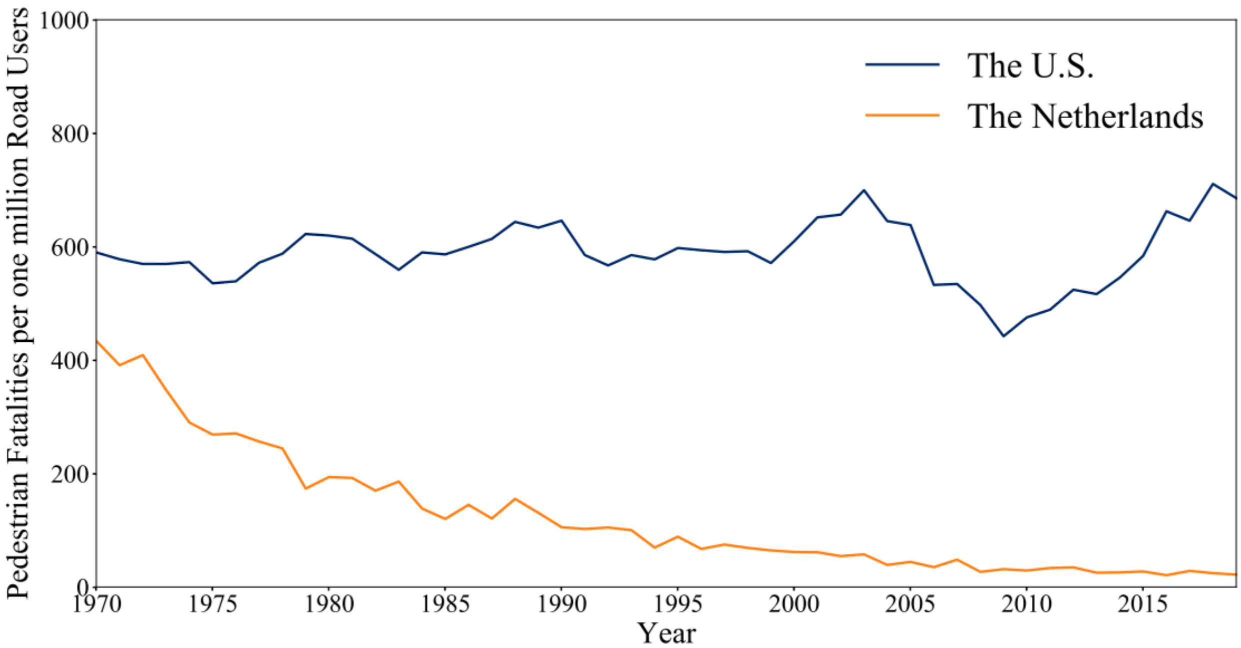

Figure 3 (c) Comparison of bicyclist fatalities per one million users in the U.S. and the Netherlands