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Sustainable Safety and the Decreasing Vulnerability of Cyclists and Pedestrians in the Netherlands: Lessons for the United States

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Sustainable Safety and the Decreasing Vulnerability of Cyclists and Pedestrians in the Netherlands: Lessons for the United States

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Abstract

Fatal road injuries are the eighth leading cause of death globally in 2016 claiming 1.4 million lives. This makes road safety a crucial focus for all countries. One aspect of road safety receiving attention recently is the growing fatalities and risk to vulnerable road users, namely cyclists and pedestrians. In recent years, pedestrian fatalities in the U.S. have increased from 4,109 in 2009 to 5,984 in 2016. That is an astounding 45% increase over a 7-year period. The Netherlands on the other hand has seen a relatively steady decline in vulnerable user fatalities as well as overall fatalities. We take a look at the historic approach to road safety in the U.S. and use the Netherlands as a case study for comparison. Both the Netherlands and U.S. hit their peak fatality tolls in 1972 with similar fatality rates of around 25 fatalities per 100,000 people. After almost four decades, the United States has drastically deviated with a road fatality rate that is nearly three times that of the Netherlands, 10.9 and 3.1 (per 100,000 population) respectively. Part of the reason for selecting the Netherlands is because of their Sustainable Safety vision, which we believe might be one of the factors driving the sustained decrease in their fatalities.

Using an established comprehensive conceptual framework, we analyze road safety indicators such as policy, infrastructure, and safety culture, which are influential in decreasing road fatalities. We looked at the change in risk to pedestrians and cyclists against cars over time using a user based risk metric that accounts for the number of users at risk on the roads. Our findings show that risk in the Netherlands has decreased and converged to the point that cars, pedestrians, and cyclists experience equal risk, 2.5, 2.7, and 3.0 fatalities per 100,000 users respectively. That is 1.2 and 1.08 times higher risk to cyclists and pedestrians than car users. In the U.S., vulnerable user risk has diverged compared to car fatality risk. Fatalities per 100,000 users are 8.2 for cars, 59.8 for pedestrians, and 42.5 for cyclists in the U.S. That is 7.3 and 5.2

times higher risk to pedestrians and cyclists than cars. The nature of the Netherlands system has decreased the vulnerability of cyclists and pedestrians and made it so that they do not need armored protection to survive on the street.

1. Introduction:

Fatal road injuries are the eighth leading cause of death globally in 2016 claiming 1.4 million lives. They are also the number one non-disease or non-health development cause (1). Just as the healthcare field diligently makes efforts to find cures to diseases and works to prevent adverse health outcomes, the field of transportation safety must do the same to reduce and ultimately prevent road deaths. The most recent years have seen smaller increases in global road deaths suggesting that progress is being made. Yet the continued increase globally points to the importance of adopting new approaches for tackling road safety (2).

In addition to the emphasis placed on rising road deaths, one aspect of road safety receiving more attention is the growing fatalities and risk of cyclists and pedestrians. In the U.S. the risks for these road users are particularly high, nearly 36 times for pedestrians and 11 times greater for cyclists compared to cars as found in one study (3). In recent years, pedestrian fatalities in the U.S. have also increased which presents a growing problem in the country and motivated us to take a closer look at safety for these so called vulnerable users. In 2009 there were 4,109 pedestrian deaths (12% of total road fatalities) and by 2016 that total had increased to 5,987 deaths (16% of total road fatalities). That is an astounding 45% increase over a 7-year period.

In this study we seek to identify aspects of road safety, as they relate to vulnerable users, which might need further attention and development in the road safety policies in the U.S. We aim to do this by taking a look at the historic approach to road safety in the U.S. and use the Netherlands as a case study for comparison. This is a country that has performed exceptionally well when it comes to vulnerable road users.

The background to this study is that many richer countries showed increased levels of motorization around the 1950s and 60s - post WWII. Out of that, road fatalities in these developed countries increased and eventually peaked around the early 1970s (4). Since then the fatality trends in developed countries have shown declining patterns. Among those countries, some of the top performers recognized for their low fatality rates are Sweden, the United Kingdom, and the Netherlands, also referred to as the SUN countries (5). In contrast, the United States struggles with road fatalities in terms of level of risk as well as in their rate of improvement (4, 6). Of the SUN countries, we decided to focus on the Netherlands to showcase some points for road safety where the United States may have room for improvement. One reason why we chose to compare the U.S. with the Netherlands is because of the increasing divergence in their safety records over time. They both hit their peak fatality tolls in 1972 with similar fatality rates of around 25 fatalities per 100,000 people. After almost four decades, the United States has drastically deviated from the Netherlands trend with a road fatality rate that is nearly three times the Netherlands rate, 10.9 and 3.1 (per 100,000 population) respectively.

Many countries around the world have begun to adopt a range of policies to promote transportation safety. Different places are both defining and implementing systems-based road safety in a way that fits the context of their country. One of the most well-known road safety visions is Sweden's "Vision Zero" (7), but other strategies include the Netherlands' "Sustainable Safety" approach. Sustainable Safety seeks to prevent road crashes, and when that is not possible, to prevent severe injury with the overall intent of creating a sustainably safe traffic system (8). Part of the reason for selecting the Netherlands is because of this road safety vision, which we believe might be one of the factors driving the sustained decrease in road fatalities in the Netherlands. Encouragingly, in the United States, there have been a growing number of safety visions emerging at different levels, all suggesting that the country is trying to place a greater emphasis on road safety.

While the Netherlands is recognized for having a pattern of low road fatality rates, they are also noted for something more, a large share of the Dutch use the bicycle for transportation. In fact, taking into account non-motorized modes, pedestrians and cyclists, the Netherlands has one of the largest non-motorized mode shares of any developed countries with a 45% share. On the other hand, the U.S. has one of the lowest non-motorized mode shares with 6% (3). Pedestrians and cyclists are two examples of vulnerable users. According to the British planner Stephen Plowden, “vulnerable users are anyone who takes to the street without armor” (9). Due to the lack of protection, these users typically have a higher chance of dying in crashes than those in cars, for example. Counter to what we might expect though, countries with a greater proportion of vulnerable users have frequently been associated with lower overall fatality rates (3). In particular, the U.S. has the highest fatality rate per 100,000 people with 10.9 and the Netherlands one of the lowest with 3.1 among developed countries. Thus, how might a country where nearly half of its road users are classified as “vulnerable,” be outperforming a country where the vast majority of its road users are surrounded by the armor of a car?

This paper seeks to address such a phenomenon to form a better understanding of why the United States has fallen behind in overall road safety. We begin with a literature review in section 2 on the progression of road safety models and where the models might have limitations. We also bring in works on pedestrian and cyclist safety and how they tie in with overall road safety. Section 3 explains the mixed methods approach we use that harnesses both quantitative and qualitative indicators of road safety analysis. Section 4 is an assessment of different road safety risk metrics. We critically examine several metrics to demonstrate the most appropriate uses for different risk representations. Section 5 presents the national risk trends in the U.S. and the Netherlands going back to the 1950s to set a historical foundation. Following that we analyze safety factors within the framework of a conceptual model between the two countries chronologically in the discussion, section 6. Section 7 presents the trends in risk over time for three classes of road users, cars, pedestrians, and cyclists. Lastly, section 8 concludes with the most important lessons to take away for the U.S.

2. Literature Review:

The literature on international road safety shows that the research has progressively become more comprehensive. Consequently, research on road safety has become more complex and difficult to model statistically as more variables are considered. In this review we will look at the literature to see what factors have been used to statistically model international road safety as well as some work that has focused on why pedestrian and cyclist safety may differ between the two countries. We also look closely at a theoretical model developed by our research team that comprehensively identifies indicators of road fatalities. It is important to recognize the achievements that have been made by statistical modelling in improving our understanding of what factors shape transportation safety. But as with any analsyis method, statistical modeling has its limitations. The limitations for statistical models are regarding certain factors that get omitted. Through a mixed methods approach that uses both quantitative and qualitative data we hope to bring more attention to the factors that statistical -models may not always capture.

2.1. International Road Fatality Modeling

Smeed produced the first traffic safety model of traffic fatalities across different countries in 1949. He considered fatalities as a function of motorization for 20 developed countries (10). His findings showed that increased car ownership, measured by registered vehicles per population, positively correlated with traffic mortality rates (measured by fatalities per population) and negatively with driving risk (fatalities per registered vehicle). In Smeed's paper, the U.S., having the largest car ownership, had one of the best rates for fatalities per registered vehicle, but fared as the worst country in terms of fatalities per population. From these opposite findings we see the importance of looking at different ways of measuring risk and what different metrics tell us. Several papers in the 70s and 80s built on Smeed's work by looking at developing countries while mainly considering vehicle ownership as well (11, 12, 13). Later, a selection of literature that looked at safety in several countries brought economics into the analysis, but focused on one or two indicators at a time. Some examples included looking at gross domestic product (GDP) per capita in a 2005 paper by Kopits and Cropper (14), as well as unemployment rates and income in a 2006 paper by Gerdtham and Ruhm (15). Their results showed that good economic conditions (higher income, higher GDP per capita, and lower unemployment) correlated with poor road safety outcomes in terms of population based fatality rates.

Among international studies, a group of literature began including several independent variables in one regression model as more factors were discovered to affect road safety. One example is a paper by Bester in 2001, which included independent variables for infrastructure, socioeconomic, and health dimensions (16). The final model included the Human Development Index (HDI), cars per population, and percent of vehicles that are not passenger cars. The findings showed that an increase in car ownership and HDI, as well as a decrease in vehicles that are not passenger cars, correlated with a decrease in fatalities per 100,000 passenger cars. In the same year, Page had a study that looked at population, vehicles per capita, percent of young people, alcohol consumption, and percentage of people in the workforce, among other factors (17). Page's results supported that an increase in fatalities correlated with increases in the five variables formerly listed, and had negative correlations with percentage of urban population and percentage of buses/coaches in the vehicle fleet. Further expanding from there, a paper by Ahangari in 2014 looked at socioeconomic factors, travel behavior, vehicle exposure and health variables (18). His findings supported the results that higher values for unemployment, gasoline prices and the HDI index correlated with lower fatality rates. Additionally, greater levels of mobility (miles traveled per vehicle) correlated with higher fatality rates. The increasing consideration of more road safety determinants in modeling found in this group of literature shows the need to capture more exogenous variables to better understand the patterns of international road safety. But, Ahangari's research went a step further in establishing a comprehensive framework around which to select road safety variables and to avoid the selection of ones that are interrelated.

Some research projects aiming to model road safety have created indexes that are based on a number of variables that can then be used to compare countries. In 2007, Al-Haji created the road safety development index (RSDI) based on 3 pillars that can be broken down into the following 8 dimensions: traffic risk, personal risk, changing trends, road user behavior, safer vehicles, safer roads, socioeconomic level, and police enforcement (19). In 2008 Hermans developed a road safety performance index based on indicators for 7 dimensions: alcohol and drugs use, protective systems, vehicle, speed, daytime running lights, infrastructure, and trauma care (20). A third example of index development was the SUNflower model. The SUNflower benchmarking comparisons were established in a 2002 report (5) and the index was presented in the 2008 SUNflowerNext report (21). SUN stands for Sweden, the United Kingdom, and the Netherlands, the three countries with the best performing road safety rates at the time. This report structured the indicators into 4 dimensions: road safety performance, policy performance, implementation performance, and structure and culture (21). These index-based models are more comprehensive and were developed through a systematic process to identify a variety of road safety indicators. This research direction informs the need for a comprehensive structure in order to understand the many interrelated trends affecting road safety. In the next section we will look more closely at the structure of a conceptual framework for understanding road fatalities.

2.2. Comprehensive Conceptual Framework

A conceptual framework is a systematic way in which to organize the various characteristics that relate to a phenomenon such as road fatalities. This structure should be designed to allow for a systematic selection of indicators for use in statistical modeling or for the selection of countermeasures and safety interventions. One of the earlier road safety frameworks was the World Health Organization (WHO) systems approach that emphasized safe vehicles, roads, and speeds (22). This model was used as a basis for developing Ahangari's comprehensive conceptual framework. By reviewing Ahangari's framework, we may begin to identify the areas where research is lacking and why. Ahangari's comprehensive conceptual framework is depicted in Figure 1 featuring eight dimensions (A to H).

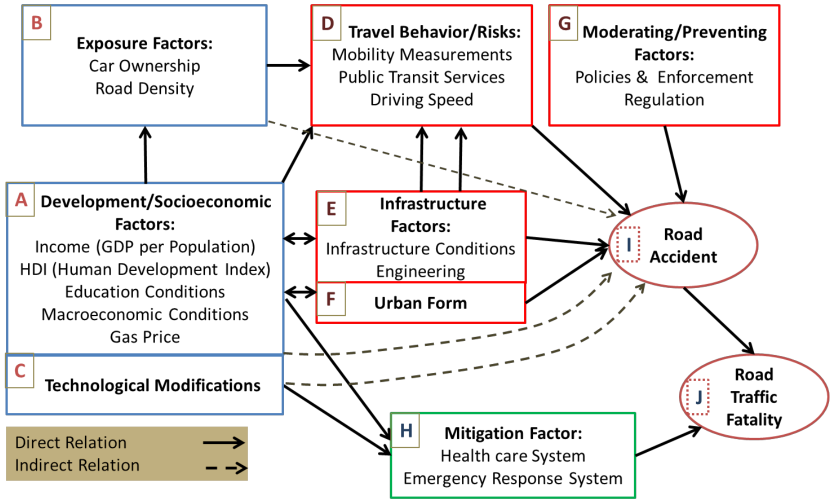

FIGURE 1: Comprehensive conceptual framework for road traffic fatalities. (8)

Ahangari used this framework to compile a list of all factors related to traffic fatalities as well as to understand the relationships between them. He also used the framework to systematically select variables for use in his statistical road safety models. This helped to reduce confounding variables. In his work, Ahangari pointed out that road safety determinants vary spatially, over time, or with both space and time. By spatially, he referred to factors that vary between places (8). This includes travel behavior (D in Figure 1), which is reflected in the common modes of travel used in a country. Also varying from place to place is infrastructure, such as street design features, and urban form, such as land use or spatial growth patterns (E and F in Figure 1). Other factors that vary between places are policies established to guide transportation development and road safety, as well as laws and enforcement that regulate safe behavior (G in Figure 1). Factors that can affect safety which vary over time and between places include: socioeconomic variables such as gas prices and income levels, exposure factors like car ownership levels, changes in technology like vehicle types or vehicle characteristics (A-C in Figure 1), and crash post-care factors that are dependent on the health care system (H in Figure 1).

Using this conceptual framework as a guide in his models, Ahangari controlled for driving levels, car ownership, gas prices, and macroeconomics like unemployment and GDP to explain the outcomes in traffic fatalities between developed countries. Beyond the selection of variables, the framework can be used to identify where data are lacking and additional research analysis is necessary. Some factors that often do not get included in statistical models between countries include infrastructure, urban form, policies, regulations, and mitigation factors. There have been a few studies that statistically modeled fatalities against Graduated Driver Licensing (GDL) Laws (23, 24), seat belt laws (25, 26), density as a measure of urban form (24), and walk share as a measure of infrastructure design (24), but these studies were using data for the U.S. at the state level. These omitted factors typically are left out of international models because the variables needed to characterize them are largely unavailable for comparing different countries. Rather, they can be captured statistically by constants in the models as we illustrate below with Ahangari's statistical assessment. These constants indicate how much of the fatality rate is not explained by the independent variables, but might be explained by changes in omitted factors (6).

In his 2015 paper, Ahangari ran two panel model regressions on road fatality rates for 16 developed countries. Panel models are a form of time series analyses used to understand changes over time. The first regression panel model was designed to give an overall traffic fatality (OTF) index for each country since in this model no controlling variables were included. The second regression panel model gave an adjusted traffic fatality (ATF) index for each country. In this case the model controlled for variations in gas prices, amount of driving, car ownership, health factors, and macroeconomics. The country effects constants in each of the two panel regression models were a measure of the variables left out of each model. Therefore, the country effects constants for the OTF represented differences due to all variables that affect traffic fatality, while the ATF constants captured omitted variables, such as infrastructure, policies, and safety culture, which were not included in this second model. Ahangari used the country effects constants from both regressions to designate indices for each country. These indices represented the safety conditions in one country relative to all developed countries in his models. A larger negative index value represented a country with safety levels better than the average of all countries in the model. A greater deviation from zero in the ATFI than the OTFI represented differences due to infrastructure conditions, policies, and safety culture (6). The results from Ahangari's study for just the Netherlands and United States are depicted in Figure 2.

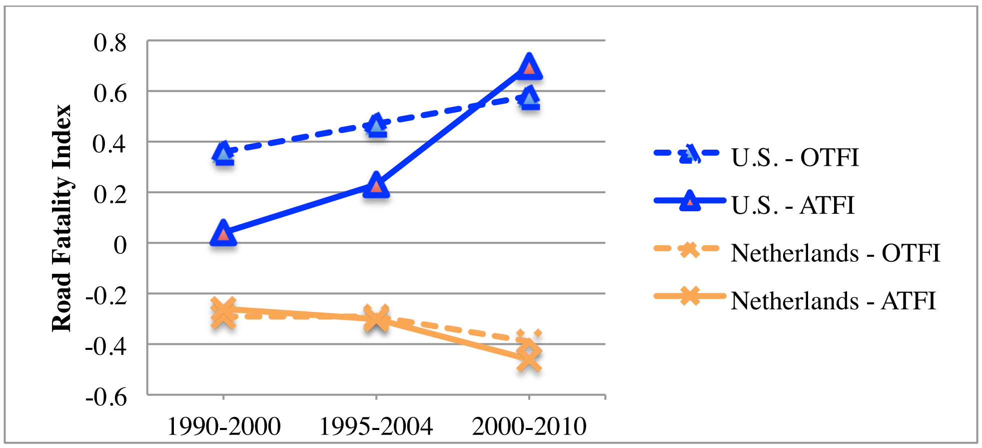

Figure 2: OTFI and ATFI for the Netherlands and U.S. replicated from Ahangari's paper. (6)

The indexes from Ahangari's models can first be used to compare the overall rate of improvement between countries. Secondly they can be used to compare the rate of improvement due to omitted factors by looking at OTFI versus ATFI for a single country. To compare the two countries we'll look at the adjusted traffic fatality index. The United States started out on par with other countries in the 90s, indicated by a value close to zero. Over time the U.S. rate of improvement became worse than other countries, indicated by the positive curve. In the Netherlands, the rate of improvement in the earlier years was slightly better than most countries, but over time has further improved. This implies that over time they were reducing fatalities by larger amounts than other developed countries. After describing the overall fatality trends, we now look at comparing the two indexes.

The ATFI showed greater negative values in the 2000-2010 interval, and a more negative trend over time, than the OTFI in the Netherlands. In the U.S. the ATFI showed greater positive values in the 2000-2010 interval, and a more positive trend over time, than the OTFI. This suggests that the Netherlands made greater rates of safety improvement compared to developed countries when it comes to changes in infrastructure, policies, and safety culture, while the U.S. has not. The Netherlands had a larger overall reduction in fatalities than the U.S. since the mid-1970s. Thus, it is likely that the larger rate of decline for the Netherlands versus the slower one in the United States was influenced by the approaches taken with infrastructure, policies, and safety culture. In this project part of our objective is to look at what the Netherlands did in these areas to see what changes can be made in the U.S. safety approach to increase the rate of decline in the U.S.

2.3. Pedestrian and Cyclist Safety

In an effort to understand transportation safety, recent literature has begun to specifically analyze the safety of walking and biking. In 2000, Pucher and Dijkstra found walking and cycling to be 36 and 11 times riskier respectively than driving in the U.S as compared to European countries like Germany and the Netherlands, which show a much smaller margin. The authors attributed the higher safety for these vulnerable modes in Europe to several factors: infrastructure, urban design, traffic calming, traffic education, police enforcement, and restrictions placed on automobiles (3).

Beyond just the safety of walking and biking itself, the literature suggests that places with more cycling and walking have safer overall road safety in terms of fatality rates (3, 27, 28). A paper in 2003 introduced the idea of "Safety in Numbers," i.e. that more cyclists and pedestrians present in an area would translate to lower fatality rates partly due to a behavioral change in motorists (27). The author looked at this phenomenon at several levels: for intersections, cities, countries, and across time periods finding similar trends. However, Wegman reframes this discussion as 'awareness in numbers" (28). That is to say that places with higher numbers of vulnerable users are increasing awareness among motorists of the presence of pedestrians and cyclists, and therefore drivers expect them on the road. To further support this idea of awareness, one paper showed that the rate of conflicts drops as the frequency of cyclists increases (70). However, places where the share of a particular mode increases often are also improving the facilities for those users, which may be a correlating factor with the safety improvement. Therefore, it is not simple enough just to say that an increase in cyclist and pedestrian mode share will improve road safety. Rather, an increase in vulnerable users coupled with supporting risk-reducing measures may lead to a higher quality of safety.

One final crucial finding in the bicycle and pedestrian literature is from a paper on 24 California cities in 2011 (29). The authors showed that road fatality risk for all road users generally improved in cities with high cycling rates. A key finding from this study was to not just look at crash rates, which may indicate that high cycling cities are less safe, but to focus on what happens after a crash in terms of the severity levels. The high cycling cities showed that crash severity was lower. This led to the conclusion that the high presence of cyclists not only makes drivers aware as previous studies indicate, but that the awareness also compels motorists to reduce their speeds. Crashes happening at lower speeds have a lower chance of resulting in a fatality. They also brought in the influence of street design characteristics and their relations to safer cities, which further supports Wegman's statement on needing risk reducing measures in addition to high cycling and walking numbers to produce safer roads.

2.4. Synthesis of Literature

Statistical models in the literature have identified a number of factors that correlate with road fatalities. Over time more variables were included in statistical modeling to improve their explanatory powers, however many variables that affect safety are still often overlooked. We have seen that the literature on road safety comparisons between countries is less extensive when it comes to factors like policies, infrastructure design, and safety culture. These variables are often omitted, because they cannot be easily modeled statistically or do not have readily available data. As a result they are sometimes overlooked as a part of the solution to road safety. Ahangari's ATF and OTF indexes suggested that variables like policies, infrastructure, and safety culture played a more significant role in the decline in traffic fatality for some countries than others. The Netherlands was one that showed larger safety improvements due to factors like policies, infrastructure, and safety culture. This was not the case in the U.S. Additionally literature shows that increases in cycling and walking have corresponded with safer places. This paper will look at road safety indicators that are overlooked in statistical modeling, but which impacted the risk to vulnerable users in the Netherlands, to understand some of the divergence in vulnerable user trends in the U.S. The type of analysis used is a mixed methods analysis.

3. Mixed Methods:

A mixed methods approach is a methodology that combines quantitative and qualitative ways of exploring questions from how the data are collected to how they are analyzed. In this paper, we use mixed methods because the factors omitted from statistical road safety models include elements that are quantifiable requiring data that are not readily available, and others that are qualitative. Looking at Figure 1, the factors that are difficult to quantify between countries include: travel behavior/risk (D) such as mode share, infrastructure (E) for example differences in street design approach, and urban form (F) such as housing density. The factors that are more qualitative include: technological modifications (C) such as in vehicles or those used to monitor road violations, and moderating/preventing factors (G) like policies, enforcement, safety education and laws.

Literature on mixed methods states that qualitative and quantitative knowledge could be used to inform one another, validate similar findings, show divergence in results, as well as expand on the limitations of one another (30). Qualitative analysis in particular is an established method in non-engineering literature such as transportation geography (31, 32, 33, 34), but not frequently used in transportation engineering. Road safety research in transportation engineering literature is typically rigid with a hypothesis, data analysis, and finally conclusions to explain the results. Qualitative analysis is a more flexible process where additional information informs existing knowledge on a topic and then the cycle repeats (30), as has been the case for this study.

For this analysis, we reviewed literature on culture, policy, and infrastructure design as well as identified historical events that impacted road safety, such as several protests and an oil crisis. As we learned about design and policy decisions made over the years, we looked at the raw data on fatality trends to correlate those decisions with patterns in the fatality rates. While doing this we identified additional patterns of change in the trends that we then sought to find explanations for through actions taken. In our paper we will present a qualitative content analysis of the policies, historical events, infrastructure, and cultural differences between the Netherlands and U.S. Throughout the paper we will develop a narrative for road safety in the two countries by presenting the qualitative findings complemented with supporting quantitative data.

4. Choosing the Appropriate Risk Metrics:

Studies on road safety utilize risk or fatality rate measures to compare levels of safety. Risk is the number of occurrences of adverse events divided by amount of chances for the event to occur, in other words the exposure (35). In this paper, we use fatalities to represent adverse road events. Hakkert and Baimaister demonstrated a number of different situations in which risk can be used to measure safety and they discuss the best metric to use for each comparison (36). The same fatality data may tell different stories about the level of safety based on different exposures. Therefore, selecting an appropriate risk measurement for a given study is important to ensure that meaningful interpretations can come out of the data. This section sets out to explain some of the risk metrics chosen to measure road safety within this paper.

For international comparisons, an aggregate measure like risk based on population is a commonly used metric. A population exposure is not based on a specific means of travel, as is the case with driving distance, and so, represents safety as it affects the entire population. This measure of risk shows the impact that road fatalities have on public health and is sometimes called a transportation mortality rate (36). Road fatalities have not typically been addressed as a matter of public health. However, with large numbers of people dying annually on U.S. roads, road fatality is a serious public health issue and should at some point be analyzed by a public health metric, such as fatalities per 100,000 people (4). This measure acknowledges the importance of reducing the effect that road fatalities have on the national public health, just as much as the importance placed on the reduction of major health epidemics for examples.

In this study, a comprehensive overview of road safety must analyze several ways of measuring risk. This leads to the second aggregate measure for international comparisons. Distance based risk has long been used as a common metric for road safety. When distance driven is used as exposure at the country level it shows an aggregate measure of how safe the roads themselves are in that country, capturing both the level of motorization and the safety advancements in roads and vehicles. This metric represents the risk of a fatality when exposed to a certain level of driving. It does not capture all the complexities of the exposure on traffic crashes in a country, therefore should not be the sole risk measure analyzed. For example, in focusing on this measure of distance-based risk as the only measure, it is easy to overlook the fact that an important strategy for reducing fatalities is to reduce the amount of driving. It might even unwittingly imply the contrary since one way of reducing this risk measure is to increase the amount of driving.

Another application for risk metrics is for comparing different modes of travel. Using distance traveled for this comparison, however, might lead to erroneous results since different modes can have widely varying speeds of travel. With faster modes people tend to travel longer distances for each trip (and over a lifetime), therefore distance might not be the best measure for comparing exposure between different modes. Some research has suggested that a risk based on time exposure might be a better measure because it is a truer measure of the amount of exposure experienced by users of different modes (35).

An alternative risk metric used to compare modes is fatalities per estimated users. For example, in the bike safety study in 24 California cities (29), the number of users of different modes in the entire population were estimated based on commute mode shares. The risk metric in this form served as a proxy for analyzing relative safety between modes and over time. It can be used to compare how much safer one mode has become over another. Larger declines in this measure might reflect a period when safety conditions for the mode in question improved. We can then search if there was a greater focus on safer legislation, infrastructure, or policies for the mode in question than there was for other modes that improved the safety conditions.

Vulnerable users have been a focus of road safety in the Netherlands for many years now and more recently the U.S. has begun to place an emphasis on them as well. With that in mind, we felt it important to get an idea of what the impacts have been on different modes. We will look at the fatality risk metrics for three different classes of road users. In this assessment vulnerable users include cyclists and pedestrians, with cars used for comparative purposes. As discussed, modes differ in their speeds; therefore a distance-based metric skews the risk for active modes relative to cars. We will compare three metrics to demonstrate this phenomenon for bicycles relative to cars as presented in Figure 3, and for pedestrians relative to cars in Figure 4. These figures are shown only for the Netherlands since their distance based exposure data is available annually and by mode for the Netherlands but not for the USA.

For each mode we compute fatalities per billion km using travel survey data and police registered fatalities (despite undercounting non-motorized modes, these numbers were the available fatality counts dating back to 1950). We derive fatalities per 100 million hours by scaling the distance-based risk using an average speed (computed using Netherlands mobility data) for each mode: 3.3 mph (5.3 kph) for walking, 7.6 mph (12.3 kph) for cycling, and 27.3

mph (44 kph) for driving (62). Lastly, we take the commute mode share percentages and multiply them by the total population each year to get an estimated number of users as the exposure for a third metric. Then we produce graphs of the relative rates of risk depicted in Figures 3 and 4. From these graphs we can see that the travel time metric closely matches the trends in the estimated user metric, while the distance based one tells a different story about relative rates. Using the risk based on exposure time would have been ideal, but due to travel time data not being explicitly available yearly for the USA, we feel the metric using estimated users serves as a close proxy for relative mode comparisons. The patterns for cyclists and pedestrians in these figures appear to tell the same skewed story for distance-based risk. Therefore, the findings support the idea that distance is not the best exposure for modal comparison; rather that time is the most appropriate. The fact that mode share based exposure tracks time exposure remarkably close validates that estimated users is a fitting alternative.

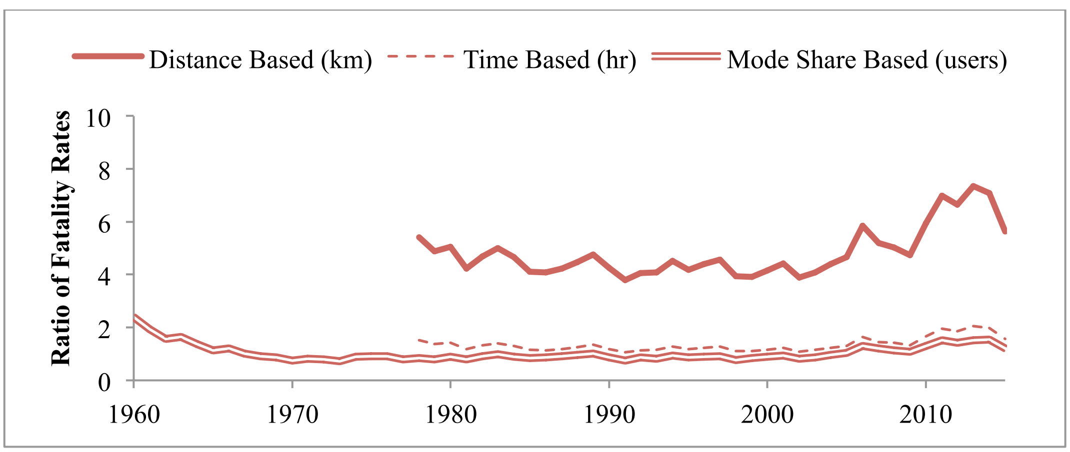

Figure 3: Cycling fatality rate relative to driving fatality rate based on 3 measures of exposure in the Netherlands.

(Data Sources: Survey Travel Behaviour (OVG) and Study of Mobility in the Netherlands (OViN) from Statistics Netherlands, and the Mobility Study Netherlands (MON) from Centre for Transport and Navigation (DVS), and BRON.)

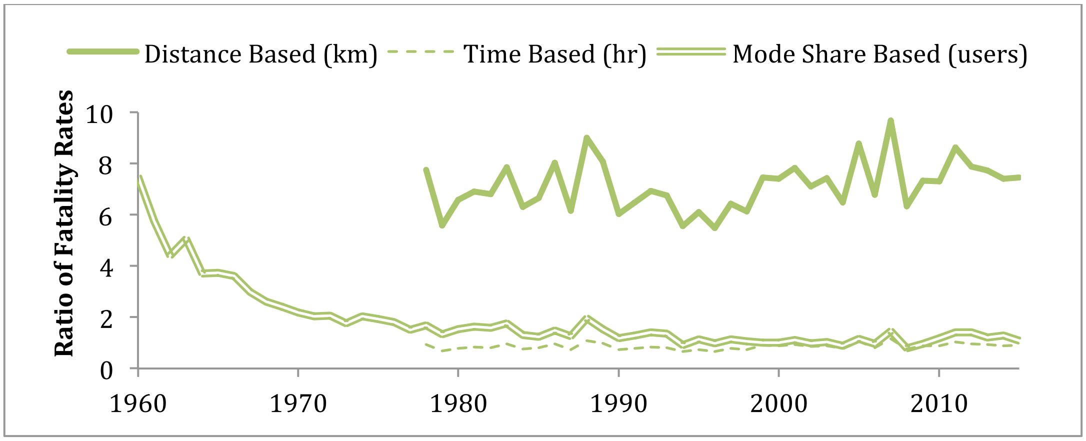

Figure 4: Pedestrian fatality rate relative to driving fatality rate based on 3 measures of exposure in the Netherlands.
(Data Sources: Same as Figure 3.)

5. National Road Safety Trends:

In this section we will analyze fatality rates from 1950 to 2015 to understand the patterns of change in road safety for the United States and Netherlands. Figure 5 shows fatalities per 100,000 people, which as we discussed above is an indicator of the health risk to the entire population due to road fatalities. Figure 6 shows fatalities per 100 million VMT, an indicator of the driving risk.

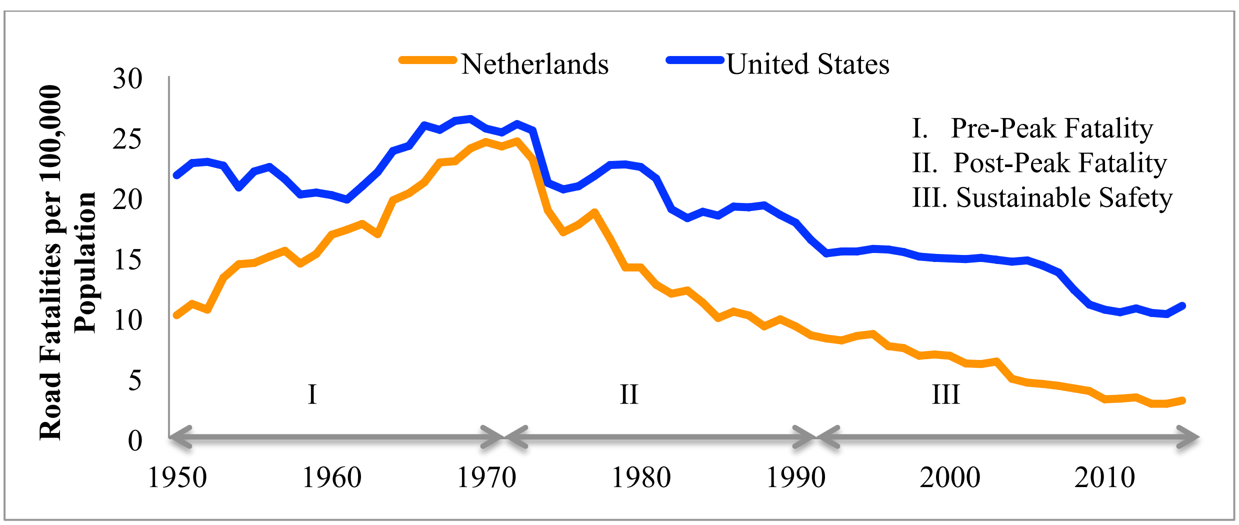

Figure 5: Road fatalities per 100,000 population for United States and Netherlands (1950-2015).
(Data Sources. Netherlands: Statistics Netherlands, BRON. United States: FARS-NHTSA, U.S. Census Bureau.)

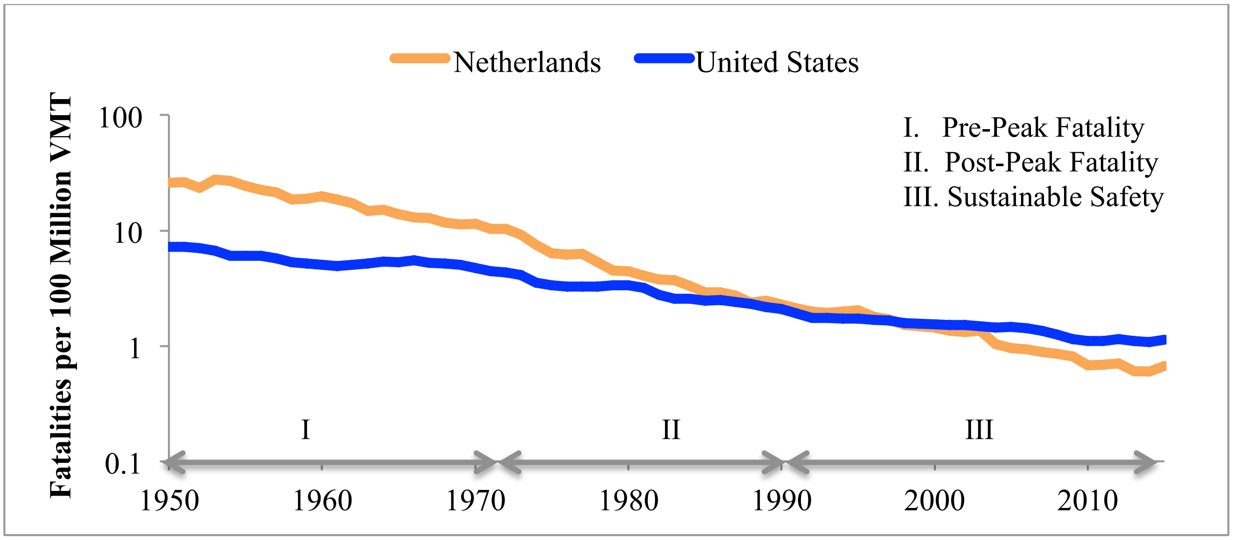

Figure 6: Road fatalities per 100 million vehicle miles for U.S. and Netherlands (1950-2015) based on a Logarithmic Scale.
(Data Sources. Netherlands: Survey Travel Behaviour (OVG) and Study of Mobility in the Netherlands (OViN) from Statistics Netherlands, and the Mobility Study Netherlands (MON) from Centre for Transport and Navigation (DVS), and BRON. United States: FARS-NHTSA, U.S. Census Bureau, FHWA.)

Our period of analysis starts in 1950 when the traffic fatality rate in the U.S. was 22 fatalities per 100,000 people, over twice that of the Netherlands at 10 fatalities per 100,000. By 1972 both countries had about the same rates at 26 and 25 per 100,000 in the U.S. and the Netherlands, respectively. In other words, over the period between 1950 and 1972, the fatality rate (Figure 5) in the U.S. grew marginally while that in the Netherlands had sky rocketed. The reason for the increase in fatalities in the Netherlands appears to be due largely to a rapid increase in travel, post World War II, rather than a decrease in safety (as measured by fatality per km) on its roads. This is borne out by the data in Figures 5 and 6. Figure 6 shows that in the period in question, fatalities per 100 million miles decreased in both countries but at a higher rate in the Netherlands than in the U.S. This decrease in risk on the road however, was overwhelmed by the increase in driving (see Figure 7) which led to a concomitant increase in fatalities. In the Netherlands, the 510% increase in annual driving per capita from 1950 to 1972 and was likely the main reason behind the 220% increase in fatalities. To emphasize just how large these increases were in the Netherlands, the U.S. annual driving per capita increased just 99% and fatalities increased 64% over the same years.

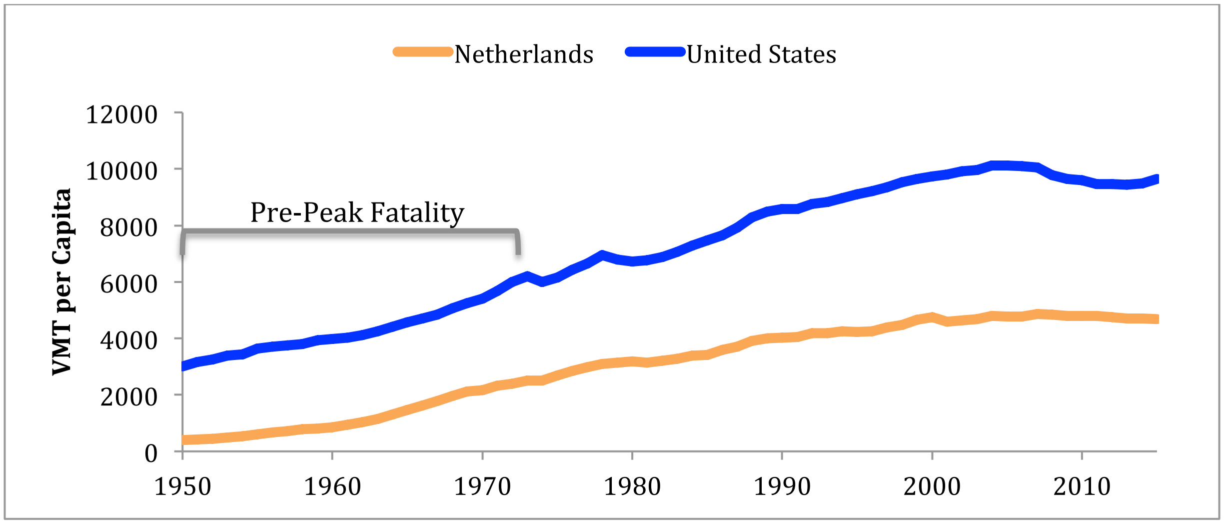

Figure 7. Vehicle miles travelled per Capita in the United States and Netherlands from 1950 to 2015.
(Data Sources: FHWA, DOT, U.S. Census Bureau.)

This data illustrates the potential problems with using fatalities per VMT as a measure of traffic safety. In a situation such as in the pre-1970s period when VMT was growing rapidly, this measure can give a distorted representation of safety. In the case of the Netherlands, the decrease in fatalities per VMT from 25.9 in 1950 to 10.3 in 1972 is largely a function of the increase in VMT. This risk measure contradicts what is shown in fatalities per 100,000 people, which is actually an increase from 10.2 in 1950 to 24.6 in 1972.

Regarding safety, 1972 was a turning point in both countries and fatalities peaked in that year, at 54,589 in the U.S. and 3,264 in the Netherlands. In both countries the initial down turn was linked to some decrease in driving that was caused by the oil crisis of 1973 as well as the emergence of a number of new vehicle technologies. Following the oil crisis, fatality rates in both countries rebounded but did not approach the 1972 peak. Ahangari documented the impact of micro-economic factors and gasoline prices on road fatalities rates in the U.S. and other OECD countries including the Netherlands (18). The pattern was one of decrease and rebound in fatalities tied to increase and decrease respectively in oil prices that repeated itself numerous times over the preceding decades in the U.S. and to a much less extent in the Netherlands.

It is also worth noting the greater rate of improvement in traffic safety as measured by fatalities per 100 million VMT in the Netherlands than the U.S. since 1972. As discussed before, in Figure 6 we can see that the Netherlands started at a much higher rate for fatalities per 100 million miles in 1950, roughly 3.6 times greater than the U.S. However, by 1988 they had matched the rate in the U.S. and since then have continued to decrease at a much higher speed. This parameter, albeit an imperfect measure nonetheless, suggests that the risk of vehicle travel in the Netherlands is much lower, almost half, than that in the U.S. today. For the U.S., some of this metric may be explained by the difference in VMT fatality risk between rural and urban states that differ in the amount of travel (69).

Since 1972, the Netherlands has seen a steady decrease in two road safety risk metrics, which also have been accompanied by a steady decrease in actual road fatalities. Conversely, in the U.S. both road safety risk metrics have also decreased but at a lower rate than in the Netherlands and have not been accompanied by a consistent pattern of decrease in actual fatalities. Ahangari's comprehensive model of road fatality suggests that decrease in risk is the accumulation of many factors including improvement in vehicle technology, emergency response, safety policy and infrastructure design. Given the differences in improvement between the Netherlands and the U.S., many of these factors might have been at play and disentangling them is difficult. Instead, a more effective safety approach would encompass firstly acknowledging all of these factors as part of the solution, rather than trying to understand how these factors affect the decrease in risk individually. Secondly, addressing multiple factors simultaneously may have a greater rate of decrease in fatalities than single targeted actions. The

Sustainable Safety vision, formally initiated in 1997, may have played an important part in the greater rate of fatality improvement for the Netherlands because it embraced these two ideas. In the following section, we will look at the safety conditions for vulnerable users over time in the Netherlands and U.S.

6. Modal Trends Based on Number of User

Vulnerable users in the Netherlands make up 24% of all fatalities (125 total) for cyclists and 11% (60 total) for pedestrians in 2015 (using police registered data). In the United States the numbers are 2% (818 total) for cyclists and 15% (5,376 total) for pedestrians. Given the results from Figures 3 and 4 earlier, we can look at the fatalities in the form of rates for three modes, cars, pedestrians, and cyclists, in the U.S. and Netherlands using the estimated user risk metric that is derived from mode share. Those results are shown in Figure 8. Infrastructure is an important factor in mode choice as survey studies, for example, have cited lack of safe facilities as reasons for users not cycling or taking particular routes (37, 38, 39). It has been found that when there is an increase in facilities for cycling and walking, there is an increase in cycling and walking mode shares (40). Given that there is a relationship between mode share and infrastructure, we feel that fluctuations in the fatality risk based on mode share may reflect changes in safe infrastructure design over time.

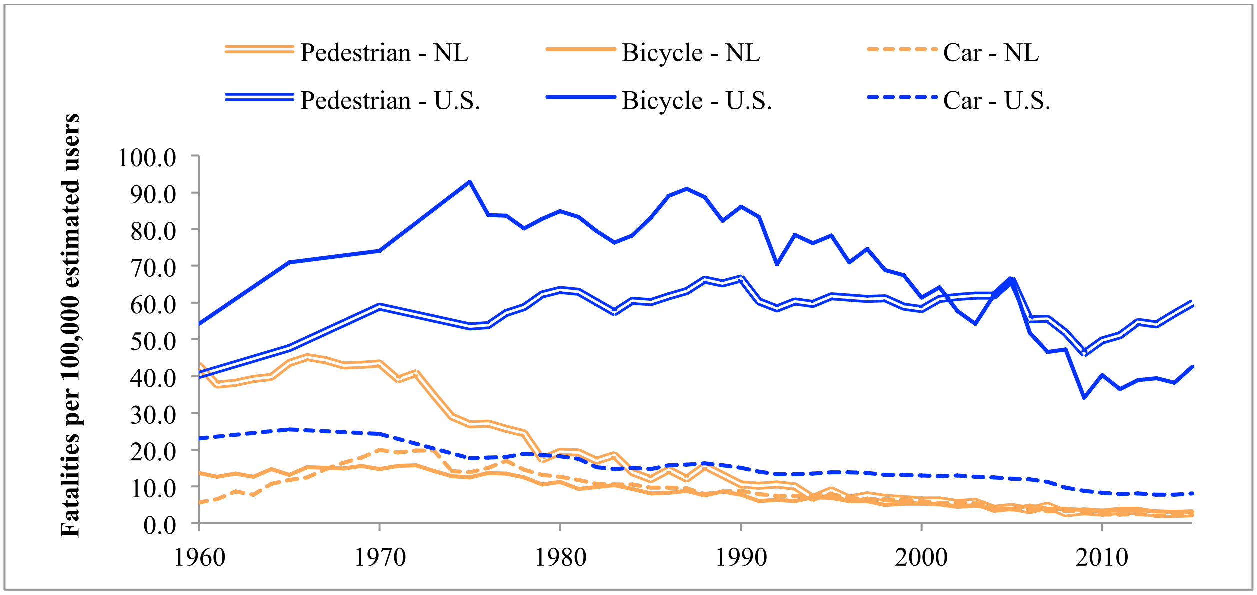

Figure 8: Road fatalities per 100,000 users estimated from work commute mode share percentages and populations (1960 – 2015).
(Data Sources. Netherlands: Survey Travel Behaviour (OVG) and Study of Mobility in the Netherlands (OViN) from Statistics Netherlands, and the Mobility Study Netherlands (MON) from Centre for Transport and Navigation (DVS), and BRON. United States: U.S. Census Bureau, Bureau of Transportation Statistics –U.S. DOT.)

In the Netherlands, the car fatality rate shows an increase between 1960-1970 when motorways were increasing. During this time the automobile was taking over urban spaces where the infrastructure was once designed for a different type of traffic (41). After 1970, the trends for all modes in the Netherlands begin to decrease, a time when new infrastructure was being built for cyclists and safer designs were implemented for all users. If we look at the U.S. in the earlier years, there is an increase in the fatality rate for vulnerable users and a steady, slightly decreasing trend for cars. This seems to align with increased infrastructure improvements for automobiles and negligence in infrastructure for other users. What is striking in the U.S. curves is how over the years, the difference in mode risks mostly grew and the vulnerability of the so-called vulnerable road users increases relative to that of car users. The difference in safety between all three modes in the Netherlands, on the other hand, has significantly decreased and has converged to the point where they are almost equal. Those numbers are 3.0 for cyclists, 2.7 for pedestrians, and 2.5 for cars. The divergence in the U.S. and convergence in the Netherlands points to a difference in infrastructure designs. Specifically, that the Dutch infrastructure design elements work to improve safety for all users. This supports the work discussed earlier by Ahangari, which shows that the safety divergence between the USA and the Netherlands attributed to infrastructure and policy was larger than for other determinants of safety including increase in driving, improvement in health care and socioeconomic factors.

Also worth pointing out in Figure 8, in the U.S. we see that the cycling fatality rate decreases after 1990. This marks a cycling renaissance when bicycle infrastructure became more popular and funding was increasingly used towards those improvements (42, 43). Infrastructure change, from increased facilities to improved design alternatives, might be an important factor that may have contributed to the different safety paths the two countries reflect in their vulnerable user fatality rates. The recent declining trend in the cycling fatality rate is very positive in that it indicates that the U.S. is moving in the right direction on that front. On a less positive note, we can see the poor state of safety for pedestrians in the U.S. as well as the worsening situation with the recent spike since 2009. The U.S. pedestrian risk warrants attention because it remained relatively flat and high in magnitude through the 80s, 90s and early 2000s. The late 2000s saw a slight decline, but nothing long-term as recent years present an increase back to earlier risk levels.

7. Discussion

In addition to the many factors identified in the literature review that affect road safety, this discussion brings out aspects specific to infrastructure, policies, and safety culture. It is likely that the larger rate of decline for the Netherlands versus the slower one in the United States was influenced by the approaches taken in terms of those factors. By looking at what the

Netherlands did in those areas we might see how safety conditions improved for vulnerable users.

7.1. Pre-1970s: Decline in Cycling

There were significant declines in cycling just after WWII when the economy in the Netherlands was improving, disposable incomes were quickly increasing, and motorization grew (44). In the U.S. cities and towns were building in a way that encouraged car use and discouraged biking. For the Netherlands the bicycle was growing in use through 1960, but during the 60s it became less common as people switched to automobiles (44). Some reasons that may have contributed to this switch were the changes in spatial patterns. New residential areas were expanding further from the city center, population densities declined as people moved away, and what resulted were longer commutes for which the bicycle became less viable (44). In the U.S. similar patterns occurred with increased sprawl and longer commute distances. That likely played at least some part in why cycling lost favor in the U.S. as well. Furthermore, bicycle traffic was neglected in national policies and visions for future development, while the automobile received greater attention (44), for both countries. Political officials, in Amsterdam for example, sometimes looked down on cycling and even thought it to be primitive in the early 70s (45, pp. 358-360). It was in the late 1970s when transportation policy finally started planning with the bicycle in mind in the Netherlands (44).

7.2. 1970s: Economic Turmoil and Protests

Both countries had their peak fatalities in 1972 followed by sharp drops the following years. This coincides with the 1973 Oil Embargo, an occurrence that affected nations worldwide.

This socioeconomic factor appears to have impacted the Netherlands and the U.S. similarly in terms of their road fatality declines. In response, both nations made cutbacks during those years on automobile usage to account for the fuel deficit. In the U.S. they reduced the highway speed limit to 55mph (88 kmph) and set various gas purchase limits (46). In the Netherlands the government implemented "Car-Free Sundays" in order to ration oil (41). This action had an effect on the public perception of automobile use and alternative modes. Car owning residents saw that there were other means of transport, and anti-car protesters, who fought for their right to cycle, finally saw the bicycle regain popularity for daily travel. The increase and decrease in gas prices during the 70s were different for the Netherlands and U.S. and Ahangari's work demonstrates some of those gas price changes in regards to safety. It is worth noting that there may have also been more or less willingness to look at non-motorized alternatives as a solution to safety due to the different effects from gas prices.

One particular protest was "Stop de Kindermoord," which translates to "Stop the child murder." It gained momentum in 1972 and was comprised of groups of children and parents fighting for their right to safe streets (41). These children were fighting for their overall road safety, but also for their right to play in the street. Given the density in urban spaces, often the streets are the play areas, which increase the exposure to road fatalities (47). In the U.S. no protests of similar magnitude came from the public, but rather the U.S. was dealing with pushback from the auto industry against attempts at implementing automobile safety standards (48). The occurrence of the Dutch protests around the time of the Oil Embargo has often been suggested as the influencing factor that altered the government's approach towards future transportation policy planning. Changing the way of thinking about safety among the political influencers was a key milestone. Pete Jordan talks about the political influencers in Amsterdam's history during the time of these protests. He mentions their shift in thinking about cycling and safety in response to those public actions (45). Public engagements, such as the protests, appear to have been essential tactics in changing the views of politicians who were too enthralled with the automobile being a symbol of progress to see the devastating decline in safety. These government influencers could then give way for the changing views among transportation and planning professionals. Targeting political figures can result in direct and even immediate changes through policies, which as a result spur progress for changing street design over a longer period.

7.3. 1970s – 1990s: A Turn in Policy and Infrastructure

Prior to the 1970s, the existing cycling traffic and infrastructure was not often planned or even considered in policies for the U.S. or Netherlands. It is not surprising then that non-motorized modes as well as public transport lost their dominance across the two countries. After fatalities peaked and the Dutch public protested in the 1970s, the national government became aware of the negative outcomes that arise from an auto dependent system. Officials began supporting policies that promoted walking, cycling, and public transport. They began to consider the importance of alternative modes in transportation planning. The government increasingly started funding those areas of transport more, while removing some of the focus from automobiles (44). Additionally, road safety goals were also integrated into transport policies. The first Transport Structure Plan in 1987 in the Netherlands called for a 25% decrease in fatalities by 2000 than there were in 1985 (49). This goal, in fact, was achieved as police registered fatalities show a 24.8% decline over that period. The Second Transport Structure Plan in 1990 took things further by setting 50% fewer fatalities by 2010 than were in 1986 as the new goal

(49). This goal was not only attained but also surpassed as police registered fatalities show a 64.8% decline. The second transport plan had set out target goals to discourage automobile use and encourage other modes. Also crucial in helping cyclists get better facilities during this time period was the creation of the Cyclists' Union (De Fietsersbond) in 1975 (44). This organization fought for cyclists' rights and promoted infrastructure projects that support safer and increased cycling as it still does today.

When it comes to new safe road designs, the Dutch have been inclined to perform demonstration projects supported by the central government, and then implement those results throughout the country. In particular we will mention traffic calming (residential zones) and cycle route planning during the 1970s-90s. In order to test the effectiveness of traffic calming and the *woonerf* design, which literally translates to "living yard", the Dutch government funded a demonstration project in 1976 ultimately selecting two districts as test facilities. Organized as an experiment with control sites and varying design options for the test sites, they studied the effects of traffic controls on car volumes, speeds, overall living conditions, as well as traffic crashes. Data were collected before and after the reclassification and reconstruction of the streets and network. The study found that creating slow zones across an area showed positive results for safety, therefore area wide traffic calming gained popularity in other parts of the country (50).

Another infrastructure design inquiry was for cycle routes and creating cycle network plans. Demonstration projects on cycle routes took place in Tilburg and The Hague around 1976. They showed some positive results on how people perceived safety. Further testing the effects of a cycle network at the city, district, and local street levels was performed in Delft in the 1980s. That study showed varying results about route choices, mode share, and safety (51). Overall, the numerous demonstration projects initiated by the national government had hoped to stimulate new design projects in other municipalities. For infrastructure, this time period was about growing the knowledge base for design alternatives that could support the new ideals set forth in the policies on safety and transport.

In the U.S. during the 1970s through 1980s policy was still limited to improving road safety through vehicle technology and highway design. Focus remained around the automobile. The turn in policies and legislation for the U.S. occurred around the 1990s and onward. One of the first tentative efforts to be more inclusive of alternative modes at the Federal level was the Intermodal Surface Transportation Efficiency Act of 1991 (63). In 1998 the state of Maryland, Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials (AASHTO) hosted a workshop, "Thinking Beyond the Pavement" (64). This along with "Flexibility in Highway Design" published in 1997 by FHWA introduced the idea of context sensitive design (65). Also at the federal level, though more recently, is the DOT Strategic Plan 2012-2016 where the U.S. started promoting public transit and non-motorized modes as a means of improving safety (52). All these federal steps opened the door for opportunities like: a street design manual prioritizing sustainability goals published by the Institute of Transportation Engineers (ITE) and Congress for New Urbanism (CNU) in 2006 (66), several design guides from the National Association of City Transportation Officials (NACTO), and numerous complete streets guides at the city level. Despite the recent progress, more concerned national level support, earlier than the 1990s, might have had the ability to push policy at the state and local levels towards more progressive planning sooner.

7.4. 1990s – Present: Sustainable Safety

For the Netherlands, their current safety system approach is called Sustainable Safety. Numerous Dutch papers extensively discuss Sustainable Safety, but the key elements to repeat are the five principles and the idea of considering the human as the fundamental unit of measurement. The five principles this vision operates under are:

1. Functionality of roads
2. Homogeneity of speed, direction of travel, and mass
3. Predictability of road design
4. Forgivingness of the environment and of road users
5. State awareness by the road user

It is important to notice that four of the five Sustainable Safety principles are tied to the physical design of the infrastructure. Infrastructure is an important element for road safety because it has the opportunity to alter user behavior; therefore improvements to design may be effective preventative measures (53, 54). The basic consideration for the human being is about considering the physical tolerance of the body, human error, and reckless driving behavior as faults in the system (55). The traffic system should correct for these vulnerable points through legislation, infrastructure, enforcement, etc. However, this type of thinking takes a certain kind of shift, a shift from the more classical reactive hotspot approach, to the proactive systems thinking.

Prior to the 1990s the Netherlands was solving traffic safety problems in a reactive manner addressing individual problems as they became aware of high-risk issues (67). This is essentially the approach used in the United States today. For example, the 1987 "Long Term Plan for Traffic Safety" had a number of "spearheads" aimed at addressing specific road safety pitfalls to tackle the overall death reduction goal of 25% fewer by 2000. Spearheads can be understood as focal groups or target elements of transportation with high risks that need to be addressed through various measures (56). While this approach is an effort at reducing casualties, it lacks overall in making continuous progress because it does not address the route cause of fatalities (49). Spearheads do not inspire a comprehensive understanding of road safety. Over time, high-risk issues diminish and become harder to identify. Risk to certain users becomes smaller and hotspot locations are harder to find as crashes appear distributed across the system rather than in clusters (67). A more sustainable road safety practice is having a comprehensive understanding of what causes a road fatality, as demonstrated by the comprehensive conceptual framework (18). The Netherlands began developing the Sustainable Safety vision in 1991, initially announcing a start-up version in 1997, and a fully updated vision in 2005 (56). Sustainable Safety is a way of thinking about road safety proactively and systematically.

In Sustainable Safety, to prevent fatalities, the traffic system should adapt to human behavior so that the possibility of a crash diminishes, and if a crash does occur, the speeds are not so high that the collision results in fatality. By studying the connections between the traffic environment, vehicles, and user behavior, conditions for likely conflicts may be identified and design solutions implemented to enforce safe behaviors. There are many studies that show certain design elements promote safer or more dangerous behaviors, such as speeding (57, 58, 59). Sustainable Safety sets out much of this theory as the foundation for constructing their vision principles. Those principles are then translated into design approaches. Similar to when the Netherlands studied bike routes and traffic calming several years ago, the central government once again initiated demonstration projects, this time to test the Sustainable Safety vision design principles (55). One example of design influenced by theory is user separation, partly based on differences of speed. Where there are high-speed roads, separate infrastructure is created for cyclist to remove potential conflict points. Alternatively, when speeds are very low, users may share the roadway such as on local residential streets (8). Another application of theory is that increased speeds lead to an increased chance of dying upon impact between a vehicle and vulnerable user (60). This emphasizes the body's tolerance for speed as a design limitation, which leads to using specific speeds for different street contexts to reduce severity outcomes.

8. Conclusion

As the U.S. takes steps towards reducing their fatality trends, it is essential to acknowledge where there is room for improvement. A committee comprised of various national stakeholders launched "Towards Zero Deaths" in the U.S., a guide for road safety strategies (68). Additionally there have been numerous "Vision Zero" programs start up in U.S. cities; all which seek to embrace the switch to systems based road safety emerging worldwide (61). In order to further the impacts of these programs though, it is important to learn from countries that have established systems-based approaches to incorporate fundamental ideas. The Netherlands was one of the first to both realize a need for and to develop a systematic safety approach. With it, they were successful in reducing overall road fatalities, and especially in building a transportation system that decreases the vulnerability to cyclists and pedestrians. Most notably is that risk has converged to the point that cars, pedestrians, and cyclists experience equal risk after accounting for number of users.

When comparing the Sustainable Safety vision and the U.S. approach in Towards Zero Deaths, one particular lesson stands out as important for a continuous reduction in fatalities, both overall and for vulnerable users. Sustainable safety explicitly states the willingness in the Netherlands to accept that reducing fatalities is a difficult task, and one that becomes harder to tackle the further fatalities drop. Thus, they show more willingness to try new solutions (8). The U.S. principles seem to acknowledge that fatalities are a serious issue, but not that the next step forward may be more difficult and require changing old methods. To get over future hurdles may mean doing politically unpopular things like replacing high automobile speeds with slower safer ones necessary for vulnerable users, or even removing car access altogether on select streets.

The Netherlands has overcome several challenges to create an environment today that makes vulnerable users just as safe as car users as measured with respect to fatalities per user. With conscious efforts put to improve safety for the most vulnerable road users, the risk to all road users has dropped. The risk metric used in this paper is one that accounts for the number of users exposed. The risk values, fatalities per 100,000 users, are 3.0 for cyclists, 2.7 for pedestrians, and 2.5 for cars in the Netherlands. That is 1.2 and 1.08 times higher risk to cyclists and pedestrians than car. The literature supports this pattern of a declining risk to all users (29). However, in the U.S., vulnerable users are still indeed extremely vulnerable by comparison to cars when we account for the amount of users. Those risks, fatalities per 100,000 users, are 59.8 for pedestrians, 42.5 for cyclists, and 8.2 for cars. That is 7.3 and 5.2 times higher risk to pedestrians and cyclists than cars. Trip length is potentially something to look further into. Particularly to see if urban, typically shorter trips, versus rural, typically longer trips, for each of the three modes in both countries still show the same converging or diverging patterns as the overall trends in Figure 8.

The findings in this paper support Wegman's statements on "awareness in numbers" and the need for risk reducing measures (28). That it is not just an increase in numbers that has made vulnerable road users in the Netherlands safer. We show that the safety trends for different modes correlate with changes to infrastructure, a key risk reducing measure. Safe facilities and design are crucial to building a transportation system where vulnerable users have a high presence on the streets while simultaneously being as safe as all users. The nature of the Netherlands system has made it so that you no longer need armor to survive on the street.

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