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Why are Bike-Friendly Cities Safer for All Road Users?

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ABSTRACT

Despite bicycling being considered on the order of ten times more dangerous than driving, the evidence continues to build that high-bicycling-mode-share cities are not only safer for bicyclists but for all road users. This paper looks to understand what makes these cities safer. Are the safety differences related to 'safety in numbers' of bicyclists, or can they be better explained by differences in the physical places or the people that inhabit them? Based on thirteen years of data from twelve large U.S. cities, we investigated over 17,000 fatalities and more than 77,000 severe injuries across nearly 8,700 block groups via multilevel, longitudinal, negative binomial regression models. We hypothesize three potential pathways towards better road safety outcomes: i) travel behavior differences (e.g. 'safety in numbers' or shifts to 'safer' modes); ii) built environment differences (e.g. infrastructure that helps promote safer environments); and iii) socio-demographic and socio-economic differences (e.g. as some cities may be more populated by those with lower transportation injury risks).

The results suggest that more bicyclists on the road is not the underlying reason these cities are safer for all road users. Better safety outcomes are instead associated with a greater prevalence of bike facilities – particularly protected and separated bike facilities – at the block group level, and even more strongly so, across the city as a whole. Higher intersection density, which typically corresponds to a more compact and lower-speed built environment, was strongly associated with better road safety outcomes for all road users. The variables representing gentrification also accounted for much of our explainable variation in safety outcomes. This first chapter helps support an evidence-based approach to building safer cities for all road users. While the policy implications of this work point to protected and separated bike infrastructure as part of the solution, we need to keep in mind that the potential pathways toward safer cites are complementary and should not be considered in isolation. Moreover, our results – particularly the safety disparities associated with gentrification – suggest equity issues and the need for future research.

The extent of the data collected for this project allowed us to delve deeper into safety-related questions of equity, age, and infrastructure. Part 2 of this report looks at road safety like a health impact begs the question: who is the most impacted? Are there urban/rural differences? How equitable are the impacts along racial/ethnic lines or with respect to income? This research considers these questions through a spatial analysis of over 970,000 geocoded road fatalities in the U.S. that took place over the course of a 24-year period (1989–2012). Unlike other research, we also distinguished between crash location and the likely home zip code of those involved. Unfortunately, Americans are not bearing the public health impact of this problem equitably. We find road fatality disparities along racial and ethnic lines, particularly for pedestrians and bicyclists in predominantly black or Hispanic neighborhoods. Our results also point to significant discrepancies across the urban/rural and population density spectrums as well as by household income. For instance, lower income neighborhoods suffer from vehicle occupant fatality rates more than 3.5X higher than wealthier neighborhoods. Also, those living in our most rural zip codes endure vehicle occupant fatality rates approximately 6X higher than those living in our most urban zip codes. This suggests that transportation and land use planning that facilitates more access with less mobility can reduce unnecessary exposure and lead to road safety outcomes on par with the safest developed countries in the world.

Part 3 of this report the decline in bicyclist fatalities seen over the last thirty years and explores age-related differences in the direction and magnitude of this trend and the impact different measures of exposure have. Using fatality data from the Fatality Analysis Reporting System (FARS) and exposure data from the National Sporting Goods Association (NSGA), we disaggregate age-specific bicyclist fatality trends for children (aged 7-17 years) and adults (aged 18+ years). We then compare safety rates using exposure measures from the NSGA, the National Household Travel Survey (NHTS), the American

Community Survey (ACS), and population counts from the U.S. Census Bureau. The results suggest that overall declines in bicyclist fatality rates have been primarily driven by a sharp decline in child bicyclist fatality rates, while adult bicyclist fatality rates have generally trended upwards. However, the utilization of different exposure metrics can shift these results. We then discuss differences between current bicycle exposure measures and the need for more complete data of we want to truly understand age-specific impacts of bicycling safety.

Part 4 specifically examines shared lane markings, which are more commonly known as sharrows. While past research confirms that sharrows may effectively influence spacing and other operational measures, the impact on safety outcomes remains unsubstantiated due to a lack of data on dooring-related bicycle crashes. Fortunately, the city of Chicago instituted a program to collect dooring crash data in 2010. Thus, the purpose of this research is to longitudinally examine the association between sharrows and bicyclist injuries. To begin to answer this question, we divide Census block groups in Chicago into three categories based on what bike infrastructure was installed between the years 2011 and 2014: i) those block groups with no bicycle facilities installed; ii) those with only sharrows installed; or iii) those with only bicycle lanes (standard, buffered, or protected) installed. Negative binomial regressions and Kruskal-Wallis tests suggest that block groups with only sharrows installed experienced the largest increase in bicyclist injury rates, with exposure being accounted for through levels of bicycle commuter activity. This relationship held true for overall crashes as well as for dooring-related crashes. These findings raise concerns regarding the safety effectiveness of sharrows as used by the City of Chicago during the study period and should be a call for more research on the subject in a variety of different contexts using various exposure metrics.

The appendices include examples of how these issues were integrated into assignments for graduate level civil engineering classes.

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1. INTRODUCTION

Bicycling as a fundamental mode of transportation is being reinvented in the United States. To begin with, Americans are becoming increasingly reliant on bicycling, as evidenced by the 51% increase in bicycling to work between 2010 and 2016 (ACS, 2018). At the same time, more and more U.S. cities are improving their bicycling infrastructure. For instance, the number of protected bike lanes in the U.S. has doubled every two years since 2009 (PeopleForBikes, 2018). Despite these changes, a recent bicycling safety report from the Organization for Economic Cooperation and Development (OECD) states that Americans still bicycle less than residents of the other 33 OECD countries and are among the most likely to die as bicyclists (OECD, 2013).

Just how dangerous is bicycling in the U.S.? Given the lack of exposure data and bicycling counts, this is a difficult question to answer definitively. However, it can be estimated in relative terms. For instance, 37,461 and 840 people were killed in motor vehicle and bicycle crashes in the U.S. in 2016, respectively (NHTSA, 2017a). Americans drove approximately 3.2 trillion miles in 2016, which equates to a fatality rate of 1.18 fatalities per 100 million VMT (vehicle miles traveled) (FHWA, 2017). Bicycling participation estimates range from less than 10% of Americans to 24% (Breakaway Research Group, 2015; Mapes, 2009; NSGA, 2017). The National Sporting Goods Association, for example, reports that 39.3 million Americans ride a bike at least once a year, which equates to about 12% of the population (NSGA, 2017). With 840 bicyclist fatalities, each of these 39.3 million bicyclists would have to bike more than 1,600 miles each year to be safer than those in motor vehicles. This would equate to 12% of Americans bicycling more than four miles every day of the year. However, this is not a realistic level of bicycle exposure in the U.S. context given current travel patterns (Mapes, 2009). Even if we increased our assumption to 24% of the population, it would still equate to more 800 miles of bicycling each year for more than 78 million people.

Despite the myriad health benefits of bicycling (Deenihan & Caulfield, 2014; Jan Garrard, 2011; Marshall, Piatkowski, & Garrick, 2015), these back-of-the-envelope calculations suggest that bicycling is significantly more dangerous than driving, and those looking to promote the health benefits of bicycling typically do so despite the known road safety risks (de Hartog, Boogaard, Nijland, & Hoek, 2011). To be more specific, Pucher and Dijkstra approximated bicycling exposure from commute data and found that the per-mile fatality rate for drivers in the U.S. was approximately ten times lower than that for bicyclists (Pucher & Dijkstra, 2003). More recently, McAndrews et al. delved deeper into the data to derive mileage-based exposure metrics and estimated similar elevated risks for bicyclists (McAndrews, Beyer, Guse, & Layde, 2013).

Transit, on the other hand, is a much safer mode of transportation than driving. Recent numbers suggest fewer than 0.06 fatalities per 100 million passenger transit miles traveled, which is approximately twenty times safer than driving (Politifact.com, 2011). Based upon this difference between transit and automobile safety, it would stand to reason that cities with a high percentage of people traveling by transit would be safer than the typical automobile-based city. At the city level, this trend turns out to be the case. In an international study, Kenworthy and Laube concluded that cities with high transit use also tended to have lower overall fatality rates (Kenworthy & Laube, 2000). In the U.S. context, Litman found that residents of automobile-oriented cities had a traffic fatality rate five times that of those living in transit-oriented communities (Litman, 2009, 2013). One reason behind these results is that more transit use tends to also lower the overall amount of vehicle use. Another explanation is that transit use is higher in relatively dense metropolitan areas with urban form designed around relatively slow speeds, thus reducing the number of deaths of travelers by just about any mode.

Given these safety trends, one might conclude that high bicycling cities must be far more dangerous than either transit-based cities or automobile-based cities. However, cities with high levels of biking also have surprisingly good traffic safety records, and not just for bicyclists, but for all road users (Marshall & Garrick, 2011b). For instance, the U.S. city long with the greatest percentage of people bicycling to work – Davis, California – endured 28 road fatalities over a recent 20-year period, with 19 of those fatalities occurring on non-limited access streets and two involving bicyclists. These results equate to a road fatality rate of 2.3 per 100,000 residents. With the current per capita crash rate in the U.S. more than five times higher at 12.4 fatalities per 100,000 residents, it is easiest to discount Davis as an anomaly. Yet, Davis is not alone. Another U.S. city that has become renowned for its bicycling – Portland, Oregon – has concurrently improved its road safety record. Between 1990 and 2010, for example, Portland's bicycle mode share increased from 1.2% to 6.0%; over this same period, the road fatality rate in Portland dropped by 75% (City of Portland Bureau of Transportation, 2011). This is a relatively impressive safety record (4.5 fatalities per 100,000 residents) for a city of over 600,000 people and is comparable internationally to the countries reporting the lowest crash rates in the world such as the Netherlands (3.4 fatalities per 100,000 residents) (Marshall, 2018). Perhaps not coincidentally, the Netherlands also boasts a bicyclist mode share of nearly 30% (Heinen, Maat, & van Wee, 2013).

Examples such as Davis, Portland, and the Netherlands are often written off as outliers because their cultures of bicycling have been prevalent for decades. New York City, however, is a relative newcomer to the bicycling experiment, having installed over 600 lane miles of bike lanes since 2006 (New York City DOT, 2018). Since then, bicycling has more than doubled in New York City while traffic fatality rates dropped to the lowest numbers on record (Donohue, 2013; Miller, 2013). While these improvements cannot simply be attributed to increased levels of bicycling, these represent trends worthy of exploration.

A number of existing papers have studied the idea of bicyclist 'safety in numbers' where individual bicyclist risk drops with an increasing number of bicyclists (Ekman, 2006; Jacobsen, 2003; Jacobsen, Ragland, & Komanoff, 2015; Jensen, 2002; Krista Nordback & Marshall, 2010; K. Nordback, Marshall, & Janson, 2014). The rationale most often given for this safety benefit is a shift in driver expectations and behavior based upon the perceived possibility of encountering a bicyclist. However, these studies only attempt to understand the difference in bicyclist safety. Fewer studies have investigated the safety effect of a high-bicycling-mode-share city on the safety of all road users (Marshall & Garrick, 2011b).

Despite conventional logic, the evidence continues to build that high bicycling places are not only safer for bicyclists but for all road users. Via a longitudinal 13-year analysis of 12 large U.S. cities, this research study seeks to understand what makes cities with high bicycling rates safer for all road users. Do these safety trends have anything to do with safety in numbers, or can they be explained by other factors? Accordingly, we hypothesize three primary possibilities:

1. Travel behavior differences, such as bicyclist safety in numbers, and/or shifts to modes that are safer or may reduce exposure;
2. Built environment differences, such as bicycling infrastructure, that may help promote lower speed environments and safer streets; and
3. Socio-demographic and socio-economic differences, as cities become more populated by populations with generally lower transportation injury risks.

The next section delves into the theory behind these possible explanations. We then describe the study in more detail along with the data collection efforts and statistical methodology. This is followed by our results and conclusions.

2. THEORY

The pervasiveness of road deaths remains one of our most unrelenting public health failures. In fact, road fatalities purge more productive years of life than any other disease, including cancer and heart disease combined (Maxton & Wormald, 2004). Just last year alone, there were more than 40,000 road deaths in the U.S. and 1.25 million worldwide (National Safety Council, 2018). According to the Centers for Disease Control and Prevention, road fatalities are the number one cause of death for every U.S. age group from 5 through 24 (CDC, 2017). Traffic safety should be considered a public health priority (Ewing & Dumbaugh, 2009). The seriousness of this issue, combined with the fact that progress in this area remains slow, suggests a need for a fundamentally different approach. This paper attempts to accomplish this via a comprehensive look at what may be influencing road safety outcomes. This section examines the existing literature related to the potential pathways for better road safety outcomes.

2.1 Travel Behavior Differences

There is considerable bicycling research focused on the "safety in numbers" phenomenon. As far back as 1996, Ekman found a significant relationship between bicyclist exposure and conflict rate (Ekman, 2006). In this comprehensive Swedish study, Ekman's results suggest that the conflict rate for an individual bicyclist was higher when the number of bicyclists was low and that this conflict rate waned as the flow of bicyclists increased. In other words, the more bicyclists, the safer it is for each individual bicyclist. Pedestrians did not experience the same benefit in Ekman's study. In a 2002 study from Copenhagen, Jensen found that a 40% increase in bicycle kilometers traveled corresponded to a 50% decrease in seriously injured bicyclists (Jensen, 2002). In one of the first U.S. studies looking at this issue, Jacobsen investigated 68 California cities and showed that the individual chance of a bicyclist being struck by a car drops with more people bicycling (Jacobsen, 2003). Larger-scale, international studies soon began to support these results (Pucher & Buehler, 2008; Pucher & Dijkstra, 2003; Robinson, 2005; Yao & Loo, 2016). Similar results are now emanating from the research focused on developing safety performance functions (K. Nordback et al., 2014).

While these studies generally focus on bicyclist-related crash outcomes and not on all road users, they do begin to shed light on why cities with high bicycling might see improved road safety outcomes. Although not explicitly studied, most of these papers assert that high levels of bicycling may influence driver behavior. In other words, when the number of bicyclists increases to the point where drivers habitually expect to see bicyclists, drivers may be more likely to, for example, look over their shoulder for a bicyclist when making a right turn. It is possible that higher driver awareness lends itself to safer outcomes for other road users as well. It is also possible that high numbers of bicyclists may even act a traffic calming measure themselves. Speeding down a street is not as easy when there are bicyclists in the way. Whereas switching from driving to bicycling might lead to worse safety outcomes in conventional circumstances, this may not be the case in cities with high bicycling rates.

Since the statistics suggest that transit is on the order of twenty times safer than driving, it stands to reason that places with high transit usage might have lower road fatality rates (Kenworthy & Laube, 2000; Litman, 2009, 2013). The same can be said for cities with higher percentages of people that work from home. The ability to access one's job without exposing oneself to the dangers of the roads should, in theory, be safer than any conventional commute. In fact, the percentage of people working from home has grown more than walking, bicycling, or transit use over the last decade (ACS, 2018; Polzin, 2016). Yet, the contribution of this growing trend to road safety outcomes remains under-researched.

2.2 Built Environment Differences

A recent development to the built environment of U.S. cities has been the growth of bicycle-focused infrastructure. Does such bicycling infrastructure actually improve road safety outcomes? The majority of papers find that bicycle paths and lanes help reduce bicyclist fatalities (Mulvaney et al., 2016; Pucher, 2001; Reynolds, Harris, Teschke, Cripton, & Winters, 2009). However as described in the introduction, the number of protected bike lanes – also known as cycle tracks – went from being almost non-existent in U.S. cities to doubling every other year since 2009 (PeopleForBikes, 2018). While there remains a relative lack of peer-reviewed safety research on protected bicycling infrastructure in the U.S. (Mulvaney et al., 2016), the results seem promising (Harris et al., 2013; Zangenehpour, Strauss, Miranda-Moreno, & Saunier, 2016). It is worth pointing out, however, that most of these papers focus specifically on the safety of bicyclist; yet, it is conceivable that such bicycle infrastructure may also function as a traffic calming measure that reduces vehicle speeds and improves road safety outcomes for other road users as well (Marshall & Garrick, 2011b). In terms of the relationship between bike infrastructure and bicycling activity, separated infrastructure has been shown to increase bicycling rates and help reduce the bicycling gender gap (J. Garrard, Rose, & Lo, 2008). Yet, the research remains mixed. For instance, a report by the University of Minnesota concludes that "the 'build it and they will come' theory is not universally applicable" when it comes to bike facilities (Douma & Cleaveland, 2008). Such results suggest that we should consider changes in bicycling rates separately from changes in bicycling infrastructure.

More generally in terms of the built environment, denser, more urban areas generally experience lower road fatality rates than more suburban or rural environments *(Eric Dumbaugh, 2006; E. Dumbaugh & Rae, 2009; Ewing, Hamidi, & Grace, 2014; Ewing, Schieber, & Zegeer, 2003; Glaeser, 2011; Marshall & Garrick, 2010b, 2011a; Myers et al., 2013)*. For example, intersection density, which typically suggests a more compact and lower speed built environment, has been shown to be associated with more property damage only crashes but significantly fewer fatalities and severe injury crashes (Marshall & Garrick, 2011a). When accounting for the built environment in terms of population density, one study found that those living in rural zip codes suffered from vehicle occupant fatality rates approximately six times higher than those living in the most urban zip codes (Marshall & Ferenchak, 2017).

In an overview of the existing evidence on the subject of safety and the built environment, Ewing and Dumbaugh cite two main reasons for these road safety disparities: i) those living in urban areas generally drive less; and ii) urban areas tend to be designed to promote lower speeds (Ewing & Dumbaugh, 2009). In fact, speeding plays a role in more than 30% of fatal crashes in the U.S. (USDOT, 2014), and the preponderance of research suggests that lower speeds help reduce injury severity (Archer, Fotheringham, Symmons, & Corben, 2008). For instance, a synthesis paper by Elvik concluded "that the relationship between speed and road safety is causal, not just statistical" (Elvik, 2005). A later paper by the same author estimated that eliminating speeding would reduce road fatalities by 25% to 33% (Elvik, 2012).

2.3 Socio-demographic and Socio-economic Differences

Gentrification – typically defined as the arrival of wealthier people, usually white, into an existing urban neighborhood and the coincident displacement of lower-income, usually non-white, residents – has become a persistent issue for U.S. cities (Grant, 2011; Maciag, 2015). In terms of road safety outcomes, income has proven to be significant in road safety outcomes, all other factors being held equal (Al-Lamki, 2010; Marshall & Ferenchak, 2017). With respect to socio-demographics, much of the literature suggests lower road fatality rates for non-Hispanic white populations (Baker, Braver, Chen, Pantula, & Massie, 1998; Harper, Marine, Garrett, Lezotte, & Lowenstein, 2000; Schiff & Becker, 1996) while other papers found higher fatality rates for American Indian and Black populations (Braver, 2003; Campos-Outcalt, Bay, Dellapena, & Cota, 2003; Mayrose & Jehle, 2002; McAndrews et al., 2013). While the existing research struggles to explain why the transportation system is not equally safe for various demographic and economic groups, it stands to reason that we need to account for the shifting demographics and incomes of cities when trying to understand the road safety disparities.

In terms of age, the existing literature suggests that both younger drivers and older drivers have increased transportation risks. For instance, younger drivers are more likely to speed and tend to underestimate risk (Constantinou, Panayiotou, Konstantinou, Loutsiou-Ladd, & Kapardis, 2011; Hatfield & Fernandes, 2009; Machin & Sankey, 2008; Rhodes & Pivik, 2011; Stradling et al., 2003). Older drivers, on the other hand, tend to have slower reaction and processing times as well as decreased visual acuity (Anstey, Wood, Lord, & Walker, 2005; Clay et al., 2005; Horswill et al., 2008).

3. STUDY OVERVIEW, DATA, & METHODS

To answer these research questions, we carried out a longitudinal spatial analysis, gathering data for the same locations over a period of thirteen years, of road safety outcomes in cities with and without high-bicycling mode shares. This section overviews the study design, followed by the data collection efforts, and finishes by describing the statistical analysis.

With respect to site selection, the fundamental intent was to select cities across a spectrum of bicycling, bicycling infrastructure, and road safety outcomes. Hence, we first acquired city-level American Community Survey (ACS) data so that we could assess mode share longitudinally. We then supplemented the ACS data with the data behind the Alliance for Biking and Walking Benchmarking Report (Milne & Melin, 2014). This included, for the fifty most populous U.S. cities, city-level bicycling-related data such as mileage of bike facility by type, density of bike facility by type, and bicyclist fatalities per 10,000 bicycling commuters. The intent was to use this data get a better sense of these cities in terms of bicycling activity and the different types of bicycling infrastructure being installed. We also retrieved fatal crash data from the Fatality Analysis Reporting System (FARS) and calculated fatal crash rates by year for each city from 1990 onward.

As discussed above, we wanted to find cities that exhibited a broad range of road safety outcomes and bicycling rates as well as cities with varying degrees of investment in bicycle-specific infrastructure. Data availability was another important criterion (for instance, despite persistent attempts, we were unable to acquire non-fatal crash data from Baltimore). Based on our assessment of the bicycling infrastructure, fatality rates, and bicycle mode shares, we limited our study to twelve cities (primarily thanks to the arduous task of collecting the longitudinal data, particularly with respect to the bike infrastructure data and the non-fatal crash data, which is described later in this section). Table 1 displays the selected cities, ranked in order of bicycle mode share to work. The most recent bicycling mode shares range from almost negligible in a few cities to 7% in Portland. This table also presents fatal crash rates aggregated by decade. Road fatality rates range from 4.1 fatalities per 100,000 residents in Minneapolis to 13.6 per 100,000 residents in Kansas City. While all cities improved their road safety records over the years, bicycling rates dropped nearly 30% in Oklahoma City but increased by over 500% in Chicago.

Table 3.1 City Selection

		Fatal Crash Rate (fatalities per 100k pop.)			1990's to 2010's		Bike Mode Share				1990 to 2015	
	Population	1990's	2000's	2010's	Δ Crash Rate	Percent Change	1990	2000	2010	2015	Δ Mode Share	Percent Change
Oklahoma City, OK	638,367	16.2	14.9	12.6	-3.6	-22.2%	0.1%	0.1%	0.2%	0.1%	0.0%	-28.1%
Memphis, TN	652,717	20.3	16.5	13.5	-6.8	-33.5%	0.1%	0.1%	0.2%	0.1%	0.0%	-25.3%
Kansas City, MO	481,420	18.3	15.3	13.6	-4.7	-25.8%	0.1%	0.1%	0.3%	0.1%	0.0%	-10.5%
Dallas, TX	1,317,929	16.5	13.6	11.2	-5.3	-32.2%	0.2%	0.1%	0.1%	0.2%	0.0%	29.5%
Houston, TX	2,303,482	14.0	13.1	11.2	-2.7	-19.5%	0.4%	0.5%	0.4%	0.5%	0.1%	42.3%
Austin, TX	947,890	12.0	11.2	8.4	-3.5	-29.5%	0.8%	0.9%	1.5%	1.3%	0.5%	67.2%
Chicago, IL	2,704,958	9.4	7.7	5.8	-3.6	-38.2%	0.3%	0.5%	1.3%	1.8%	1.5%	541.4%
Denver, CO	682,545	11.1	10.5	6.6	-4.5	-40.3%	0.9%	1.0%	2.3%	2.1%	1.2%	143.4%
Seattle, WA	704,352	11.6	5.6	4.6	-7.0	-60.6%	1.5%	1.9%	3.4%	4.0%	2.5%	163.8%
San Francisco, CA	864,816	8.9	6.2	4.5	-4.4	-49.3%	1.0%	2.0%	3.4%	4.3%	3.3%	348.1%
Minneapolis, MN	413,651	6.4	5.5	4.1	-2.3	-36.2%	1.6%	1.9%	4.1%	5.0%	3.4%	207.8%
Portland, OR	639,863	14.0	7.4	5.1	-8.9	-63.5%	1.2%	1.8%	6.1%	7.0%	5.8%	504.5%

We narrowed our study period down to 2000 through 2012 based on the availability of non-fatal crash data (we were particularly interested in severe injury crashes) and historic Google Earth satellite imagery, which was used to determine bike infrastructure installation periods. Since this paper focuses on large cities, it is important to point out that these results are not generalizable to smaller cities. The next sub-section focuses on the data collection efforts. Table 2 presents the descriptive statistics for the accumulated data.

3.1 Data

3.1.1 Crash Data

The FARS database was created in the mid-1970s by the National Highway Traffic Safety Administration (NHTSA) to document all motor vehicle crashes resulting in a fatality (within 30 days of crash) on public roadways (NHTSA, 2017b). While the underlying FARS data is compiled from police crash reports and hospital reports separately by different states and multiple agencies, NHTSA staff cross-check all data before it enters the final database. For our time period of 2000 through 2012, we were able to geocode nearly all crashes occurring after 2001 using latitude and longitude information. The remaining fatal crashes were geocoded (using ESRI Online geocoding in combination with the online mapping services MapQuest and Google) to the highest degree of accuracy possible based on the location information provided by FARS. The location information for these crashes typically included the name of the street where the crash occurred and the nearest cross street, and such crashes were geocoded to the nearest intersection. Within this step, we tested a subset of geocoded crashes for accuracy or systematic errors and found no issues. In total, we were able to successfully geocode all of the approximately 17,000 fatal crash records.

We collected non-fatal crash data from each of the cities. Three cities (Denver, Minneapolis, and Portland) had the data already available in GIS format. Four other cites (Austin, Chicago, Dallas, and Houston) gave us spreadsheet data with latitude/longitude columns included. The data for the remaining cities had some coordinate data but mostly had to be geocoded in the same fashion that we used for the FARS data. Due to differences by city in terms of crash severity definitions, we separated the crash data into two groups: those that resulted in a severe injury and all other crashes. This process resulted in 77,456 severe injury crashes and 3,531,504 total crashes with a geocoding success rate of 97.9%.

Using GIS, each of the geocoded crashes was counted and summed at the Census block group level of geography. The Census block group is the unit of analysis for our study because it is the smallest geographic unit that has journey to work data available. Our twelve cities include 8,686 block groups (at an average of approximately 724 block groups per city), each with 13 years of data, for a total of 112,918 observations. According to the Census, a block group averages 250–500 housing units but varies in terms of area depending upon housing density.

It is worth pointing out that such aggregated Census data may be affected by the modifiable areal unit problem and that similar studies based on a different geographic unit may find different results (Spielman, Folch, & Nagle, 2014). Another potential limitation is the ecological fallacy, so we should be careful not to assume that relationships found at the group level also apply at the individual level (Kramer, 1983; Schwartz, 1994).

3.1.2 Census and American Community Survey Data

In order to control for travel behavior changes, we collected journey-to-work Census data from the National Historical Geographic Information System (NHGIS) for the years 2000 and 2010 as well as ACS data for 2012 for both the city and block group level (Manson, Schroeder, Riper, & Ruggles, 2017). Our variables of interest were bicycle mode share to work, transit mode share to work, and the work from home mode share. Driving mode share had a high inverse correlation with transit mode share and was not included in the analysis. For the sake of the longitudinal analysis, we interpolated between the Census and ACS years for each variable using the trend function in Microsoft Excel, which performs a linear least squares statistical regression. While annual data would have been preferred, such data was not available for these variables.

Akin to the travel behavior data, we collected socio-demographic and socio-economic changes – in terms of age, race/ethnicity, and income – from the Census and ACS. In terms of age, we developed several age-related variables based on groups that the literature suggests have the highest risk. We created variables identifying the percent of the population age 15 to 24 and the percent of the population age 65 or older, with the thinking being that places with a higher percentage of those age groups may have worse road safety outcomes, all things being equal. Our race/ethnicity variables were highly correlated with one another and could result in multicollinearity and biased estimators; as a result, we aggregated the data into a variable representing the percentage of non-Hispanic white residents. Income variables represented median household income in thousands of dollars.

3.1.3 Built Environment Data

With this research, we want to understand the influence that bike infrastructure might have on road safety outcomes. Although most of our cities managed bike infrastructure GIS layers, only Portland included the year each facility was built as an attribute. For our other cities, collecting longitudinal bike infrastructure proved to be relatively difficult and time consuming. The objective was to categorize and time stamp each piece of bike infrastructure in each city by type (i.e. protected/separated bike facilities, bike lanes, and shared lane markings or sharrows) and the year it was built. This required a combination of emails/phone calls with city planners and in-depth review of old bike maps and historic satellite imagery available in Google Earth. The goal was to be as accurate as possible given the data limitations, so most of this work was done manually and ended up being quite time consuming. When we compared our ability to discern bike infrastructure via Google Earth imagery against old bike maps, our results matched up well. During the Google Earth work, however, we noticed that some protected/separated cycle tracks, for instance, were previously bike lanes or sharrows. This led us to perform the same satellite imagery review for Portland as well. After categorizing and time stamping each piece of bike infrastructure based on Federal Highway Administration (FHWA) definitions, we calculated the cumulative length and density of each facility type for each year (FHWA, 2015).

To control for the impact of the built environment, we also sought out population density data. Population density has long been used as a measure of urban form and has been shown to be associated with fatal crash outcomes (Ewing & Dumbaugh, 2009; Ewing et al., 2014; Marshall & Ferenchak, 2017; Marshall & Garrick, 2010a; Tsai, 2005). Since boundaries sometimes change over time (such as when a city annexes new land), we wanted to be careful not to simply calculate population density based upon the most recent areas. Accordingly, we downloaded historic GIS shapefiles from NHGIS and calculated population density using time series population data and the shapefile from the nearest year.

We also collected cross-sectional intersection density data at the block group level, calculated as the number of intersections, including dead ends, per square mile (Marshall & Garrick, 2012). Intersection density is a measure of street network compactness or density (Marshall & Garrick, 2012) and has been shown to be associated with road safety outcomes (Marshall & Garrick, 2011a) as well as vehicle speed. Yokoo and Levinson (2016) used GPS data to study actual travel speeds in relation to street network variables and found long links to be conducive to higher speeds (Yokoo & Levinson, 2016). In order to gain a better sense of the impact of the built environment on vehicle speeds, we also collected data from an open source program called CitySpeed that aggregates an average driving speed in each city by mapping the distance and duration of over 1,000 routes in each city (Kleint, 2009). Based upon an origin-destination matrix determined by popular coffee shops and schools, this Python script then collects data for each origin-destination pair from the Google Maps API regrading average speed, distance, duration, number of turns, and the number of turns per mile. We collected data from the CitySpeed program for each of our cities and tested the city-level average driving speed result in the statistical analysis.

3.2 Statistical Methodology

This research tries to understand what makes high-bicycling-mode-share cities safer for all road users. The dependent variable for our analysis is a crash count. One common problem with road safety research relates to the handling of injury severity. For instance, some studies intermingle fatal crashes with minor injury crashes and property damage only crashes (Scheiner & Holz-Rau, 2011). Thus, a handful of property damage only crashes could outweigh one or two fatal crashes. We focus on fatalities and severe injuries in order to maintain an emphasis on road safety outcomes as a health impact.

Given that our dependent variable is count-based data, a typical linear regression model may not be appropriate because of the requirement that the dependent response variable be normally distributed (Long, 1997). Researchers, instead, frequently apply generalized linear models (GLM) when analyzing crash data because they can account for a non-normal distribution using a link function that relates the linear portion of the model to the mean of the dependent variable. Link functions allow the response variable to relate to the explanatory variables in a nonlinear way (Long, 1997).

Since our dependent variable is count data, we initially looked to a Poisson distribution (which is a discrete probability distribution intended to measure the rate of occurrence of some event) to see if it had the correct distributional properties, but since our data is considered over-dispersed (i.e. the variance in our response variables exceeds the mean), the negative binomial is more appropriate. The negative binomial model is a generalized version of the Poisson model that accounts for this over-dispersion by introducing a random stochastic component to the log-linear Poisson mean function relationship (Long, 1997; Lord, Washington, & Ivan, 2005; Noland & Quddus, 2004).

We conducted a longitudinal study since it can help provide insight into the potential causal factors underlying changes in transportation safety outcomes (Zhou, Ivan, & Sadek, 2009). We also used a multilevel, hierarchical statistical approach. Multilevel statistical models have become standard practice for researchers conducting spatial health studies over the last two decades (Burton et al., 2009; Healy, 2001; Li, Fisher, Brownson, & Bosworth, 2005; Radenbush & Bruk, 2002; Rundle et al., 2007; Subramanian, Jones, & Duncan, 2003). Multilevel models help account for spatial autocorrelation and the idea that block group-level outcomes in the same cities share the characteristics of those cities, which would infringe upon the independence assumption of typical statistical models (Ewing, Schmid, Killingsworth, Zlot, & Raudenbush, 2003). Since our data consists of road safety outcomes and possible explanatory factors on both the block group and city levels, we grouped those levels accordingly.

In developing our database, one consistent issue was high correlation among some of our variables. For instance, population density and transit mode share had a Pearson correlation coefficient of 0.95 at the city level, which suggests a very high positive correlation. The related statistical problem was that including such highly-correlated variables in the same model could result in multicollinearity and biased estimators. While we would normally omit one of the offending variables from the final statistical model to deal with this issue, one objective of this paper was to understand the relative influence of the possible pathways to road safety outcomes. To best assess these differences, we separated the pathways into statistical blocks and initially tested each one separately against our dependent variables. The following and the left-hand portion of Table 2 indicates our block structure:

- Block 1: Travel Behavior Data
- Block 2: Built Environment Data

- Block 3: Socio-demographic and Socio-economic Data

After presenting the results of each block, we combine them into final models. First stepping through the results block-by-block meant that we could eliminate non-significant variables found in the block models from the full models, which was useful in dealing with the multi-collinearity issues (see Appendix 1 for a correlation matrix). The model fit variables shown in the results tables include log-likelihood and Wald chi-square. While these fit statistics cannot be compared across models, we used them to help with final variable selection for the full models using Stata 15.

We account for exposure in all of our models with population data at the block group level. Population-based exposure metrics are considered a better measure of road safety as a health statistic and are common in studies that consider socio-demographic and socio-economic issues (Campos-Outcalt et al., 2003; Gallaher, Fleming, Berger, & Sewell, 1992; Marshall & Ferenchak, 2017; Marshall & Garrick, 2010b; Schiff & Becker, 1996; Sewell et al., 1989). According to McAndrews et al., for example, outcomes based on population-based exposure reflect overall societal risk while those based on travel exposure (e.g. distance or time) reflect travel risk (McAndrews et al., 2013).

Table 3.2 Descriptive Statistics (selected variables)

Block	Level	Variable	Obs	Mean	SD	Min	Max
Dependent Variables							
	Block Group Level:	Fatal Crashes	112,918	0.15	0.51	0	29
	Block Group Level:	Fatal & Severe Injury Crashes	112,918	0.84	1.64	0	40
Population Variables							
	City Level:	Population *(in 1000s)*	156	942	705	383	2,896
	Block Group Level:	Population	112,918	1,479	576	0	13,362
Travel Behavior Variables							
Block 1	*City Level:*	Bicycle Mode Share to Work	156	1.52	1.52	0.11	7.01
Block 1	*City Level:*	Transit Mode Share to Work	156	10.90	9.51	0.53	32.67
Block 1	*City Level:*	Work from Home Modal Share	156	4.19	1.46	1.73	7.64
Block 1	*Block Group Level:*	Bicycle Mode Share to Work	112,918	1.06	2.51	0	62.40
Block 1	*Block Group Level:*	Transit Mode Share to Work	112,918	13.53	13.96	0	100
Block 1	*Block Group Level:*	Work from Home Modal Share	112,918	3.75	4.31	0	100
Built Environment Variables							
Block 2	*City Level:*	Density of Protected/Separated Bike Facilities *(100s of ft. per sq. mi.)*	156	30.8	30.8	0	111.6
Block 2	*City Level:*	Desnity of Bike Lanes *(100s of ft. per sq. mi.)*	156	29.3	35.8	0	135.8
Block 2	*City Level:*	Density of Sharrows *(100s of ft. per sq. mi.)*	156	41.5	106.3	0	588.3
Block 2	*City Level:*	Population Density *(pop. per sq. mi.)*	156	5,282	4,571	816	17,234
Block 2	*City Level:*	Intersection Density *(intersections per sq. mi.)*	12	181.0	97.8	53.0	396.0
Block 2	*City Level:*	Driving Speed Variable *(mph)*	12	27.8	6.2	18.0	40.1
Block 2	*Block Group Level:*	Density of Protected/Separated Bike Facilities *(100s of ft. per sq. mi.)*	112,918	61.8	1,717.2	0	144,085
Block 2	*Block Group Level:*	Desnity of Bike Lanes *(100s of ft. per sq. mi.)*	112,918	120.8	3,866.8	0	467,729
Block 2	*Block Group Level:*	Density of Sharrows *(100s of ft. per sq. mi.)*	112,918	24.2	877.0	0	149,120
Block 2	*Block Group Level:*	Population Density *(pop. per sq. mi.)*	112,918	14,361	21,538	0	1,412,671
Block 2	*Block Group Level:*	Intersection Density *(intersections per sq. mi.)*	8,686	338	220	0	1,947
Socio-economic & Socio-demographic Variables							
Block 3	*City Level:*	Percent of Population Age 15 to 24	156	15.16	1.89	11.77	20.33
Block 3	*City Level:*	Percent of Population Age 65 or older	156	10.49	1.79	6.78	14.09
Block 3	*City Level:*	Percent of Population Identifying as White	156	60.19	13.42	28.81	81.28
Block 3	*City Level:*	Median Household Income *(in 1000s)*	156	46.01	8.92	32.29	77.52
Block 3	*Block Group Level:*	Percent of Population Age 15 to 24	112,918	14.22	7.31	0	100
Block 3	*Block Group Level:*	Percent of Population Age 65 or older	112,918	10.65	7.14	0	100
Block 3	*Block Group Level:*	Percent of Population Identifying as White	112,918	54.11	29.76	0	100
Block 3	*Block Group Level:*	Median Household Income *(in 1000s)*	112,918	49.60	28.90	0	291.12

4. RESULTS

4.1 Block Model Results

As described in the statistical methodology section above, we initially developed statistical models for each data block individually. These results are presented first and include a fatality model followed by a fatal and severe injury model. If a variable in one of these models was determined to be non-significant in these block-by-block results, we were able to remove it from the corresponding full model. Every model controls for population at the block group level, and to ease interpretation of the resulting coefficients, all independent variables were standardized (for each variable, we subtracted the mean and divided by the standard deviation so that the standardized value represents the number of standard deviations above or below the mean and the resulting coefficients are more directly comparable). When dealing with multi-collinearity issues, we selected the presented models based upon model fit statistics. The dispersion parameters all indicate the negative binomial model to be appropriate, and the city variance variable suggests the same about the hierarchical modeling.

4.1.1 Travel Behavior Results

When assessing the association between bicycling mode share and fatalities, we find a 'safety in numbers' effect when the data remains ungrouped. However, when we run multilevel fatality models nested at the city level, as in Table 3, bicycling mode share at both the city and block group level become non-significant. This suggests that factors other than bicycling mode share may better account for differences in fatal crash outcomes. In the fatal and severe injury model, bicycling mode share – at both the city and block group level – is significantly associated with worse safety outcomes. Simply put, the results do not suggest a 'safety in numbers' effect.

City-level transit mode share was non-significant in both models but associated with more crashes when measured at the block group level. While riding transit is generally considered to be safer than driving, transit usage requires additional time as a pedestrian, which could potentially explain the seemingly increased risk. This result may also speak to socio-demographic and socio-economic differences with respect to road safety risk. As the existing literature described above suggests, minority populations and lower income groups tend to be associated with additional crash risk, all other variables being held equal. At the same time, these populations have also been shown to have higher transit rates (Rosenbloom & Clifton, 1996). Since this block model does not include socio-demographic or socio-economic variables, it makes sense that higher transit usage at the block group level may be associated with worse safety outcomes despite per-mile transit being safer than driving. City-level work from home mode share was significant in the fatality model and associated with fewer crashes.

While the time variable is non-significant in this first fatality model, it is highly significant in all of the other models presented in this paper. The results are consistent and suggest fewer fatalities over time but additional severe injury crashes over time.

Table 4.1 Block 1 Negative Binomial Statistical Models

		Variable	Fatal Crash Model			Fatal & Severe Injury Model		
			Coefficient	p-value	S.E.	Coefficient	p-value	S.E.
		Constant	- 1.9431	<.0001	0.1083	- 1.2372	<.0001	0.2443
Block 1	Travel Behavior	*City Level Variables*						
		Bike Mode Share	-			0.2668	<.0001	0.0211
		Transit Mode Share	-			-		
		Work from Home Share	- 0.1422	0.001	0.0420	-		
		Block Group Level Variables						
		Population	0.1626	<.0001	0.0081	0.1692	<.0001	0.0051
		Bike Mode Share	-			0.0284	<.0001	0.0069
		Transit Mode Share	0.0938	<.0001	0.0133	0.1041	<.0001	0.0069
		Work from Home Share	-			-		
		Longitudinal Effects						
		Time (years)	- 0.0002	0.968	0.0052	0.1226	<.0001	0.0019
		Model Fit						
		log of Dispersion Parameter	0.7388		0.0269	0.2870		0.0105
		Hierarchical Effects: City Variance	0.1327		0.0568	0.7147		0.2937
		Log-Likelihood	-49,078			-130,408		
		Wald Chi-Square	554			8,791		
		No. of Observations Used	112,918			112,918		
		Number of Groups	12			12		

4.1.2 Block 2: Built Environment Results

In terms of bike infrastructure, the variables representing the density of protected/separated bike facilities and the density of standard bike lanes were highly correlated with one another at both the city and block group levels (Pearson correlation coefficients of 0.68 and 0.60, respectively). The results suggest that increased density of bike facilities (either protected/separated or standard bike lanes) is associated with fewer crashes across both severity levels. Since the model employing both the city and block group-level protected/separated bike facilities variables led to the strongest model fit statistics, Table 4 displays these results. The density of shared lane markings (road markings used to indicate a shared lane for bicycles and cars and more commonly known as sharrows) turned out to be non-significant.

Higher intersection density at the block group level, a measure of street network compactness and typically illustrative of slower speed streets, was associated with fewer road fatalities as well as fewer fatal and severe crashes. Population density suggested similar trends (i.e. higher population density significantly associated with better road safety outcomes), but the variable was highly correlated with intersection density but with reduced model fit statistics. The cross-sectional, city-level speed variable was not significant in either model.

Table 4.2 Block 2 Negative Binomial Statistical Models

		Variable	Fatal Crash Model Coefficient	p-value	S.E.	Fatal & Severe Injury Model Coefficient	p-value	S.E.
		Constant	- 1.9413	<.0001	0.0550	- 1.2678	<.0001	0.1672
Block 2	Built Environment	*City Level Variables*						
		Population Density	-			-		
		Density of Protected/Separated Bike Facilities	- 0.2566	0.023	0.0425	- 0.2317	<.0001	0.0622
		Density of Standard Bike Lanes	-			-		
		Density of Sharrows	-			-		
		Driving Speed Variable	-			-		
		Block Group Level Variables						
		Population	0.1433	<.0001	0.0081	0.1549	<.0001	0.0051
		Population Density	-			-		
		Intersection Density	- 0.2724	<.0001	0.0136	- 0.1152	<.0001	0.0067
		Density of Protected/Separated Bike Facilities	- 0.0322	0.046	0.0161	- 0.0300	<.0001	0.0078
		Density of Standard Bike Lanes	-			-		
		Density of Sharrows	-			-		
		Longitudinal Effects						
		Time (years)	- 0.01123	<.0001	0.0026	0.14289	<.0001	0.0021
		Model Fit						
		log of Dispersion Parameter	0.69453		0.0273	0.28610		0.0105
		Hierarchical Effects: City Variance	0.03238		0.0141	0.33349		0.1367
		Log-Likelihood	-48,881			-130,470		
		Wald Chi-Square	954			8,744		
		No. of Observations Used	112,918			112,918		
		Number of Groups	12			12		

4.1.3 Block 3: Socio-demographic and Socio-economic Results

With regard to race and income, the Block 3 results in Table 5 generally support the literature findings. In terms of fatalities, the results suggest that, all things being held equal, we would expect fewer fatalities as block groups as cities gain higher proportions of white residents. Income results were similar, in that higher incomes were associated with better road safety outcomes, but income was highly correlated with the race variable, which resulted in the stronger models that are presented. The block-group race variable holds in the fatal and severe injury model as well but is non-significant at the city level.

In terms of age, cities with a higher percentage of the population older than 65 are significantly associated with fewer fatalities. The same can be said when looking at fatal and severe injuries with respect to the percent of the population older than 65 at the block group level. While older populations may have increased risk on a per-mile basis, they may also have lower exposure and reduced population-based crash rates. As for young people age 15 to 24, we find more young people at the block group level to be significantly associated with more fatal and severe injury crashes.

Table 4.3 Block 3 Negative Binomial Statistical Models

		Fatal Crash Model			Fatal & Severe Injury Model		
	Variable	Coefficient	p-value	S.E.	Coefficient	p-value	S.E.
	Constant	- 1.7543	<.0001	0.1238	- 1.2508	<.0001	0.1772
Block 3 Socio-economic & Socio-demographic	*City Level Variables*						
	Age: % of Population 15 to 24	-			-		
	Age: % of Population 65 Plus	- 0.1326	0.021	0.0576	-		
	Race: % of Population White	- 0.3069	<.0001	0.0910	-		
	Median HH Income (1000's)	-			-		
	Block Group Level Variables						
	Population	0.1653	<.0001	0.0081	0.1583	<.0001	0.0051
	Age: % of Population 15 to 24	-			0.0379	<.0001	0.0056
	Age: % of Population 65 Plus	-			- 0.0281	<.0001	0.0055
	Race: % of Population White	- 0.1644	<.0001	0.0099	- 0.0999	<.0001	0.0055
	Median HH Income (1000's)	-			-		
	Longitudinal Effects						
	Time (years)	- 0.01578	<.0001	0.0024	0.13729	<.0001	0.0015
	Model Fit						
	log of Dispersion Parameter	0.72331		0.0270	0.28581		0.0105
	Hierarchical Effects: City Variance	0.16877		0.0809	0.37527		0.1532
	Log-Likelihood	-48,952			-130,380		
	Wald Chi-Square	795			8,893		
	No. of Observations Used	112,918			112,918		
	Number of Groups	12			12		

4.2 Full Model Results

This section combines all the significant variables found above into full statistical models. Table 6 presents the resulting statistical models, and the dispersion parameters indicate that the negative binomial model is appropriate. Table 7 presents the percent change in expected crash counts based upon changing the level of a single variable and holding all other variables at their mean value for the dataset. These values are mathematically the same as elasticity measures but easier to visualize and comprehend (Noland & Quddus, 2004). The reference values tend to be close to the mean of that variable, and the levels generally correspond with the standard deviation. For example, consider the lower right box of Table 7, which presents the expected crash outcomes at different levels of the variable representing the percent of the population age 65 or older. At the reference value, 10% of the block group population is age 65 or older. With all other variables held at their mean, we could expect 0.79 fatal/severe injury crashes per block group per year, which equates to a crash rate of 53.4 fatal/severe injury crashes per 100,000 residents annually. In a block group where 20% of the population is 65 or older, we would expect only 0.76 fatal/severe injury crashes per block group per year. This equates to a fatal/severe injury crash rate of 51.2 per 100,000 residents annually, a 4.2% decrease.

The remainder of this section describes the results based upon such expected crash rate differences.

4.2.1 Block 1: Travel Behavior Results

When combining the three variable blocks in the same models, nearly all the travel behavior variables lose their significance. This includes the transit variables that become non-significant when either the race or income variables are added. The remaining travel behavior variable is bicycling mode share at the block group level in the fatal/severe injury model. For a block group with 3% bike mode share compared to the reference value of 1.3%, this equates to 3.9% more fatal/severe injury crashes, holding all other variables at their mean. So, when we ask the question as to what makes high-bicycling-mode-share cities safer for all road users, the answer does not seem to be a ‘safety in numbers’ effect.

4.2.2 Block 2: Built Environment Results

Though bike mode share did not explain much in terms of differences in safety outcomes, the infrastructure cities build for bicyclists played a more significant role. For example, with the variable representing the density of protected/separated bike facilities at the city level, the reference value of 25 equates to 2,500 linear feet of protected or separated bike facilities per square mile. At that density of protected/separated bike infrastructure, we would expect 0.14 fatalities and 0.79 fatal/severe injury crashes per block group per year. This equates to annual crash rates of 9.7 fatalities per 100,000 residents and 53.4 fatal/severe injury crashes per 100,000 residents. If we increase the density of protected/separated bike facilities to 5,000 linear feet per square mile (approximately 1 standard deviation increase), and holding all other variables at their mean value, we would expect 0.12 fatalities and 0.61 fatal/severe injury crashes per block group per year. With annual crash rates of 7.9 fatalities per 100,000 residents and 41.5 fatal/severe injury crashes per 100,000 residents, this suggests a nearly 18% drop in the fatal crash rate and more than a 22% drop in the fatal/severe injury crash rate. At the highest level of citywide protected/separated bike infrastructure, we would expect a 44% reduction in the fatal crash rate and more than 50% drop in the fatal/severe injury crash rate, all other variables held at their mean.

While a higher density of protected/separated bike facilities at the block group level is associated with fewer crashes in both models, the results suggest that bike infrastructure at the city level is more important. For instance, we would expect about a little less than a 3% reduction in both fatalities and fatal/severe crashes when the density of protected/separated bike infrastructure increases from the mean reference level to approximately one standard deviation higher. We also tested the variables representing the density of standard bike lanes in place of the protected/separated bike facility variables, and even though both standard bike lane variables were significant in the block models, they interestingly become non-significant in the full models. This suggests that improved road safety for all road users is tied to the prevalence of protected/separated bike facilities much more so than the prevalence of standard bike lanes.

With the built environment results, we also found that higher intersection densities at the block group level correspond with fewer expected crashes across both severity levels when holding all other variables at their mean. Since intersection density has been shown to be an appropriate proxy for the level of urbanity, these results support the research showing that more urban neighborhoods have better safety outcomes (Ewing et al., 2014; Marshall & Ferenchak, 2017).

4.2.3 Block 3: Socio-demographic and Socio-economic Results

For the variables representing gentrification and the changing demographics of a city or neighborhood, the results suggest fewer fatalities as a city or neighborhood becomes whiter. Median household income would have been similarly significant to the race variables, but the resulting models were not as strong. In terms of the city-level race variable, it was non-significant in the second model, but we would expect a 10% decrease in the fatality rate when a city changes from 50% to 60% white. The block group race variable had a similar effect in both models but to a lesser extent. As the block gentrifies and a greater percentage of white residents arrive, a jump from 50% to 60% white suggests an expected drop in fatalities of 5% and a drop in fatal and severe crashes of just over 3%. These results support studies that suggest changing demographics and economics can play a role in road safety outcomes (McAndrews et al., 2013). They are also suggestive of equity disparities that deserve additional research.

In the full fatality model, the age variables become non-significant. The block group-level age subgroup variables, however, remain significant in the fatal/severe injury model while the city-level age variables both drop out. This suggests that city-level age distributions do not seem to be important factors in block group-level crash outcomes. In terms of block group-level age categories, an increase in those aged 15 to 24 from 10% to 15% of the block group population suggests an almost 3% increase in fatal/severe injury crashes. If the population of those aged 65 or older similarly increases from 10% to 15% of the block group population, we would expect a 2% decrease in fatal/severe injury crashes. These results may speak to the possibility of reduced travel exposure for those over 65 years old. In other words, their risk may be higher per mile of travel, but if they travel less, the result may be improved road safety outcomes.

Table 4.5 Full Negative Binomial Statistical Models

	Variable	Fatal Crash Model			Fatal & Severe Injury Model		
		Coefficient	p-value	S.E.	Coefficient	p-value	S.E.
	Constant	- 1.8853	<.0001	0.0579	- 1.2554	<.0001	0.1682
Block 1 Travel Behavior	*City Level Variables*						
	Bike Mode Share	-			-		
	Transit Mode Share	-			-		
	Work from Home Share	-			-		
	Block Group Level Variables						
	Bike Mode Share	-			0.0559	<.0001	0.0054
	Transit Mode Share	-			-		
	Work from Home Share	-			-		
Block 2 Built Environment	*City Level Variables*						
	Population Density	-			-		
	Driving Speed Variable	-			-		
	Density of Protected/Separated Bike Facilitie	- 0.1939	<.0001	0.0436	- 0.2505	<.0001	0.0623
	Density of Standard Bike Lanes	-			-		
	Density of Sharrows	-			-		
	Block Group Level Variables						
	Population Density	-			-		
	Intersection Density	- 0.2715	<.0001	0.0137	- 0.1213	<.0001	0.0068
	Density of Protected/Separated Bike Facilitie	- 0.0297	0.059	0.0158	- 0.0286	<.0001	0.0077
	Density of Standard Bike Lanes	-			-		
	Density of Sharrows	-			-		
Block 3 Demographics & SES	*City Level Variables*						
	Age: % of Population 15 to 24	-			-		
	Age: % of Population 65 Plus	-			-		
	Race: % of Population White	- 0.1255	0.041	0.0613	-		
	Median HH Income (1000's)	-			-		
	Block Group Level Variables						
	Population	0.1465	<.0001	0.0080	0.1521	<.0001	0.0051
	Age: % of Population 15 to 24	-			0.0389	<.0001	0.0056
	Age: % of Population 65 Plus	-			- 0.0307	<.0001	0.0055
	Race: % of Population White	- 0.1591	<.0001	0.0098	- 0.1002	<.0001	0.0056
	Median HH Income (1000's)	-			-		
	Longitudinal Effects						
	Time (years)	- 0.0130	<.0001	0.0026	0.1414	<.0001	0.0021
	Model Fit						
	log of Dispersion Parameter	0.6745		0.0275	0.2705		0.0105
	Hierarchical Effects: City	0.0315	<.0001	0.0181	0.3374	<.0001	0.1384
	Log-Likelihood	-48,741			-130,163		
	Wald Chi-Square	1,219			9,328		
	No. of Observations Used	112,918			112,918		
	Number of Groups	12			12		

Table 4.6 Expected Change in Crash Counts for Full Models

	Fatality Model					Fatal & Severe Injury Model				
	Expected Crashes[1]	p-value	S.E.	Crash Rate[2]	Percent Change[3]	Expected Crashes[1]	p-value	S.E.	Crash Rate[2]	Percent Change[3]
Base Annual Expected Crash Outcomes/Crash Rates[1]	0.143	<.0001	0.0086	9.6	-	0.788	<.0001	0.1439	53.3	-
Block 1 - Travel Behavior Differences										
BG Level: Bicycling Mode Share to Work										
0.0%						0.770	<.0001	0.1406	52.1	-2.8%
1.3% (reference value)						0.792	<.0001	0.1447	53.6	-
3.0%						0.823	<.0001	0.1503	55.6	3.9%
5.0%						0.860	<.0001	0.1572	58.2	8.6%
7.0%						0.899	<.0001	0.1646	60.8	13.5%
Block 2 - Built Environment Differences										
City Level: Protected/Separated Bike Facility Density *(in 100s of feet per sq. mi.)*										
0	0.174	<.0001	0.0135	11.8	21.6%	1.018	<.0001	0.2036	68.8	28.8%
25 (reference value)	0.143	<.0001	0.0086	9.7	-	0.790	<.0001	0.1443	53.4	-
50	0.117	<.0001	0.0084	7.9	-17.8%	0.614	<.0001	0.1142	41.5	-22.4%
100	0.079	<.0001	0.0112	5.4	-44.4%	0.370	<.0001	0.0913	25.0	-53.2%
BG Level: Protected/Separated Bike Facility Density *(in 100s of feet per sq. mi.)*										
60 (reference value)	0.143	<.0001	0.0085	9.6	-	0.788	<.0001	0.1437	53.3	-
1,750	0.139	<.0001	0.0085	9.4	-2.8%	0.766	<.0001	0.1400	51.8	-2.7%
3,500	0.134	<.0001	0.0091	9.1	-5.7%	0.744	<.0001	0.1363	50.3	-5.5%
7,000	0.126	<.0001	0.0111	8.6	-11.3%	0.702	<.0001	0.1300	47.5	-10.9%
BG Level: Intersection Density										
81	0.196	<.0001	0.0120	13.3	19.5%	0.908	<.0001	0.1660	61.4	8.3%
144	0.181	<.0001	0.0110	12.3	10.5%	0.877	<.0001	0.1602	59.3	4.6%
225 (reference value)	0.164	<.0001	0.0099	11.1	-	0.839	<.0001	0.1532	56.7	-
324	0.145	<.0001	0.0087	9.8	-11.5%	0.794	<.0001	0.1450	53.7	-5.3%
Block 3 - Socio-economic/Socio-demographic Differences										
City Level: Percent of Population Identifying as White										
30%	0.185	<.0001	0.0309	12.5	22.4%					
40%	0.167	<.0001	0.0200	11.3	10.6%					
50% (reference value)	0.151	<.0001	0.0117	10.2	-					
60%	0.136	<.0001	0.0074	9.2	-9.6%					
70%	0.123	<.0001	0.0088	8.3	-18.3%					
BG Level: Percent of Population Identifying as White										
30%	0.162	<.0001	0.0098	11.0	11.3%	0.855	<.0001	0.1561	57.8	7.0%
40%	0.154	<.0001	0.0093	10.4	5.5%	0.826	<.0001	0.1509	55.9	3.4%
50% (reference value)	0.146	<.0001	0.0088	9.9	-	0.799	<.0001	0.1459	54.0	-
60%	0.138	<.0001	0.0083	9.3	-5.2%	0.773	<.0001	0.1411	52.2	-3.3%
70%	0.131	<.0001	0.0079	8.9	-10.1%	0.747	<.0001	0.1364	50.5	-6.5%
BG Level: Percent of Population Age 15 to 24										
0%						0.731	<.0001	0.1337	49.4	-5.2%
5%						0.750	<.0001	0.1371	50.7	-2.6%
10% (reference value)						0.771	<.0001	0.1407	52.1	-
15%						0.791	<.0001	0.1445	53.5	2.7%
20%						0.813	<.0001	0.1483	55.0	5.5%
BG Level: Percent of Population Age 65 Plus										
0%						0.825	<.0001	0.1508	55.8	4.4%
5%						0.808	<.0001	0.1475	54.6	2.2%
10% (reference value)						0.790	<.0001	0.0144	53.4	-
15%						0.774	<.0001	0.1412	52.3	-2.1%
20%						0.757	<.0001	0.1383	51.2	-4.2%

[1] *calculated using mean values for all other variables* [2] *crash rates calculated per 100,000 block group residents*

[3] *percentage change from reference value when holding all other variables at their mean*

5. CONCLUSIONS

What makes high-bicycling-mode-share cities so much safer than many of their counterparts? Our results suggest that more bicyclists on the road is not as important as the infrastructure we build for them. More specifically, our results suggest that improving bike infrastructure with more protected/separated bike facilities is significantly associated with fewer fatalities and better road safety outcomes. It stands to reason that such infrastructure may help improve bicyclist safety. Then again, our study finds protected/separated bike facilities significantly associated with better safety for all road users, so such infrastructure may have a traffic calming effect and facilitate safer speeds. Given our results, we also cannot ignore the possibility that the lower road safety risks of the people that tend to inhabit high-bicycling-mode-share cities also plays a role, as our variables representing gentrifying neighborhoods were also significant. This outcome may be indicative of inequity issues in need of additional research.

In terms of study limitations, it is important to understand that the relationship between safety outcomes and bicycling activity is quite complex and possibly bi-directional. Better safety outcomes – or at least the perception of better safety – can lead to increased bicycling. Statistically, the related methodological problem is called endogeneity (Sweet, 2014). The issue is that this could create a situation where the error term in the statistical model is correlated with the variable representing bicycling activity, which could in turn violate the independence assumption and perhaps bias the model (Baum-Snow, 2007; Chatman & Noland, 2014; Duranton & Turner, 2011; Hymel, 2009; Sweet, 2011, 2014). Future studies should attempt to control for potential endogeneity issues. While our study was an extensive data collection project that included twelve large U.S. cities and thirteen years of data, more cities, in more countries, and more years of data would still have been preferable. At this point, the results should not be considered generalizable to other countries or smaller cities.

Taking a broader view, it is important to understand that the potential pathways for safer places are complementary and should not be considered in isolation. Compact street networks in many U.S. cities, for example, are typically representative of lower-speed urban environments with better bike facilities, increased traffic calming, and improved emergency response (Pucher & Dijkstra, 2000; Retting, Ferguson, & McCartt, 2003). Those looking towards trying to fulfill the promise of Vision Zero and the goal of zero fatalities or serious injuries on the roads – as opposed to the business-as-usual, whack-a-mole approach to road safety – are in need of evidence-based research. This paper helps fulfill this need and can inform cities in their effort toward a safer and healthier transportation system.

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PART 2: Assessing Equity and Urban/Rural Road Safety Disparities

7. INTRODUCTION

Road fatalities in the United States went from being a non-factor at the turn of the twentieth century to being grouped among the top ten leading causes of death less than a generation later in 1926 (CDC, 2000). By 1951, the number of Americans killed in car crashes had surpassed one million; not long thereafter, the number of U.S. traffic deaths eclipsed the total number of Americans killed in all U.S. wars combined, including the American Revolution (Weingroff, 2003). Across the world, we face 1.2 million deaths and another 50 million injuries in road crashes each year (World Health Organization, 2004). One might assume this issue would be treated in the same vein as other international catastrophes. However, the fact that more people die on the roads globally every single day than in the September 11th terrorist attacks does not engender the same level of public outcry (World Health Organization, 2004). In the U.S., roads continue to take the lives of at least 32,000 people each year and purge more productive years of life than any other disease, including more than cancer and heart disease combined (G. Lovegrove, Lim, & Sayed, 2010; Maxton & Wormald, 2004). Moreover, road crashes are the number one cause of death for every U.S. age group from 4 through 34 (CDC, 2014). Unfortunately, we perceive this problem as part of the cost of doing business rather than what it truly is: a public health failure.

Looking at road safety like a health impact begs the question: how equitable are the impacts? Equity refers to the fairness with which impacts – both benefits and costs – are distributed (Litman, 2015). With respect to transportation, poor safety outcomes persist as a major cost. If this particular cost is not being distributed across socio-demographic/socio-economic lines or geographic areas relatively evenly, this paper intends to highlight these disparities. In other words, how equitable are the impacts along income and race/ethnicity lines? Are there geographic or urban/rural differences?

This research delves into these questions through a spatial analysis of over 970,000 road fatalities in the U.S. that took place over the course of a 24-year period (1989 – 2012). For this timespan, we attempted to geocode the entire Fatality Analysis Reporting System (FARS) database, separating out vehicle occupants from pedestrian/bicyclist fatalities, and analyzing crashes both in terms of where the crash occurred as well as by the home zip code of the driver (NHTSA, 2014). By distinguishing between where the crash happened and where those involved were likely from allowed us to better understand the impact of our transportation system on various communities and populations. Accordingly, we are able to consider road safety in a manner unlike any of the previous research that exclusively focused on crash location. This fills a major gap in the literature and facilitates a heretofore-unseen equity analysis of road safety at the zip code level of geography for the entire U.S. over a substantial 24-year timeframe.

After a brief background and literature review, we further detail the data and methodologies before presenting results and conclusions.

8. BACKGROUND

8.1 Measuring Road Safety as a Health Impact

Figure 8.1 illustrates the drop in road fatalities per 100 million miles driven in the U.S. for the last 116 years.

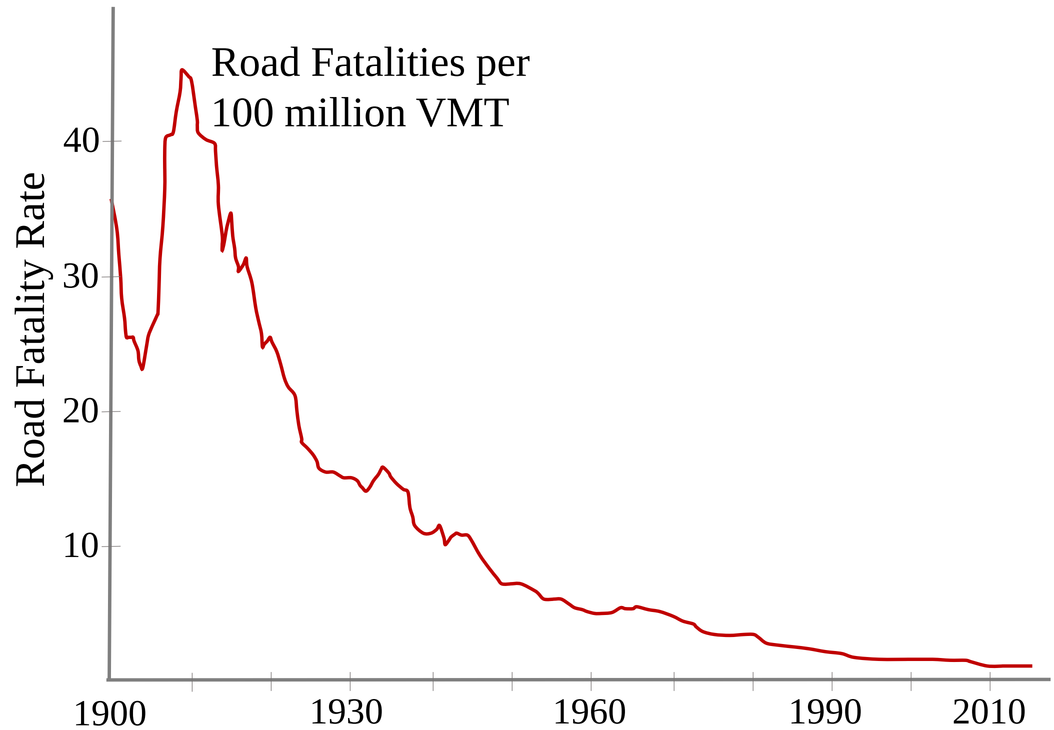

Figure 8.1 U.S. Road Fatalities per 100 million VMT (1900 – 2015)

Based on such graphs, road safety engineers boast that the U.S. transportation system is safer than ever. Looking at Figure 8.1, this point is difficult to argue. However, consider the following example comparing two hypothetical cities in Table 8.1.

Table 8.1 Road Safety Outcomes Example

	City A	City B
Annual Road Fatalities	8 deaths	8 deaths
Annual Vehicle Miles Traveled	8 hundred millions miles	1 hundred million miles
Population	50,000 people	100,000 people
Fatality Rate per Hundred Million Miles Driven	1.0	8.0
Fatality Rate per Hundred Thousand Population	16.0	8.0

Both cities in Table 8.1 experienced eight road casualties last year. Those living in City A drove a total of 8 hundred million miles while those living in City B drove 1 hundred million miles. Given the differing levels of exposure, City A has a road fatality rate of one death per hundred million vehicle miles traveled (VMT), and City B has a road fatality rate of eight per hundred million VMT. Based on such numbers, it is easy to think that City A is safest.

However, what if City A has a population of 50,000 and City B a population of 100,000? If we used population as the exposure metric, how would that change our impression of safety? Now, the road fatality rate is sixteen per 100,000 population for City A and eight per 100,000 population for City B. Using this metric – akin to how we compute other public health outcomes – City B seems safer.

Which city really is safer? To shed light on that question, we compare some example residents of City A and City B. Based on the VMT estimates, the average person in City A drives more than 40 miles per day while the average person in City B drives just over 10. For the sake of the example, let us assume that the City A resident commutes 20 miles each way to work while the City B resident commutes 5 miles each way to work, for a total of approximately 10,000 and 2,500 annual commuting miles, respectively. Over the course of the year, let us also assume that the City A resident gets into 2 crashes while the City B resident gets into only 1 crash. Using miles traveled as the exposure metric, the results would argue that the City A resident is twice as safe because they were only involved in 1 crash every 5,000 miles while the City B resident experienced 1 crash every 2,500 miles driven. However, if we consider this from the perspective of those involved, most people would rather be in the shoes of the City B resident since they were able to accomplish their daily tasks with fewer crashes. The problem with using miles driven as the exposure metric: the more one drives, the safer one seems.

Other exposure metrics include: the number of trips taken, the time spent traveling, traffic volumes, the number of streets crossed, the number of registered cars, and the number of licensed drivers (Beck, Dellinger, & O'Neil, 2007; Carroll, 1973; McAndrews, Beyer, Guse, & Layde, 2013). The problem with many of these exposure measures – such as VMT – is that neighborhood characteristics impact travel habits, which presents an endogeneity problem when it comes to trying to understand safety (Ewing & Cervero, 2001, 2010; W. E. Marshall & Garrick, 2010). For instance, living in a place where one needs to drive more to carry out his or her daily activities is: i) potentially a part of the problem when concerned with the health impacts of the transportation system; and ii) not the sort of variable we should use to normalize crashes because it rewards inefficient transportation and land uses patterns with better perceived safety outcomes. In contrast, transportation and land use planning, which has the ability to facilitate a population that lives, works, and plays in the same area, would be penalized in terms of safety outcomes due to relatively low driving exposure. The overarching problem is that with conventional mileage-based exposure metrics, populations with lower levels of driving often end up being considered less safe, even when a much lower percentage of the population is dying on the roads. This confounds the relationships among urbanism, exposure, and road safety.

Population-based exposure metrics represent a method used by several other studies that also looked at socio-demographic and socio-economic issues and are considered a better measure of road safety as a health statistic (Campos-Outcalt, Bay, Dellapena, & Cota, 2003; Gallaher, Fleming, Berger, & Sewell, 1992; W. E. Marshall & Garrick, 2011a; Schiff & Becker, 1996; Sewell et al., 1989). Figure 8.2 depicts the overall U.S. fatality rate with population as the denominator. The population-based metric tells a bit of a different story than we saw in Figure 7.1. While road safety statistics in the U.S. still seem to be headed in the right direction, presenting fatality rates with population as the exposure does a better job of representing health impacts and is the approach we employ in the remainder of the paper.

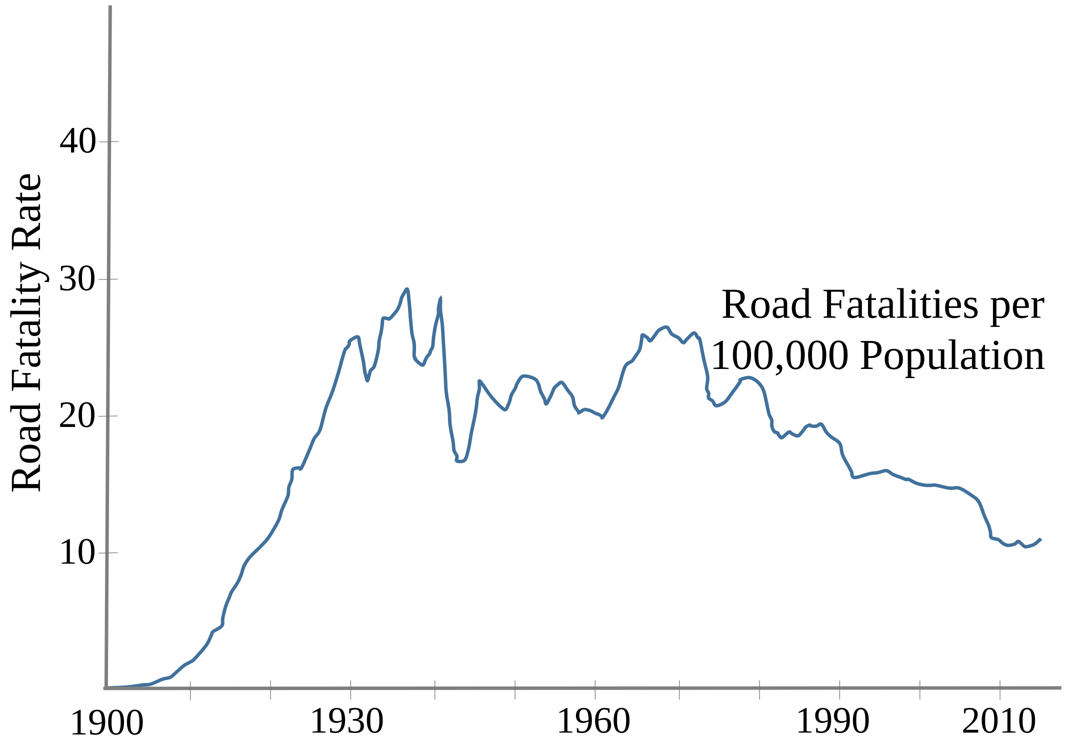

Figure 8.2 U.S. Road Fatalities per 100,000 Population (1900 - 2015)

8.2 Literature Review

The papers related to road safety and the equity/geographic issues we investigate generally fall into one of two categories: i) those that look at safety with respect to socio-demographic characteristics such as race and ethnicity; and ii) those that look at safety with respect to geographic location in terms of urban, suburban, and rural characteristics. We will briefly cover each of these literature strands before discussing some of the general limitations we seek to resolve.

The existing literature uses a variety of methods in attempting to identify road safety disparities by socio-demographic variables. Trends tended to surface – such as higher crash rates for American Indian and Black populations (Braver, 2003; Campos-Outcalt et al., 2003; Mayrose & Jehle, 2002; McAndrews et al., 2013) – but overall, the findings lacked consistency. For instance, most papers suggest higher road fatality rates for Hispanic populations as compared to non-Hispanic whites (Baker, Braver, Chen, Pantula, & Massie, 1998; Harper, Marine, Garrett, Lezotte, & Lowenstein, 2000; Schiff & Becker, 1996). However, one of the few national studies also found higher crude rates for Hispanic populations, but this result was deemed insignificant when controlling for socio-economic status (Braver, 2003). Another paper accounted for crash location across the urban-rural spectrum and found significantly *lower* fatality rates for Hispanic populations (Campos-Outcalt et al., 2003). This last paper focused on Arizona at the county level using seven years of crash data, which was representative of the general limitations of the existing work. For example, Braver's paper, while national in scope, relied upon a single year of crash data (Braver, 2003). We intend to conduct a national study at a smaller level of geography, the zip code, using 24 years of fatal crash data.

The second major strand of literature related to this paper looks at road safety with respect to geographic location. Given the national overall injury death database, it is easy to show that most deaths happen to urban residents (CDC, 2013; Myers et al., 2013). Looking more specifically at road safety, it is also easy to show that places with more people, jobs, and roads see more total crashes (Hadayeghi, Shalab, & Persaud, 2003; Hadayeghi, Shalaby, Persaud, & Cheung, 2006; Klein & Löffler, 2001; Kmet, Brasher, & Macarthur, 2003; Ladron de Guevara, Washington, & Oh, 2004; Levine, Kim, & Nitz, 1995a, 1995b). Due to a number of issues, these studies shed little light on relative risk and whether urban populations are actually less safe than those living in other contexts (Ewing, Hamidi, & Grace, 2014). One common problem relates to injury severity. Some studies intermingle fatal crashes with injury crashes and property damage only crashes (Scheiner & Holz-Rau, 2011). As a result, a handful of fender benders – which are more likely to occur in urban areas anyway – would outweigh one or two fatal crashes. Given that we are interested in the health impacts of the transportation system, we focus on road fatalities. Preferably, we would include injury-related crashes as well, particularly those of a severe nature, but that data is not consistently available nationally.

In attempting to uncover road safety disparities based on where one lives, a third limitation of most existing crash studies is the focus on crash location (Ewing et al., 2014; Lucy, 2003). For instance, a road fatality taking place in a major city may solely involve long-distance commuters instead of local residents. In other words, the location of the crash does not necessarily equate to the place of residence of those involved. Attributing that fatality to the place where the crash occurred might lead to false findings regarding the relative risk of living in a particular place. The urban area may seem to be the issue; however, sparse, homogenous land uses leading to the need to commute to that urban area in the first place may be the underlying problem. Since we seek to understand these underlying issues, we joined each FARS crash in GIS with the home zip code of the driver (which is included in a different table within the overall FARS dataset) to determine where the deceased was likely from and differentiate between where the crash took place and the communities where the populations are being impacted. This effort is similar to the methods used by Scheiner and Holz-Rau (2011) in a Germany-based study where they found fatality rates increasing with decreasing population density to the point where the most rural places had twice the risk of the most urban (Scheiner & Holz-Rau, 2011).

The next section details the data and methodology.

9. DATA & METHODS

A significant data collection effort was needed to understand the road safety research questions we present. The initial concept was to geocode as much FARS crash data as possible and assemble the most appropriate socio-demographic and socio-economic data available. Given that the driver's crash record included his/her home zip code, we focused on the zip code as the unit of analysis.

9.1 Crash Data

Administered by the National Center for Statistics and Analysis (NCSA) of the National Highway Traffic Safety Administration (NHTSA), the Fatality Analysis Reporting System (FARS) was created in 1975 to document all motor vehicle crashes resulting in a fatality (within 30 days of crash) on public roadways (NHTSA, 2014). Initial annual FARS reports are released each August for the preceding year. Approximately eight months later, the final dataset is released, which includes more than 125 pieces of information (Briggs et al., 2005).

For this project, fatal crash data from the years 1989 through 2012 was retrieved from the FARS database, and each crash record was geocoded into a GIS database. Fatal crashes occurring post approximately 2001 were typically coded using latitude and longitude information. Fatal crashes up until around 2001 were geocoded to the highest degree of accuracy possible based on the location information provided by FARS. Geocoding was conducted using ESRI Online geocoding in combination with the online mapping services MapQuest and Google. With each step, a subset of geocoded crashes were tested for accuracy and/or any systematic errors; if errors were found, the crashes would be re-geocoded using another technique. The overall geocoding success rate was 99.9995%. We excluded crashes prior to 1989 due to a lack of information sufficient for geocoding and a resulting lower success rate. Table 9.1 shows the geocoding results by method employed over three-year increments. The total number of successfully geocoded fatalities over the 24-year period of analysis included 831,399 vehicle occupant deaths and 140,207 deaths of those not within a motor vehicle (e.g. pedestrians and bicyclists) for a total of 971,606 fatalities. This equates to more than 40,483 road fatalities for each year of our 24-year study period. These fatalities corresponded to 872,929 crashes. We were able to successfully geocode 872,925 of those crashes. Thus, only 4 crashes (0.0005% of the total number of crashes) were not geocoded or included in the analysis.

Table 9.1 Geocoding Results

Years	Total Fatalities	Vehicle Occupant Fatalities	Ped/Bike Fatalities	Total Fatal Crashes	Crashes with Coordinates	Crashes Needing Geocoding	Successfully Geocoded	Geocoded with ArcGIS	Geocoded with MapQuest	Geocoded with Google
1989-1991	131,689	110,339	21,350	117,514	0	117,514	117,510	115,761	0	1,749
1992-1994	120,116	101,110	19,006	106,976	0	106,976	106,976	12,407	71,691	22,878
1995-1997	125,895	107,141	18,754	112,059	0	112,059	112,059	15,506	66,652	29,901
1998-2000	125,163	108,037	17,126	111,773	359	111,414	111,414	15,478	66,862	29,074
2001-2003	128,085	111,541	16,544	114,831	102,065	12,766	12,766	1,504	7,446	3,816
2004-2006	129,054	112,417	16,637	116,344	111,735	4,609	4,609	472	2,665	1,472
2007-2009	112,565	97,300	15,265	102,469	100,633	1,836	1,836	265	857	714
2010-2012	99,039	83,514	15,525	90,963	89,701	1,262	1,262	429	201	632
Totals	**971,606**	**831,399**	**140,207**	**872,929**	**404,493**	**468,436**	**468,432**	**161,822**	**216,374**	**90,236**

After geocoding, we then counted road deaths in two manners: i) by geocoded location (i.e. where the crash happened); and ii) by summarizing the driver's home zip code (i.e. where the deceased was likely from). This was done in order to differentiate between where fatal crashes physically took place and the communities being impacted by these fatalities. With respect to pedestrian and bicyclist road fatalities, we followed the methodology in the Scheiner and Holz-Rau (2011) paper and classified residence as the same location where the crash occurred (Scheiner & Holz-Rau, 2011). This may overestimate the number of pedestrian and bicyclist fatalities in, for instance, downtown areas; however, this was unavoidable due to the limitations of our dataset and will be accounted for when interpreting the results.

With the first step, each of the geocoded road fatalities was counted and summed at the zip code level of geography. The second GIS step involved attributing the driver's home zip code (that is available within the vehicle tables of the FARS database) to each vehicle occupant death. After linking the appropriate zip code to the person table, we summarized the total number of fatalities by zip code and joined the summary table to the zip code GIS file. The result represents the risk to an individual from that zip code under the supposition that the vehicle occupant killed was likely from the same zip code as the driver. While not ideal, this again is a limitation of our dataset.

9.2 Socio-demographic and Socio-economic Data

Beginning in 1999, FARS requested states include data for race and Hispanic ethnicity with each crash report. At that time, approximately 85% of crashes included race information (Briggs et al., 2005). Using three years of more recent data from 2010 through 2012, we calculated that only 85.9% of fatalities included race data. In terms of assessing relative accuracy for the FARS race/ethnicity data, a study by Rosenberg et al. (1999) compared death certificate data with self-reported data on race and ethnicity and found 98% accuracy for white and black populations, 83% for Asian populations, 57% for American Indian, and 90% for Hispanic ethnicities (Rosenberg et al., 1999). Given some of the issues associated with the race and ethnicity data, particularly with respect to the ten years of data from 1989 through 1998 prior to FARS including race and ethnicity, we elected to focus on the socio-demographics of the communities impacted. Accordingly, we collected Census data from the National Historical Geographic Information System (nhgis.org) for the years 1990, 2000, and 2010 and linked each crash to the nearest temporal decennial Census year (e.g. 1996 FARS data is compared to 2000 Census data). We attributed each crash to the appropriate zip code, first by crash location and second by driver's zip code. This facilitated an analysis where we could assess the relative impact of road fatalities on communities with higher or lower percentages of each population. We then collected data from the 2012 American Community Survey (ACS) and analyzed the entire crash database against the 2012 ACS socio-demographic data. The trends within each set of results (i.e. based upon the nearest temporal decennial Census year and based only on the 2012 ACS) were remarkably similar; as a result, we focused the results presented in this paper on the 2012 ACS data for the sake of consistency and clarity.

FARS does not include data related to socio-economic status. As an alternative, we followed the methodology documented by Lerner et al. (2001) and Briggs et al. (2005) where they linked the driver's zip code from the FARS database to the median household income data from the Census, or in our case, the 2012 ACS. We compared these results to that which would be found by using median household income based on crash location. This allowed us to distinguish between the concentration of fatal crashes taking place in, for instance, our lowest income neighborhoods versus the relative impact of road fatalities on those living in the same neighborhood. In other words, our methodology allowed us to estimate whether, for example, residents of poorer or wealthier neighborhoods experience an overall greater risk of road death and assess how that risk compares to methods based on crash location instead of zip code residence. Incomes are reported in 2012 dollars.

9.3 Fatality Rates and Statistical Methodology

The fatality rates presented were calculated as the number of fatalities per year per 100,000 population. During our preliminary analysis, we also found that averaging the fatality rates resulted in noticeably different results than if the fatality rates were weighted by population. Take for example: one zip code with 100,000 residents and a fatality rate of 8 deaths per year per 100,000 population; and a second zip code with only 5,000 residents but a fatality rate of 15 per year per 100,000 population. Simply averaging the two would result in a fatality rate of 11.5, which would not be representative of reality. As a result, we weighted the results by population. In this case, the average weighted fatality rate for these two zip codes would be 8.3. Thus, the fatality rates presented in the next section are population-weighted averages.

We also calculated 95% confidence intervals for the population-based fatality rates based upon the gamma distribution, which has the following relationship with the Poisson distribution and is preferred over the Normal distribution for non-negative count data such crash outcomes (Fay & Feuer, 1997):

$$\Pr[X \geq x|\mu] = \Pr[Z \leq \mu|E(Z) = x, var(Z) = x]$$

where: X is Poisson with mean μ
Z is a random variable distributed by the gamma distribution with $E(Z) = x = var(Z)$

The lower and upper confidences limits are then calculated using the following Excel equations (Kochanek, Murphy, Anderson, & Scott, 2004):

$L(\alpha)$ =GAMMA.INV(p, α, β) and U(α)=GAMMA.INV(1-p, α+1, β)

where: L *and* U represent the Lower and Upper confidence limits
p = probability = 0.025 for calculating the 95% confidence interval
α = the total number of fatalities over the 24-year period for the category of interest
β = 1 for the standard gamma distribution

After determining the lower and upper confidence limits for the total number of deaths, we calculated the upper and lower fatality rates based on the weighted population totals. This method followed the approach of McAndrews et al. (2013), and due to the extensive crash data considered for our study, resulted in relatively tight confidence intervals for most categories of interest.

10. RESULTS

The results are presented in Tables 9.1 through 9.3. Table 9.1 depicts the fatality rates and 95% confidence intervals for urban vs. rural, by population density, and by household income. We classify "urban" and "rural" areas based upon the Census Bureau definition of urban areas as: i) Urbanized Areas with populations of 50,000 or more; or ii) Urban Clusters with at least 2,500 people but less than 50,000 (U.S. Census Bureau, 2010). All locations not deemed urban are then classified as rural. Given that this binary classification is not ideal, nor representative of the spectrum of built environment types, we also disaggregate our results by population density.

Table 9.2 shows the same results by race/ethnicity, while Table 9.3 divides these categories into urban and rural contexts. The number of zip codes for each category is represented by the n value shown in the tables. The vehicle occupant results are also color-coded by relative level of safety with:

- Green = 0 to 5 fatalities per year per 100,000 residents;
- Yellow = 5 to 10 fatalities per year per 100,000 residents;
- Orange = 10 to 15 fatalities per year per 100,000 residents; and
- Red = 15+ fatalities per year per 100,000 residents.

Green is on the order of some of the safest countries in the world, such as the Netherlands, which has a fatality rate of 4.0 road fatalities per 100,000 residents (OECD, 2011). The latest road fatality rate for the U.S. is approximately 11.0 per 100,000 residents.

The results in Table 10.1 show a significant difference between the road safety health impacts of the transportation system of those living in urban areas versus those living in rural areas. This was true when aggregating by crash location as well as place of residence (by driver's zip code); in both cases, the fatality rate in rural areas was double that of urban areas. On the other hand, the pedestrian/bicyclist fatality rates were remarkably similar in urban and rural areas, despite the likelihood of large exposure differences (i.e. higher rates of walking and bicycling in urban areas) (Pucher & Renne, 2004). This may speak to a safety in numbers effect.

The population density results magnify the urban/rural comparison. Overall, those living in the sparser locations find a fatality rate more than 6X greater than those living in the densest areas. This equates to our more urban and dense areas being as safe as some of the safest developed nations in the world and our more rural areas being akin the most dangerous developed countries in the world. When evaluating from most sparse to most dense, the results show significantly greater safety with greater population densities. In fact, those living in our most rural zip codes with 50 or fewer people per square mile (which represents more than 37.5% of all zip codes) suffer from vehicle occupant fatality rates between 6X (based on driver's zip code) and 10X (based on crash location) higher than those living in our most urban zip codes. Also, the difference in pedestrian/bicyclist fatality rates were significantly different between these groups but far more similar than one might expect despite such ostensibly different rates of active transportation (Pucher & Renne, 2004).

Analyzing the fatality rates across categories of household income generated much bigger differences between the crash location results and those aggregated by the driver's zip code. For instance, with the wealthiest zip codes, the fatality rate exceeded 19 per 100,000 residents when considering where the crash occurred but less than 6 when looking at the driver's zip code. This suggests that while there might be high motor vehicle fatality numbers in our wealthiest neighborhoods, they rarely involve somebody from that neighborhood. When focusing on the driver's zip code results, lower income neighborhoods (20k – 40k median household income) experienced vehicle occupant fatality rates 3.6X higher than wealthier neighborhoods (160k to 200k median household income).

The wealthiest zip codes tended to have an exceedingly high pedestrian/bicyclist fatality rate. However, these highest income zip codes were much more likely to be located near the downtowns of major cities; thus, it is difficult to judge whether the pedestrians and bicyclists killed were residents of the same wealthy neighborhoods or downtown visitors. On the other hand, the poorest zip codes also saw a relatively high pedestrian/bicyclist fatality rate (albeit about half the rate of the wealthiest zip codes). This high rate may instead be due to a combination of an unsafe walking environment and/or a population with little choice but to walk. Overall, the income trends suggest – particularly when focusing on the driver's zip code results that are intended to be more representative of the road safety impact on the local population – tremendous disparities along income thresholds.

Table 10.2 shows that the results by race/ethnicity had fewer differences when comparing crash location and driver's zip code. Interestingly, neighborhoods with mostly white residents saw the highest fatality rate while those with relatively high Asian populations saw the lowest fatality rates. In contrast to some of the existing literature, predominantly black or Hispanic neighborhoods were significantly safer than neighborhoods with high percentages of non-Hispanic white residents. However, neighborhoods with high percentages of black or Hispanic residents saw significantly higher rates of pedestrian and bicyclist fatalities as compared to white or Asian neighborhoods. For instance, the pedestrian and bicyclist fatality rate for zip codes with less than 10% white residents was 3.3; when that percentage of white residents increased to more than 90%, the fatality rate dropped to 1.4. On the other hand, neighborhoods with less than 5% black or Hispanic residents had pedestrian and bicyclist fatality rates of 1.6 and 1.7, respectively. When black or Hispanic resident population percentages increased to more than 50%, the pedestrian and bicyclist fatality rates jumped to 3.2 and 2.7, respectively.

We disaggregated the race and ethnicity results into urban and rural categories, as shown in Table 10.3. The most noticeable differences were again in the rural versus urban findings for each category. Across the board, the rural residents had fatality rates 2X to 3X higher than those of their counterparts in almost every race/ethnicity category. The difference in pedestrian/bicyclist fatality rates between urban and rural areas was not as noticeable; however, similar race and ethnicity disparities to what we saw in Table 10.2 persisted for both urban and rural residents. More specifically, neighborhoods with high percentages of white residents were remarkably safer for pedestrians and bicyclists as compared to neighborhoods with relatively high populations of black or Hispanic residents.

Table 10.1 Road Fatality Rates by Geography and Income with 95% Confidence Intervals

Fatality Rate (fatals/100k pop)	Color Coding
0 - 5	Green
5 - 10	Yellow
10 - 15	Orange
15+	Red

		Vehicle Occupant Fatality Rate				Pedestrian/Bicyclist Fatality Rate	
	n	Crash Location	95% C.I.	Driver's Zip Code	95% CI	Crash Location	95% C.I.
Urban vs. Rural							
Urban	8,404	6.74	(6.72, 6,77)	7.79	(7.76, 7.81)	1.99	(1.98, 2.00)
Rural	24,249	17.41	(17.35, 17.45)	15.44	(15.39, 15.48)	1.82	(1.81, 1.84)
Population Density (people / sq. mi.)							
0 - 50	13,436	31.35	(31.20, 31.49)	24.49	(24.36, 24.62)	2.22	(2.18, 2.25)
50 - 200	7,107	18.82	(18.74. 18.90)	17.01	(16.93, 17.09)	1.81	(1.79, 1.84)
200 - 500	3,132	12.32	(12.25, 13.39)	11.55	(11.48, 11.62)	1.65	(1.62, 1.68)
500 - 1,000	2,097	8.73	(8.66, 8.79)	8.96	(8.90, 9.03)	1.58	(1.55, 1.61)
1,000 - 3,000	3,362	6.91	(6.87, 6.95)	7.88	(7.83, 7.92)	1.70	(1.68, 1.72)
3,000 - 5,000	3,362	5.89	(5.84, 5.94)	7.73	(7.68, 7.79)	2.04	(2.01, 2.07)
5,000 - 7,000	1,649	5.56	(5.49, 5.63)	7.46	(7.39, 7.54)	2.41	(2.17, 2.46)
7,000 - 9,000	712	4.33	(4.25, 4.42)	6.33	(6.23, 6.44)	2.25	(2.19, 2.32)
9,000 - 12,000	360	4.61	(4.51, 4.71)	6.00	(5.89, 6.12)	2.69	(2.62, 2.77)
12,000+	540	2.96	(2.91, 3.01)	4.12	(4.06, 4.18)	2.58	(2.53, 2.62)
Household Income							
0 - 20k	1,193	22.17	(21.73, 22.62)	13.03	(12.69, 13.37)	5.69	(5.46, 5.91)
20k - 40k	8,980	15.31	(15.25, 15.37)	14.98	(14.92, 15.04)	2.83	(2.80, 2.85)
40k - 80k	19,419	10.48	(10.46, 10.51)	10.55	(10.52, 10.58)	1.74	(1.73, 1.75)
80k - 120k	2,541	5.81	(5.76, 5.86)	5.62	(5.57, 5.66)	1.22	(1.19, 1.24)
120k - 160k	400	5.21	(5.08, 5.35)	4.28	(4.16, 4.40)	1.23	(1.17, 1.30)
160k - 200k	82	5.43	(5.08, 5.79)	4.12	(3.81, 4.44)	0.87	(0.74, 1.03)
200k+	38	19.16	(17.59, 20.83)	5.64	(4.81, 6.58)	10.84	(9.66, 12.11)

Table 10.2 Road Fatality Rates by Race/Ethnicity with 95% Confidence Intervals

		Vehicle Occupant Fatality Rate				Pedestiran/Bicyclist Fatality Rate	
	n	Crash Location	95% C.I.	Driver's Zip Code	95% CI	Crash Location	95% C.I.
Race / Ethnicity							
% White							
0 - 10%	486	9.56	(9.29, 9.74)	11.61	(11.42, 11.80)	3.34	(3.24, 3.45)
10 - 30%	773	8.84	(8.74, 8.94)	9.04	(8.94, 9.15)	2.99	(2.93, 3.05)
30 - 50%	1,433	9.27	(9.20, 9.35)	9.06	(8.99, 9.13)	2.69	(2.65, 2.73)
50 - 70%	2,971	9.21	(9.16, 9.27)	9.53	(9.48, 9.59)	2.30	(2.28, 2.33)
70 - 90%	8,064	9.54	(9.50, 9.57)	9.81	(9.77, 9.84)	1.76	(1.75, 1.78)
90+%	15,186	14.46	(14.41, 14.51)	13.40	(13.35, 13.45)	1.42	(1.40, 1.44)
% Black							
0 - 5%	23,572	11.69	(11.66, 11.73)	11.28	(11.24, 11.31)	1.63	(1.62, 1.65)
5 - 10%	2,672	8.59	(8.54, 8.64)	9.00	(8.95, 9.06)	1.82	(1.80, 1.85)
10 - 20%	2,451	9.78	(9.72, 9.84)	10.14	(10.07, 10.20)	2.06	(2.03, 2.09)
20 - 30%	1,277	10.46	(10.37, 10.55)	10.70	(10.61, 10.79)	2.25	(2.21, 2.29)
30 - 50%	1,346	12.46	(12.36, 12.56)	11.81	(11.71, 11.90)	2.67	(2.62, 2.71)
50+%	1,301	11.89	(11.78, 11.98)	11.69	(11.59, 11.79)	3.16	(3.10, 3.21)
% Asian							
0 - 5%	29,447	12.85	(12.82, 12.88)	12.52	(12.49, 12.55)	1.95	(1.94, 1.96)
5 - 10%	1,709	6.01	(5.96, 6.06)	6.45	(6.40, 6.50)	1.74	(1.72, 1.77)
10 - 20%	951	4.91	(4.85, 4.97)	5.42	(5.36, 5.48)	1.91	(1.87, 1.94)
20+%	546	4.42	(4.35, 4.49)	4.66	(4.59, 4.73)	2.08	(2.03, 2.13)
% Hispanic							
0 - 5%	21,401	14.32	(14.28, 14.37)	13.31	(13.26, 13.35)	1.67	(1.66, 1.69)
5 - 10%	4,268	9.51	(9.46, 9.56)	9.47	(9.42, 9.52)	1.80	(1.78, 1.83)
10 - 20%	3,207	8.63	(8.58, 8.69)	8.83	(8.78, 8.89)	1.93	(1.91, 1.96)
20 - 30%	1,338	8.70	(8.63, 8.78)	9.10	(9.02, 9.17)	2.23	(2.19, 2.27)
30 - 50%	1,226	7.97	(7.90, 8.04)	9.17	(9.09, 9.24)	2.21	(2.18, 2.25)
50+%	1,178	8.24	(8.17, 8.31)	9.35	(9.27, 9.42)	2.69	(2.65, 2.73)

Table 10.3 Fatality Rate by Race/Ethnicity by Urban and Rural with 95% Confidence Intervals

		Vehicle Occupant Fatality Rate				Pedestiran/Bicyclist Fatality Rate	
	n	Crash Location	95% C.I.	Driver's Zip Code	95% CI	Crash Location	95% C.I.
Urban							
% White							
0 - 10%	174	7.14	(6.98, 7.30)	9.36	(9.18, 9.55)	2.99	(2.89, 3.10)
10 - 30%	405	6.84	(6.74, 6.94)	7.53	(7.43, 7.64)	2.97	(2.91, 3.04)
30 - 50%	733	6.47	(6.40, 6.54)	7.18	(7.10, 7.25)	2.58	(2.54, 2.63)
50 - 70%	1,499	6.63	(6.58, 6.69)	7.55	(7.49, 7.60)	2.30	(2.27, 2.33)
70 - 90%	3,383	6.33	(6.30, 6.37)	7.61	(7.57, 7.65)	1.72	(1.70, 1.74)
90+%	2,002	8.05	(7.98, 8.11)	8.86	(8.79, 8.92)	1.33	(1.31, 1.36)
% Black							
0 - 5%	4,030	6.21	(6.18, 6.25)	7.30	(7.26, 7.33)	1.64	(1.63, 1.66)
5 - 10%	1,398	6.32	(6.26, 6.37)	7.47	(7.41, 7.53)	1.88	(1.85, 1.91)
10 - 20%	1,204	6.99	(6.93, 7.05)	8.07	(8.00, 8.14)	2.04	(2.01, 2.08)
20 - 30%	562	6.92	(6.83, 7.01)	8.14	(8.05, 8.24)	2.24	(2.19, 2.29)
30 - 50%	559	8.12	(8.02, 8.21)	8.44	(8.34, 8.54)	2.66	(2.60, 2.72)
50+%	643	8.61	(8.51, 8.70)	9.60	(9.50. 9.70)	3.11	(3.05, 3.16)
% Asian							
0 - 5%	5,925	7.82	(7.79, 7.85)	9.09	(9.06, 9.13)	2.04	(2.02, 2.06)
5 - 10%	1,253	5.47	(5.41, 5.52)	6.12	(6.07, 6.18)	1.80	(1.77, 1.82)
10 - 20%	796	4.47	(4.41, 4.52)	5.26	(5.20, 5.32)	1.92	(1.89, 1.96)
20+%	430	4.17	(4.10, 4.24)	4.56	(4.48, 4.63)	2.17	(2.12, 2.23)
% Hispanic							
0 - 5%	3,358	8.13	(8.08, 8.17)	8.55	(8.50, 8.60)	1.66	(1.64, 1.68)
5 - 10%	1,708	6.45	(8.50, 8.60)	7.30	(7.24, 7.35)	1.83	(1.80, 1.85)
10 - 20%	1,496	6.01	(5.96, 6.07)	7.08	(7.03, 7.14)	1.95	(1.92, 1.98)
20 - 30%	659	6.36	(6.28, 6.43)	7.71	(7.63, 7.79)	2.24	(2.20, 2.28)
30 - 50%	615	5.80	(5.74, 5.87)	7.67	(7.60, 7.75)	2.25	(2.20, 2.29)
50+%	561	6.30	(6.23, 6.37)	8.14	(8.06, 8.22)	2.72	(2.68, 2.77)

		Vehicle Occupant Fatality Rate				Pedestiran/Bicyclist Fatality Rate	
	n	Crash Location	95% C.I.	Driver's Zip Code	95% CI	Crash Location	95% C.I.
Rural							
% White							
0 - 10%	312	23.89	(23.17, 24.63)	24.88	(24.15, 25.63)	5.41	(5.07, 5.77)
10 - 30%	368	21.89	(21.45, 22.34)	18.93	(18.52, 19.34)	3.12	(2.95, 3.29)
30 - 50%	700	21.26	(21.00, 21.52)	17.11	(16.88, 17.35)	3.14	(3.04, 3.24)
50 - 70%	1,472	16.77	(16.63, 16.91)	15.36	(15.22, 15.49)	2.31	(2.26, 2.37)
70 - 90%	4,681	15.44	(15.36, 15.51)	13.86	(13.79, 13.93)	1.84	(1.82, 1.87)
90+%	13,184	18.04	(17.97, 18.11)	15.93	(15.86, 16.00)	1.47	(1.45, 1.49)
% Black							
0 - 5%	19,542	17.31	(17.25, 17.37)	15.35	(15.30, 15.41)	1.62	(1.61, 1.64)
5 - 10%	1,274	14.56	(14.43, 14.69)	13.04	(12.91, 13.16)	1.68	(1.63, 1.72)
10 - 20%	1,247	16.21	(16.07, 16.35)	14.89	(14.76, 15.03)	2.09	(2.04, 2.14)
20 - 30%	715	18.10	(17.89, 18.31)	16.24	(16.04, 16.44)	2.25	(2.18, 2.33)
30 - 50%	787	22.05	(21.81, 22.29)	19.25	(19.03, 19.48)	2.67	(2.59, 2.75)
50+%	658	24.96	(24.63, 25.28)	20.03	(19.75, 20.33)	3.35	(3.24, 3.48)
% Asian							
0 - 5%	23,522	18.31	(18.26, 18.36)	16.25	(16.20, 16.30)	1.85	(1.84, 1.87)
5 - 10%	456	8.67	(8.53, 8.82)	8.04	(7.90, 8.18)	1.49	(1.43, 1.55)
10 - 20%	155	9.00	(8.77, 9.25)	6.88	(6.67, 7.09)	1.75	(1.65, 1.86)
20+%	116	6.38	(6.13, 6.63)	5.45	(5.23, 5.69)	1.34	(1.23, 1.46)
% Hispanic							
0 - 5%	18,043	19.39	(19.32, 19.46)	17.20	(17.13, 17.26)	1.68	(1.66, 1.70)
5 - 10%	2,560	15.03	(14.93, 15.14)	13.38	(13.28, 13.48)	1.77	(1.73, 1.80)
10 - 20%	1,711	15.22	(15.09, 15.35)	13.23	(13.11, 13.35)	1.89	(1.85, 1.94)
20 - 30%	679	15.41	(15.22, 15.61)	13.08	(13.90, 13.26)	2.21	(2.14, 2.28)
30 - 50%	611	14.95	(14.75, 15.14)	13.99	(13.80, 14.18)	2.12	(2.04, 2.19)
50+%	617	14.45	(14.27, 14.64)	13.22	(13.04, 13.40)	2.58	(2.50, 2.66)

11. CONCLUSIONS

At a 1949 conference on road safety, President Truman spoke about the continuing "*frightful slaughter on our streets and highways*," citing the fact that the number of road fatalities in just 1948 was more than double the number of troops lost during the six-week Normandy campaign (Weingroff, 2003). Truman went on to highlight the 429 road fatalities that had occurred on Memorial Day of the previous year (Weingroff, 2003).

> *Now, if a town had been wiped out by a tornado or a flood or a fire and killed 429 people, there would be a great hullabaloo about it. We would turn out the Red Cross, and we would have the General declare an emergency... Yet, when we kill them on the road…, we just take it for granted. We mustn't do that.*
>
> − President Harry S. Truman, June 2, 1949

Now, more than 65 years after President Truman spoke about inadequate road safety and a lackadaisical attitude of the general public towards road deaths, it is hard to believe how little things have changed. With horrific car crashes a common occurrence on the nightly news, we continue to treat road fatalities as part of the cost of doing business. Unfortunately, all Americans are not bearing the costs of this problem equitably.

When the existing research uses metrics such as traffic counts as exposure, rural locations often appear safer (Hadayeghi et al., 2003; Klein & Löffler, 2001; Gordon Lovegrove & Sayed, 2006). However, the lion's share of recent research has taken an area-wide, population-based approach and found that urban places are generally safer (Eric Dumbaugh, 2006; E. Dumbaugh & Rae, 2009; Ewing & Dumbaugh, 2009; Ewing et al., 2014; Ewing, Schieber, & Zegeer, 2003; Glaeser, 2011; W. E. Marshall & Garrick, 2011a; Myers et al., 2013). Our research – which focuses on road safety as a health impact – comport with the finding that urban areas experience better road safety outcomes. Beyond the vast urban-rural divide, we also find significant discrepancies across the population density spectrum as well as by household income. For instance, those living in our most rural zip codes suffered from vehicle occupant fatality rates approximately 6X higher than those living in our most urban zip codes. Moreover, lower income neighborhoods experienced fatality rates as high as 3.6X those in wealthier neighborhoods. If the cost of doing business is people dying on the roads, it is noteworthy that those living in areas with low incomes tend to be the most impacted.

Our results also suggest road fatality disparities along racial and ethnic differences, particularly for pedestrians and bicyclists in predominantly black or Hispanic neighborhoods. While we were not able to account for the relative levels of walking and bicycling in these neighborhoods at this time, the results suggest inequities with respect to the provision of safe active transportation facilities in neighborhoods with high percentages of black or Hispanic populations as compared to neighborhoods with more white residents. Future work should take into account rates of walking and bicycling in order to better gauge safety by mode for different races and ethnicities. Other limitations of this study include the lack of person-specific income data in the FARS dataset. While we were instead able to focus on the characteristics of where the driver lives, such data being included in the FARS dataset along with the home zip code of any other victims (i.e. pedestrians, bicyclists, and motor vehicle passengers) would have been preferable. Another potential limitation relates to the fact that not everybody updates their driver's license – and their stated home code – immediately after moving.

A number of factors likely contribute to these results, including differences in transit use (Litman, 2016), emergency medical care (Lucy, 2003), alcohol consumption (Voas, Tippetts, & Fisher, 2000), and seat belt norms (Lerner et al., 2001; Wells, Williams, & Farmer, 2002). The existing research also suggests that safety decreases with increased per capita driving (Litman & Fitzroy, 2005). As such, transportation design and land use differences are also likely to play a major role in road safety outcomes. Lewis Mumford once wrote: "*a good transportation system minimizes unnecessary transportation*" (Mumford 1963). This quote from Lewis Mumford is not intended to place value judgments or specifically define what constitutes economically or socially valuable transportation. Instead, the intent is to suggest the value of facilitating more access with less travel. If one person lives on the same mixed-use block as their dentist, another lives along the same light rail corridor as their dentist, and a third person lives in a bedroom community where going to the dentist requires a 20-mile driving trip, it is important to recognize that these transportation and land use differences can have road safety impacts. Even though this driving trip for the last person might very well be economically and socially productive, the transportation and land use systems for the first two people make this driving trip – and the exposure experienced – unnecessary.

While the U.S. road fatality rate is almost as low as it has been since around the advent of the automobile, it is worth asking how the U.S. is doing as compared to the rest of the world. Given the all the engineering, vehicle, policy/regulation, and medical advances, it would make sense if the U.S. was one of the safest countries in the world when it comes to road safety. Unfortunately, this is not the case. Less than forty years ago, there were a dozen major countries with road fatality rates exceeding that of the U.S. (International Traffic Safety Data and Analysis Group, 2005). The U.S. world ranking on this front dropped to the point where nearly every single one of the Organisation for Economic Co-operation and Development (OECD) countries with road safety statistics had a lower road fatality rate per population than the U.S., and ten of those countries now have rates less than half the U.S. rate (OECD, 2011). The obvious question: what is the U.S. doing wrong?

Notwithstanding data showing that urban places were safer than rural areas as far back as the 1950s, the approach that the U.S. decided to take in trying to improve road safety over the last 65 years focused on solutions that were decidedly rural. For instance, consider the clear zone concept. The clear zone refers to the removal of trees and other "fixed-object hazards" from the roadside and has been standard design practice since the 1967 AASHO[1] publication of Highway Design and Operational Practices Related to Highway Safety, which cited the need for a 6-meter (19.7') clear zone (AASHO, 1967). Soon thereafter, the recommended lateral clearance increased to 9-meters (29.7') and explicitly included both rural and urban locations (AASHTO, 1970). While today's traffic engineers acknowledge that urban right-of-ways are often extremely restricted, the 2011 AASHTO Roadside Deign Guide continues to encourage clear zone application wherever practical (AASHTO, 2011; FHWA, 2006) despite research suggesting that such safety "improvements" may actually be a safety detriment due to issues of risk compensation (Eric Dumbaugh & Gattis, 2005; Ivan, Raghubhushan, Pasupathy, & Ossenbruggen, 1999; W. Marshall, Garrick, & Hansen, 2008; W. E. Marshall & Garrick, 2011a, 2011b; Naderi, Kweon, & Maghelal, 2008; Noland & Oh, 2004; Ossenbruggen, Pendharkar, & Ivan, 2001).

This clear zone idea originated with the 1966 Congressional road safety hearings when a General Motors engineer named Kenneth Stonex said the following (Eric Dumbaugh & Gattis, 2005; Weingroff, 2003):

> *What we must do is to operate the 90% or more of our surface streets just as we do our freeways… [converting] the surface highway and street network to freeway and Proving Ground road and roadside conditions*.
>
> − Kenneth Stonex, GM Engineer, 1966

[1] AASHO, or the American Association of State Highway Officials, was the original name of present-day AASHTO, author of the "Green Book" and also known as the American Association of State Highway and Transportation Officials.

Stonex derived this design approach from the fact that limited access highways are far safer on a per-mile basis than most other street types. However, this type of mileage-based thinking does not fully account for the costs and health impacts of our transportation system. While such designs may help facilitate longer travel distances at higher speeds – and better safety on a per-mile basis – there is a significant exposure increase and mortality cost that comes with such advantages. Good urbanism can provide more access with less mobility, and when touting the advantages of good urbanism, better road safety can be added to that list.

There is also a small strand of relevant research from England regarding the fundamental differences in how we can approach road safety issues. Davis (1993) and Tight el al. (1998) proposed what they called the "danger reduction" approach to road safety in contrast to the conventional "casualty reduction" approach. The conventional approach to road safety focuses on crash investigation, reconstruction, and prevention using performance measures based on the number of crashes per some measures of exposure. The objective is usually to devise countermeasures that diminish the chance that such crashes or injuries would occur in the future. In turn, the safety-related performance metrics should improve.
The danger reduction approach, on the other hand, takes a more comprehensive view of the road safety issue (Davis, 1993; Tight, Page, Wolinski, & Dixey, 1998). While this approach also tries to reduce crashes and injuries, it focuses more on the sources of the danger rather than the behaviors of the victims. For instance, if a bicyclist gets hit by a car, the conventional approach might focus on making sure that bicyclists wear helmets so that the chance of head trauma decreases. The danger reduction approach instead focuses on the source of the danger – in this case the car – and looks to solutions that reduce or eliminate that danger, such as improved bike infrastructure, lower driving speeds, and mode shift away from cars into modes with less chance to harm others.

This type of thinking extends to issues with crash data. A street with no pedestrian or bicyclist crashes would be deemed safe under conventional thinking. A more comprehensive approach considers the possibility that a seemingly dangerous road might be suppressing walking and biking modes. Thus, the underlying reason for the lack of pedestrian/bicyclist crashes is a lack of use. When we look to transportation as a multi-objective function where the outcomes include issues related to public health instead of just mobility, then unmet active transportation demand is also a valid concern. Despite the complexity, future road safety research needs to build upon these issues so that we can better assess the health and safety impacts of our transportation and land use systems in the proper context.

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PART 3: Age-Specific Bicycling Safety Trends, 1985-2015

13. INTRODUCTION

Despite a recent increase since 2011 (Appleyard et al. 2017), bicyclist fatalities have been in a general decline in the U.S. since at least the mid-1970's (Pucher and Dijkstra 2003; IIHS 2016). Once exposure (e.g. bicycle trips, bicycle commuters, etc.) is controlled for, trends suggest that bicycling continues to get safer (Pucher et al. 2011; Pucher and Buehler 2016). However, preliminary research notes that child bicyclist fatalities have seen a sharper decline during this time frame than other age groups (Pucher and Dijkstra 2003; IIHS 2016; Pucher et al. 1999; Williams 2014; Buehler and Pucher 2012). Has bicycling actually gotten safer, or is the downward trend in bicyclist fatality rates driven by a drop in child bicyclist fatalities? How important is age when examining bicycling safety?

Limited data pertaining to bicycling exposure has precluded a complete understanding of the impact age has on bicycling safety. Age-specific trends have been examined using a number of different exposure metrics, including per-capita fatality rates (Vargo et al. 2015) and per kilometer cycled fatality rates derived from national travel survey data (Buehler and Pucher 2017). While these methods provide important insight, we add to the conversation by examining the problem with age-specific bicycling participation data over a thirty-year time frame using exposure data from the National Sporting Goods Association (NSGA). Combined with fatality counts from the Fatality Analysis Reporting System (FARS), this paper explores the magnitude and direction of age-specific trends in bicyclist fatality rates from 1985 through 2015. The results help to define the importance of considering age when analyzing bicycling safety and add to the critical conversation of bicycle exposure metrics.

14. BACKGROUND

It is commonly reported that bicycling safety in the U.S. has generally been improving over the last forty years. Other than an increase since 2011 (Appleyard et al. 2017), the overall number of bicyclist fatalities has been in a steady general decline (Figure 14.1). Annual bicyclist fatalities have gone from a high of 1,003 in 1975 (the first year for which FARS data is available) to a low of 621 in 2010 (IIHS 2016).

These trends towards safety have been confirmed by controlling for bicyclist exposure. Exposure is commonly defined as the number of potential opportunities for a crash to occur. Both analysis of historical trends and predictive models of causation – such as safety performance functions – utilize exposure in their analyses (Turner et al. 2017). However, exposure is often measured in a number of different ways. Exposure metrics that account for the time and/or distance bicyclists spend exposed to traffic safety risks are generally preferred (Molino et al. 2012). The number of bicycle trips is also a close indicator of exposure, although not as favorable because trips can vary by time and distance. Such data are typically obtained through travel surveys such as the National Household Travel Survey (NHTS). An important aspect of these time/distance/trip exposure metrics is that they can account for the "safety in numbers" concept (Molino et al. 2012). "Safety in numbers" is an inverse non-linear relationship between bicycling levels and safety outcomes that takes effect after certain thresholds are reached (Jacobsen 2003; Nordback et al. 2014). In other words, when there are more cyclists present, those cyclists are safer than similar cyclists that do not have as many fellow riders. Drawbacks of these time/distance/trip exposure metrics include: i) difficulty in accurately recalling or recording the amount of time or distance that was cycled; and ii) adults tend to underestimate the number and duration of children's bicycle trips (Molino et al. 2012).

Figure 14.1 U.S. Bicyclist Fatalities (1975-2015)

Numbers of bicycle commuters or bicycle participants are also commonly used as measures of bicyclist exposure. Unfortunately, these metrics do not account for the number, distance, or duration of bicycle trips. For example, while two individuals may both identify themselves as bicycle riders, one may take multiple long trips each day while another rides a few short trips each month, thusly having substantially different levels of exposure. Such data can be obtained from surveys, with the American Community Survey (ACS) being a common source of bicycle commuter data.

Finally, raw population has also been used as a measure of bicyclist exposure even though the metric does not account for the number of bicyclists, number of trips, or duration/distance of those trips (Dennis et al. 2013; DiMaggio et al. 2016). Population-based exposure metrics work on the assumption that areas with more residents will experience more crashes, although it is not substantiated whether those residents are bicyclists. These population-based metrics can therefore not account for “safety in numbers” (Molino et al. 2012). Researchers have also used population data to derive exposure metrics that estimate numbers of bicyclists through the multiplication of population and commute mode share (Marshall and Garrick 2011).

One primary factor that none of these exposure metrics capture is where bicyclists are riding their bicycles. Bicyclists that ride on-road intrinsically have higher levels of exposure to traffic than bicyclists that ride off-road, where exposure to motor vehicles is typically limited to roadway crossings.

15. LITERATURE REVIEW

Researchers have utilized these various bicyclist exposure metrics at the national scale to confirm the broad trend toward improved bicyclist safety for cyclists of all ages. In the U.S. from 1977 through 2009, bicyclist fatality rates per 10 million bicycle trips (all trip purposes; from the National Personal Transportation Survey (NPTS) and the NHTS) fell from 5.1 to 1.8 (Pucher et al. 2011). From 1980 through 2008, bicyclist fatality rates per 10,000 bicycle commuters (from the U.S. Census Bureau) fell from 21 to 9 (Pucher et al. 2011). More recently, research found that bicyclist fatalities per 100 million kilometers cycled (from the NHTS) dropped from 6.8 in 2001-2002 to 4.7 in 2008-2009 (Buehler and Pucher 2017). In eight major U.S. cities, bicyclist fatalities and severe injuries per 100,000 bicycling trips decreased between 43% and 79% from the early- and mid-2000's to 2015 (Pucher and Buehler 2016). Bicycling trips were calculated by assuming that each bicycle commuter (from the U.S. Census Bureau) made two commuting trips per day, and those commuting trips accounted for 17% of all urban bicycle trips (an assumption from the 2008-2009 NHTS). There appears to be a consensus that general bicyclist fatality rates have trended downwards over the last thirty years.

While these drops in bicyclist fatalities and fatality rates are promising, past studies have noted that such trends are at least partially explained by sharp declines in child bicyclist fatalities (Pucher and Dijkstra 2003; IIHS 2016; Pucher et al. 1999; Williams 2014; Buehler and Pucher 2012). Declines in child bicyclist fatalities are reflected in the fact that the average age of bicyclist fatality victims in the U.S. increased from 39 years of age in 2005 to 45 years of age in 2014 (NHTSA 2016).

As with overall bicyclist fatality trends, it is important to account for exposure when examining age-specific bicyclist fatality trends. Unfortunately, while bicycle exposure data is rare, such data that is age-stratified and available longitudinally is even rarer. Many popular exposure metrics – such as commuter (16 years or older) counts from the ACS – do not account for children. One method to account for such deficiencies in exposure data has been to utilize population-based exposure metrics. Such per-capita fatality rates do not account for differing levels of bicycling (bicyclists, trips, or distance/duration) but instead assume that bicycling levels remain relatively consistent over time. Vargo et al. (2015) examined annual bicyclist mortality rates per 100,000 age-specific persons, finding that trends varied in direction and magnitude for different age groups (Vargo et al. 2015). While bicyclist fatality rates for children aged less than 15 years declined by 92% between 1975 and 2012, the rate for adults aged 35-54 years increased threefold (Vargo et al. 2015). Sanford et al. (2015) found similar trends for per-capita bicyclist injury rates and per-capita bicycling-related hospital admissions from 1998 to 2013. While the proportion of bicycle injuries and hospital admissions decreased for bicyclists aged 18 years to 44 years, they increased for bicyclists aged 45 years and up (Sanford et al. 2015). Although findings from these works are insightful, they utilize population-based exposure metrics, a form which does not account for actual levels of bicycling. We will explore the age-specific bicyclist safety trend with an exposure metric that accounts for the number of bicyclists.

Researchers have also studied age-specific bicycling fatality rates with kilometers cycled (from the NHTS) as an exposure metric (Buehler and Pucher 2017). Fatality rates decreased for all age groups from 2001-2002 to 2008-2009. The largest drop (while not statistically significant) was seen for individuals aged 15 years to 24 years (10.0 to 4.2 bicyclist fatalities per 100 million kilometers) while the smallest drop (statistically significant) was for children aged 5 years to 14 years (5.9 to 4.1 bicyclist fatalities per 100 million kilometers). Such exposure metrics – while insightful because they account for distance of bicycle travel – provide only two snapshots over a relatively small timeframe. This paper will examine each year over a thirty year period with an exposure metric that accounts for the number of bicycle riders. While bicycling fatalities and fatality rates in the U.S. have been found to generally decrease over the most-recent decades, important differences in age have been identified that warrant further exploration.

16. DATA

16.1 Crash Data

In order to study age-specific differences in bicycling safety, we utilized bicyclist fatalities from FARS, a database maintained by the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA). We would have preferred to look at data pertaining to all bicyclist injuries and fatalities because other factors (e.g. improved emergency medical care) may have concurrently impacted fatality rates over the study period. Unfortunately, examining all bicyclist injuries on the national level is not currently feasible due to bicyclist injuries being underreported and inconsistently reported (Pucher and Dijkstra 2003). To be included in the FARS database, a crash must involve a motorist on a roadway that is open to the public and must result in a fatality (either vehicle occupant or non-occupant) within 30 days of the collision. Lone bicyclist crashes, bicyclist-on-bicyclist crashes, bicyclist-on-pedestrian crashes, and dooring crashes that result in a fatality are missed in this database. We queried person tables for non-occupant bicyclists whose injuries were classified as fatal. We also utilized the age variable, which has been consistently reported (other than a change in the designation of unknown ages) across the study years. Bicyclist fatality victims with unknown ages were not used in the analysis (149 of the 23,872 total bicyclist fatalities from 1985-2015).

16.2 Exposure Data

We then needed an age-specific exposure metric. We utilized participation data from the National Sporting Goods Association (NSGA) for this end. Data from the NSGA was used because it has been consistently reported over the last thirty years. The NHTS and its predecessor the NPTS have been run every 5-8 years in 1969, 1977, 1983, 1990, 1995, 2001, and 2009. However, because the survey shifted from recalling prior trips to a travel diary in 1995, children below five years of age were included beginning in 2001, and prompts were incorporated in 2001 to remind respondents to include walk/bike trips, it is difficult to compare data longitudinally (Santos et al. 2011). Bicycling data from the U.S. Census Bureau is available decennially for 1980, 1990, and 2000, and for every year from 2001 to the present. However, numbers provided are for commute trips by workers 16 years and over and do not include children or recreational trips. A population-based exposure metric can be used for the thirty-year timeframe, but population-based exposure metrics do not account for levels of bicycling activity. While bicycling participation is not as ideal as a distance- or duration-based exposure metric, the participation exposure metric from the NSGA is available with a consistent survey methodology over thirty years and is age-specific.

On behalf of the NSGA, Survey Sampling International (SSI) maintains a panel that is used to reach out to random households across the U.S. Data pertaining to activity participation over the previous year is collected for household members that are seven years of age or older. Approximately 34,000 – 35,000 individuals annually have returned surveys since an online format was introduced in 2010, while 10,000 – 15,000 households were mailed surveys from 1985 to 2009. The NSGA weights responses to demographic compositions based on state of residence, household income, and population density, higher weights being given to population segments with lower return rates. Data is then projected to the U.S. population by age and gender to become nationally representative, despite relatively small annual sample sizes. According to the NSGA, African Americans and Hispanics have been somewhat underrepresented since the 2010 format transition (NSGA 2016).

By asking for the number of days of participation in “Bicycle Riding” over the last year, the survey measures the number of participants and the frequency of participation (days per year). Bicycle riding participants are defined as individuals who rode their bicycle six or more times in the last year. Both recreational and utilitarian bicycling trips are accounted for in the “Bicycle Riding” category used in this analysis. A separate category in the NSGA data that captures mountain bicycling participation was not used in this analysis. The survey covers a total of 55 sports and recreational activities, which are shown in alphabetical order for half of respondents and reverse-alphabetical order for the other half of respondents in order to reduce bias.

Participation levels measured by the NSGA are not direct measures of exposure, as explained in the literature review. It is certainly possible that bicyclists in 1985 rode for longer or shorter distances or durations than bicyclists in 2015. Ideally, bicycle trip distance or time spent exposed to traffic would be used as a direct measure of bicyclist exposure to traffic. However, participation levels can be an approximate indicator of bicycling exposure levels. NSGA data is commonly used as an exposure metric in health and safety studies (Mello et al. 2009; Conn et al. 2004; Pappas et al. 2011; Xiang et al. 2005; Bakhos et al. 2010; Kyle et al. 2002).

17. METHODS

Because of existing NSGA age designations, we defined children as individuals aged 7 years to 17 years and adults were defined as individuals aged 18 years or older. Children six years of age and younger were not included in the NSGA dataset and were therefore not included in the analysis. After querying data for appropriate age groups, we derived rates of bicyclist fatalities per 100,000 bicyclists. We also examined gender-specific trends in fatality rates. However, because gender did not provide a unique longitudinal trend while age did, gender-specific trends are not included in the analysis. This is further detailed in the Conclusions.

18. RESULTS

In the U.S. between 1985 and 2015, there were 22,744 vehicle-related fatalities of bicyclists with known ages greater than 7 years (an average of 734 annually). Bicyclist fatalities generally decreased over much of this time period, going from a high of 878 bicyclist fatalities in 1987 to a low of 610 bicyclist fatalities in 2003 (Figure 18.1). For child bicyclists aged 7 years to 17 years, fatalities dropped precipitously from a high of 444 bicyclist fatalities in 1986 to a low of 63 bicyclist fatalities in 2015. For adults aged 18 years and older, fatalities generally increased from 381 bicyclist fatalities in 1985 to 743 bicyclist fatalities in 2015.

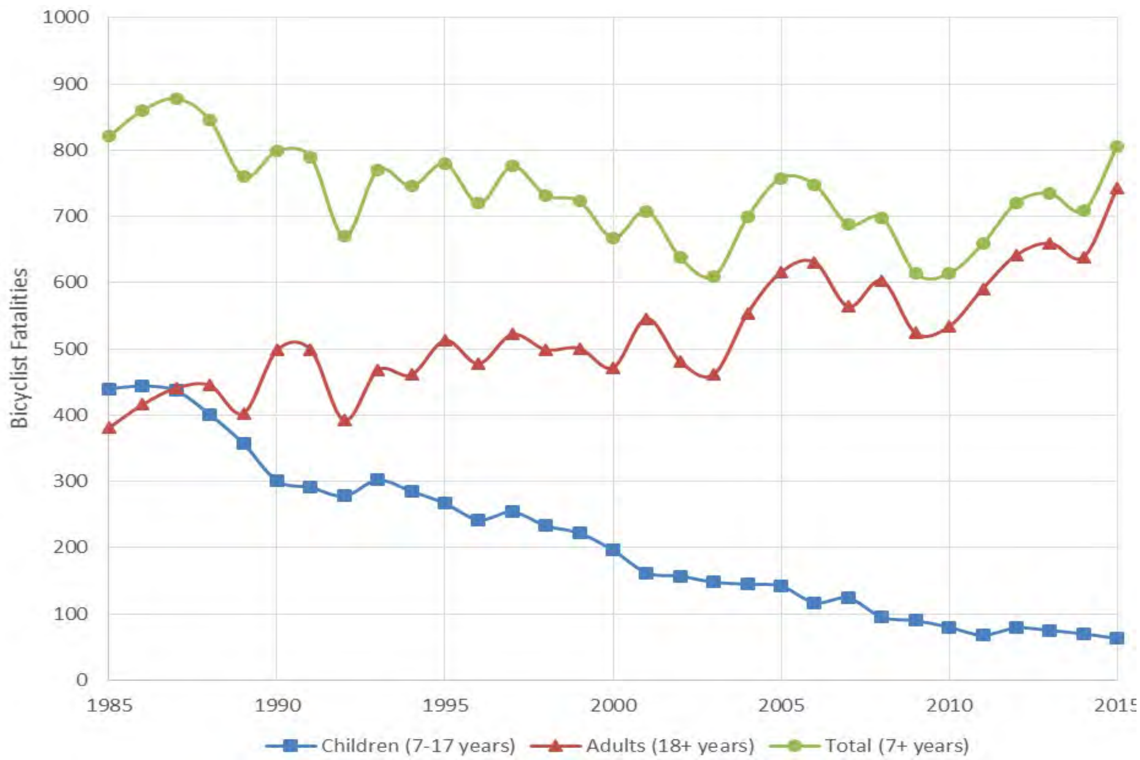

Figure 18.1 Age-specific Bicyclist Fatalities (1985-2015)

The questions that arise from these raw bicyclist fatality trends are: i) is the drop in child bicyclist fatalities because child bicyclists are getting safer or because of lower levels of child bicycling; and ii) is the increase in adult bicyclist fatalities because adult bicyclists are getting less safe or because of higher levels of adult bicycling? To answer these, we begin by looking at participation trends which leads to the analysis of fatality rates.

According to NSGA data, overall bicycling participation reached its height in 1989 with 56.9 million bicycling participants and saw the lowest participation levels in 2013 and 2014 with 35.6 million bicycling participants (Figure 18.2). Child bicycling participants went from a high of 22.9 million in 1995 to a low of 10.1 million in 2013. Adults went from a high of 35.4 million in 1988 to a low of 21.1 million in 2003.

Bicyclist fatality rates for all ages (7 years and older) went from a low of 1.22 bicyclist fatalities per 100,000 bicyclists in 1992 to a high of 2.24 bicyclist fatalities per 100,000 bicyclists in 2015 (Figure 18.3). The substantial drop in fatality rates experienced in 1992 was result of a sharp decline in bicyclist fatalities for that year. Age-specific bicyclist fatality rates vary in both direction and magnitude. Child bicyclists aged 7 years to 17 years experienced declining fatality rates, going from a high of 2.39 bicyclist fatalities per 100,000 bicyclists in 1986 to a low of 0.49 bicyclist fatalities per 100,000 bicyclists in 2011. Adult bicyclists aged 18 years and older experienced increasing fatality rates, with a low of 1.15 bicyclist fatalities per 100,000 bicyclists in 1989 and a high of 2.95 bicyclist fatalities per 100,000 bicyclists in 2006. Adult bicyclist fatality rates surpassed child bicyclist fatality rates between the years 1990 and 1993.

For comparisons sake, the graph below shows bicyclist fatality trends from 1985 – 2015 when using different exposure metrics (Figure 18.4). As can be seen, different exposure metrics tell different stories, many of which are erratic or incomplete.

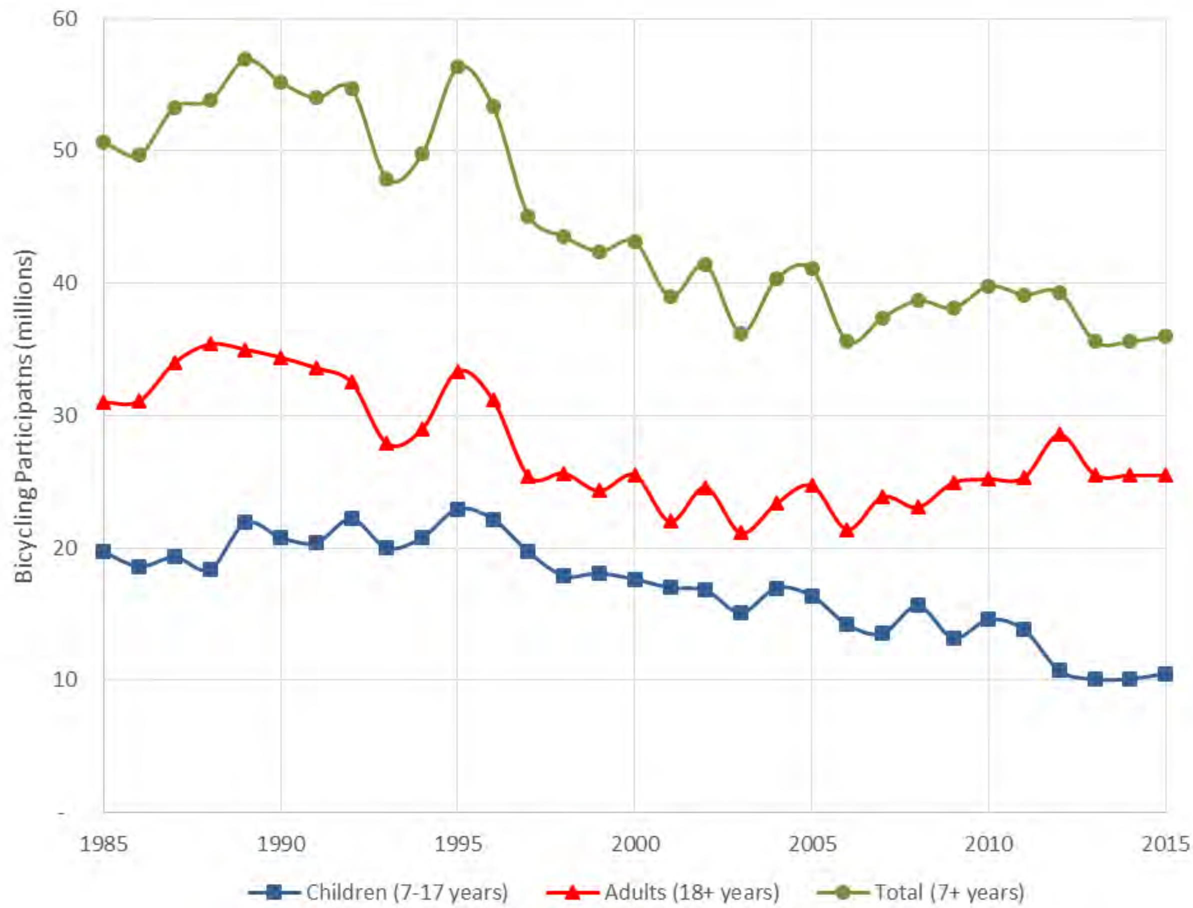

Figure 18.2 Age-specific Bicycling Participants (1985-2015)

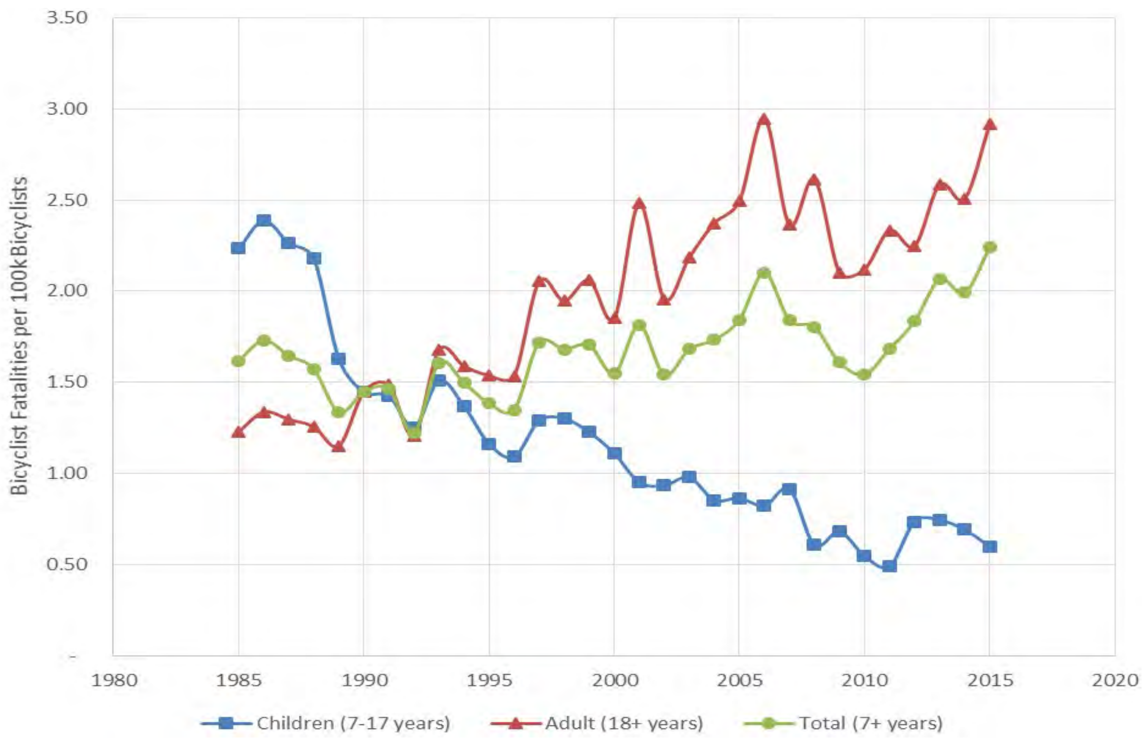

Figure 18.3 Age-specific Bicyclist Fatality Rates (1985-2015)

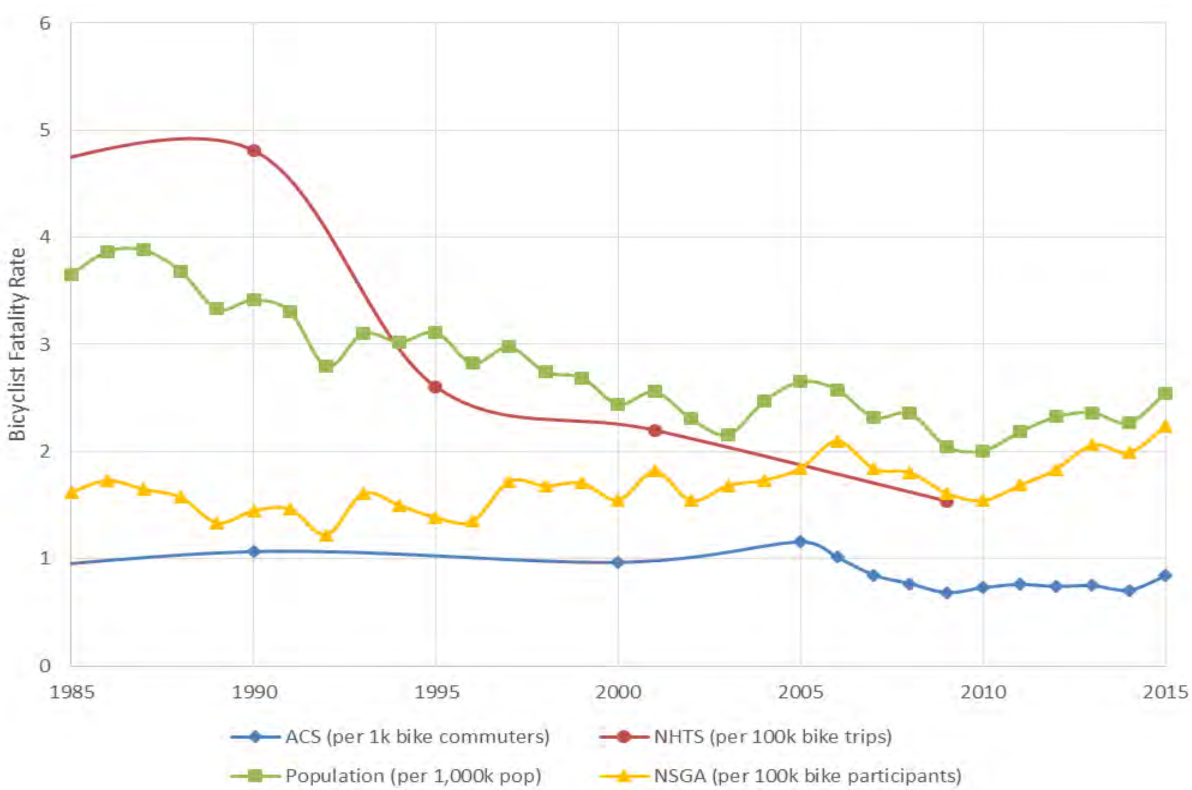

Figure 18.4 Bicyclist Fatality Rates with Different Exposure Sources
(ACS includes ages 16+, NSGA includes ages 7+, Population includes all ages, and NHTS includes ages 5+ before 2001 and all ages from 2001 on)

19. CONCLUSIONS

Findings suggest that age is an important lens through which to examine the issue of bicycling safety. Because of distinct age-specific longitudinal trends in bicycling safety which vary in direction and magnitude, it is apparent that simply examining age-aggregated trends may hide important patterns. While more evidence is necessary to determine whether bicycling has been getting more or less safe, we can definitively say that age plays an important role in that answer.

Gender-specific trends in fatality rates were also examined in the analysis. However, gender-specific analysis did not elucidate trends with unique magnitudes or direction and were therefore not included in this study. Female bicyclists were found to be much safer than male bicyclists. However, fatality rates for both female and male adult bicyclists increased throughout the study period, while fatality rates for both female and male child bicyclists decreased throughout the study period. Because gender did not provide a unique longitudinal trend while age did, gender-specific trends are not included in the analysis.

Limitations of the study are primarily focused around measuring exposure. While bicycling participation may be a general indicator of bicycling levels, it is not a direct measure of the amount of exposure bicyclists have to possible traffic collisions. The NSGA survey is also a small survey relative to other sources of bicyclist exposure data, with responses returned by approximately 35,000 individuals annually. In comparison, the NHTS had responses returned by over 300,000 individuals in 2009 and the ACS had responses returned by over 2.46 million individuals in 2015 (Santos et al. 2011; U.S. Census Bureau 2017). Furthermore, there are inconsistencies between data provided by the NSGA and data provided by the federal government in terms of bicyclist gender. Responses from the NHTS indicate that women made 24% of all bicycle trips in 2009 while the ACS indicates that 30.8% of bike commuters were women in 2015 (Alliance for Biking & Walking 2016). Bicycling participation numbers from the NSGA suggest that slightly more than 43% of bicycle participants in 2015 were women, significantly higher than the federal numbers. However, a recent PeopleForBikes survey (with responses from approximately 24,000 individuals) reported that 43% of individuals that rode a bicycle in 2014 were women (PeopleForBikes 2017). In addition to these other concerns, the NSGA participation data does not differentiate by type of riding (recreational/utility) or location (on-road/off-road).

Another important factor to consider when looking at bicyclist safety is the geographic level of the analysis. In this study, we took a broad approach by looking at national safety trends. Such macro-scale analysis is effective at identifying pervasive trends, such as the age-specific trends identified in this paper. Such results that inform broader discussions of bicyclist safety may not be readily applicable for practitioners. More fine-grained analyses are able to provide concrete recommendations for amending scenario-specific issues.

While findings from this work may not provide a conclusive answer on the topic of bicycling safety, the results should catalyze questions regarding the structure of bicycling safety, acting as a call for future research. If the goal is to improve safety for bicyclists, might we now turn to child bicyclists to better understand safety? Have youths changed their bicycling behavior in ways that adults have not? Have engineering treatments been especially beneficial for children? Are youths riding off-road more? Or have helmet regulations or education played a role in increased safety? We can similarly ask which factors have contributed to the poor safety outcomes experienced by adults. It is questions such as these that must be examined with full consideration of age differences if we wish to have a complete view of bicycling safety.

The work should also be a call for better bicyclist data in terms of exposure. From changes in methodology and inconsistent reporting to infrequent surveying and small sample sizes, each data source has unique drawbacks. If we want to better understand bicycling safety, it needs to start with better data.

An ideal exposure metric would account for the number of bicycle trips, distance and time spent exposed to traffic, trip purpose, and rider demographics all on different geographic levels and over a longitudinal time frame. Steps to achieve such an exposure metric might have cities and planning organizations moving away from short-term manual counts toward continuous automated counts through pneumatic, video, or thermal detection and mobile technologies.

Past work has contributed much to the understanding of how to best keep bicyclists safe on our streets. However, neglecting age-specific trends in bicycling safety can hide important patterns, thereby inhibiting a complete understanding. By obtaining a more holistic view of age-specific bicycling safety through improved data sources, we may be better able to reach our goal of keeping bicyclists safe.

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PART 4: ADVANCING HEALTHY CITIES THROUGH SAFER CYCLING: AN EXAMINATION OF SHARED LANE MARKINGS

21. INTRODUCTION

Bicycling has been shown to have an overall positive impact on the health of those who ride (de Hartog et al., 2010). However, one of the primary barriers to bicycling is traffic safety concerns (Fowler et al., 2017). By improving traffic safety outcomes for bicyclists, we can expect not only direct health benefits in terms of reduced injuries and fatalities, but indirect health benefits accrued through greater participation and increased physical activity. Research has also shown that cities with elevated levels of bicycling have better safety outcomes for all road users and lower air pollution, further amplifying the health benefits of bicycling (Marshall and Garrick, 2011; Johansson et al., 2017). In terms of advancing healthy cities, enabling more bicycling through improved safety is a worthy cause.

One common method of improving traffic safety for bicyclists is through the implementation of bicycle treatments and facilities. An extensive toolbox of such treatments exists, ranging from signage and wayfinding to dedicated and protected facilities exclusive to bicyclists. A relatively new treatment is the shared lane marking.

Shared lane markings – more commonly known as sharrows – trace their origins to Denver, Colorado, in the early 1990s (Alta Planning + Design, 2004; Pein et al., 1999). The markings were initially purposed to improve bicyclist safety by raising driver awareness of bicyclists and reducing wrong-way riding (City and County of Denver, 1993). They have since evolved to serve a number of different functions, such as reducing sidewalk riding and avoiding collisions with the doors of parked cars (i.e., dooring crashes). The markings have become a popular substitute for more expensive and expansive alternatives, such as bicycle lanes and cycle tracks (Figure 21.1). Today, sharrows comprise the majority of the bicycle network in nearly every major city in the United States and have become a staple in the toolboxes of transportation planners and engineers. In 2009, sharrows were added to the Federal Highway Administration's Manual on Uniform Traffic Control Devices (MUTCD), solidifying their place as an accepted bicycle treatment (U.S. Department of Transportation, 2009). However, little past research has adequately examined whether these markings help make bicyclists safer.

One of the main reasons for this lack of safety research is a result of the lack of data on dooring crashes. Since one of the stated justifications for sharrow installation is to help move bicyclists out of the door zone, a safety analysis without dooring crashes would be insufficient. Nearly all cities neglect dooring crashes because the crashes do not involve a moving motor vehicle, therefore failing to meet the standard of what constitutes a motor vehicle crash. One of the only exceptions is the City of Chicago. In 2010, Chicago initiated a program to systematically collect dooring crash data. The release of this dooring crash data marks the first time that the impact of sharrows on bicyclist safety can begin to be properly studied.

With bicycling popularity rising in cities across the country, this paper aims to longitudinally examine safety outcomes, in terms of bicyclist injuries, Chicago block groups that had sharrows installed against block groups that installed bicycle lanes (standard, buffered, or protected) as well as those that added no new bicycle facilities. More specifically, we investigate changes in bicyclist injury counts within these treatment typology groups by utilizing negative binomial regressions. We then analyze changes in injury rates between the different typologies through a Kruskal-Wallis test.

Over the past two decades, interest in bicycling has continued to increase across the United States and the health benefits of such activity have become better understood. Coinciding with this increased interest in bicycling, sharrows have become a standard bicycle treatment. However, a void exists in the research as to how these treatments influence actual safety outcomes. This paper will utilize spatial and statistical analyses to examine the relationship between sharrows and bicyclist injuries.

Figure 21.1 Example of a Sharrow

22. THEORY

Although their overall goal is to improve bicyclist safety, the exact operational function of sharrows is multifaceted and seems to have evolved over time. Many early studies that examined sharrows identified the altering of bicycle and vehicle spacing as an objective, including the spacing of bicyclists to avoid dooring crashes (Alta Planning + Design, 2004; U.S. Department of Transportation, 2010; Pucher et al., 2010). Similarly, four of the MUTCD's five objectives for sharrows deal with lateral spacing, the first of which is to assist bicyclists with lateral positioning to avoid a bicyclist's impacting of the open door of a parked vehicle (U.S. Department of Transportation, 2009). While results are mixed, past studies suggest that the effects of sharrows on spacing tend to be theoretically positive. In other words, the mean distance between bicycles and parked cars, between bicycles and the curb, and between bicycles and moving vehicles can increase up to 10.5 inches with the installation of sharrows, which gives bicyclists more space to operate (Hunter et al., 2011; Hunter et al., 2012; Brady et al., 2010; Sando, 2014). However, other studies suggest no significant changes in lateral spacing at certain sites (Pein et al., 1999).

Today, this objective of altering spacing is less often the primary aim when installing a sharrow. Guidelines such as the MUTCD and the National Association of City Transportation Officials' (NACTO) Urban Bikeway Design Guide recommend using sharrows to accomplish a variety of other operational objectives, such as alerting road users of bicyclists' presence, encouraging safe passing behaviors, reducing wrong-way riding, indicating the proper riding path over hazards such as railroad tracks, functioning as wayfinding devices, and reducing sidewalk riding (U.S. Department of Transportation, 2009; NACTO, 2011).

The academic community has also focused on the impact that sharrows have on these other operational measures (Pein et al., 1999; Furth et al., 2011; Hunter et al., 2011; Hunter et al., 2012). Overall, past studies have reported inconsistent findings regarding the installation of sharrows in terms of weaving through vehicle queues, sidewalk riding, and wrong-way riding (Hunter et al., 2012; Alta Planning + Design, 2004; U.S. Department of Transportation, 2011; Brady et al., 2010). While sharrows have been used to accomplish a wide array of operational objectives with varying levels of success, the impact on the overall goal of improved bicyclist safety has been largely neglected (Brady et al., 2010).

The lone piece of research we found that examines the impact sharrows have on safety suggests sharrows may be less safe than other bicycle treatments or even less safe than having no bicycle treatments present at all (Harris et al., 2013). Although not reaching statistical significance, the results of Harris et al. (2013) suggest that sharrows increase bicyclists' risk for injury at non-intersection locations, while cycle tracks and bicycle lanes significantly decrease the risk of injury for bicyclists compared with similar roadways that lacked bicycle infrastructure. This case-crossover study, which took place in Vancouver and Toronto, Canada, examined adult bicyclists who were injured and treated at a hospital. The researchers identified the injury location (the case site), selected two other locations along each bicyclist's route (control sites), recorded roadway characteristics of the sites, and then compared the likelihood of being injured based on the different roadway characteristics. Crashes that did not result in a hospital stay were not included in order to better focus on safety-related health outcomes. Dooring crashes were also not explicitly included or separately analyzed. This lack of dooring crash data presents a gap in the current literature, as past research gives reason to believe that dooring crashes are an important crash type to account for when examining the impact of sharrows on bicyclist safety.

23. DATA

In order to explore the relationship between sharrows and bicyclist safety outcomes, we examined Chicago on the block group level between 2011 and 2014. To do so, we needed data regarding bicyclist injuries, bicyclist exposure, and bicycle treatments. We then examine the changes in bicyclist injuries both within the individual treatment typologies and between the treatment typologies.

The City of Chicago, through the Illinois Department of Transportation, provided us with bicyclist injury data. These data included the location of bicyclist injuries from both dooring and non-dooring crashes within Chicago from 2011 through 2014. The severity of the bicyclists' injuries was not provided and was therefore not utilized in this study. We used injuries instead of fatalities because of the relative scarcity of bicyclist fatalities within Chicago. Originally in spreadsheet format, we geocoded the injury data using ArcGIS and created a layer with each injury crash represented as one spatial point.

Beyond the typical absence of dooring crash data, another reason for the lack of sharrow safety research is inadequate bicycle exposure data. An ideal exposure metric would include bicyclist counts for every segment and intersection within the city and across the desired time frame. Unfortunately, no cities collect such extensive bicycling data, especially not on an adequately wide longitudinal timeframe.

An alternative approach to accounting for bicyclist exposure is through bicycle commuter data from the American Community Survey (ACS). The underlying assumption that bicycle commuters are an indicator of total bicycling exposure has been shown by past research to be a reasonable assumption (Barnes and Krizek, 2005; Turner et al., 1997) and applicable for bicycle safety studies (Aultman-Hall and Kaltenecker, 1999; Marshall and Garrick, 2011; Chen et al., 2012). While not meeting the characteristics of an ideal exposure metric, ACS data allowed us to conduct this study with bicycle commuter counts on the block group level. These journeys to work data (five-year compilations) were made available through the National Historical Geographic Information System (NHGIS) for each of the study years.

We then obtained bicycle treatment data from the City of Chicago Data Portal in ArcGIS format. Because these data did not include dates of installation, we dated the bicycle treatments by utilizing historic satellite imagery from Google Earth, historic Google Street View, Chicago bicycle maps, and communications with city planners. Installation years were identified for each roadway segment. Because we examined treatments implemented between 2011 and 2014, the available resources were able to provide the necessary precision. We obtained 2010 block group boundary layers from the U.S. Census Bureau's TIGER Products.

There were considerable increases in the mileage of both bicycle lanes and sharrows in Chicago between 2011 and 2014 (Table 23.1). These bicycle lanes and sharrows were distributed throughout the city (Figure 23.1). There were 1,948 block groups within the city that had no bicycle treatments installed in 2012 or 2013, 42 block groups that had only sharrows installed, and 149 block groups that had only bicycle lanes installed. There were also 19 block groups that had both sharrows and bicycle lanes installed in 2012 or 2013, and 20 block groups that had bicycle lane upgrades. These latter 39 block groups were not included in the analysis.

Table 23.1 Descriptive Statistics for Study Block Groups

	N	Mean	SD	Min	Max
Bicyclist Injuries					
2011-2012	3,060	1.4	2.6	0	41
2013-2014	3,174	1.5	2.6	0	40
Bicyclist Commuters					
2011-2012	13,985	6.5	15.9	0	156
2013-2014	16,903	7.9	17.0	0	167

	Mileage (2011)	Mileage (2014)	Block Groups
Sharrows	33.5	41.4	42
Bicycle Lanes	122.1	157.0	149
Standard	122.1	131.6	n/a
Buffered	0	18.2	n/a
Protected	0	7.2	n/a
None	n/a	n/a	1,948

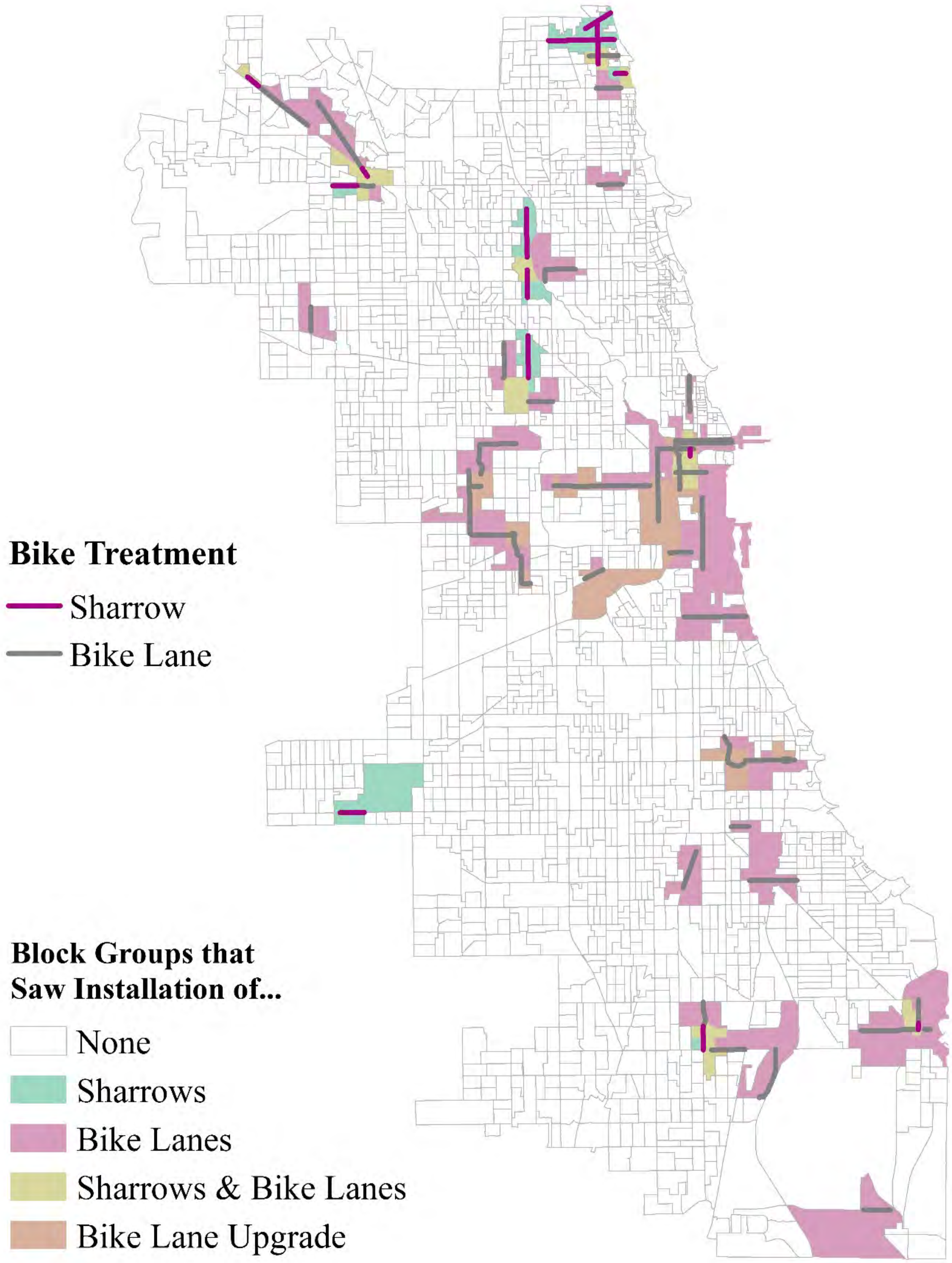

Figure 23.1 Blocks Groups with Different Types of Bicycle Infrastructure and Treatments Installed in 2012 and 2013

24. METHODS

In order to examine the relationship between sharrows and bicyclist safety, we first explore the longitudinal change in injury counts within each individual treatment typology with negative binomial regressions. We then explore the changes in injury rates between the different treatment typologies through a Kruskal-Wallis test.

After obtaining all necessary data, we operationalized bicycle treatments on the block group level by designating each 2010 block group as one of three types: i) block groups that had no bicycle infrastructure or treatments installed in 2012 or 2013, ii) block groups that had only sharrows installed in 2012 or 2013, and iii) block groups that had only bicycle lanes (standard, buffered, or protected) installed in 2012 or 2013. We designated our "before" period as 2011-2012 and our "after" period as 2013-2014. Block groups that had both sharrows and bicycle lanes installed were not included in the analysis, as combining the two types of treatments may have resulted in a unique impact on safety. While these block groups could have been considered as their own category, their rarity (only 19 out of 2,178 block groups) precluded any statistical significance. If a block group had a standard bicycle lane that was upgraded to a protected bicycle lane (20 block groups), we did not include it in the analysis. Including these block groups with any of the other categories could confound the results. Using data on the block group level employs the assumption that the impacts of bicycle treatment installation are experienced throughout the entire block group. While this macro-scale approach limited the detailed exploration of the impacts of street design and other roadway characteristics, the methodology did allow us to accomplish a city-wide analysis on the block group level – a geographic level that has been shown to be effective – that included dooring data and bicyclist exposure.

We derived the number of bicyclist injuries in the before and after periods by spatially joining the injury point layer to the block group layer in ArcGIS. Edge issues were avoided by utilizing a 500-foot buffer around each block group. We then joined the number of bicycle commuters in both the before and after periods for each block group from the ACS spreadsheets. In this way, every block group included a typology (bicycle lanes, sharrows, or none), the number of bicyclist injuries (both dooring and non-dooring) that occurred in the before period (2011-2012) and the after period (2013-2014), and the number of bicycle commuters in the before period and the after period. Again, our goal is to first examine the change in bicyclist injury counts over the study period within each individual treatment typology (using negative binomial regressions) and then examine whether any of the treatments had a significantly better or worse outcome in terms of bicyclist injury rates (using a Kruskal-Wallis test).

Using the above data, we utilized negative binomial regressions to analyze the significance of the change in bicyclist injury counts over the study period within each individual treatment typology. Negative binomial regressions have been shown to be an appropriate approach when examining differences in macro-level and block-group-level bicyclist safety relative to changes in bicycle treatments (Wei and Lovegrove, 2012; Dumbaugh and Li, 2010). The negative binomial regression accounts for the overdispersion that we had in our data – and which is typically seen in traffic crash and injury data – and is the most appropriate and accepted practice for road safety researchers. We utilized the number of commuters and facility typology as independent variables and injury counts as the dependent variable in our models.

We then sought to compare the safety impacts of the different treatments. Because the analysis called for the comparison of the changes between pre- and post-installation scenarios for three different groups, a Kruskall-Wallis test was appropriate. This is a common approach for testing pre- and post-scenarios across multiple groups, especially in medical literature (Brennan et al., 1997; Ratcliffe et al., 2002; Şentürk et al., 2002). The Kruskal-Wallis test is a non-parametric one-way analysis of variance used to compare data when the data are not normally distributed. ANOVA was not used in this case because, although the differences among group rate means were being explored, the unbalanced sample sizes proved problematic for this type of statistical analysis, and the data did not fit the normal distribution (Shaw and Mitchell-Olds, 1993).

In order to complete the Kruskal-Wallis tests, we calculated bicyclist injury rates in the form of bicyclist injuries per 100 bicycle commuters. We then weighted these rates based on the number of bicyclists in each block group. For instance, the injury rate of a block group with 100 bicycle commuters was given more weight in the overall average than a block group that had only one bicycle commuter. We used the margin of errors provided by the ACS in order to create confidence intervals around the rates. Using the Kruskal-Wallis test, we first compared bicyclist injury rates within individual treatment typologies and then compared the changes between the different treatment typologies.

25. RESULTS

We first analyzed the number of bicycle commuters in relation to the type of treatment that was installed over the study period. Block groups with only sharrows installed had the largest increase in bicycle commuters, while block groups that had no treatments installed had the smallest increase in bicycle commuter counts and block groups that had bicycle lanes installed had the smallest percentage increase (Table 24.1). These changes were significant, according to paired t-tests, for block groups that had no bicycle treatments installed and block groups that had sharrows installed.

Table 25.1 Change in Bicycle Commuters for Block Groups with Different Types of Bicycle Infrastructure Installed and Corresponding Paired T-Test Results

		Bicycle Commuters per Block Group				
	n	**Before**	**After**	**Change**	**% Change**	**p-value**
None	1,948	6.07	7.34	1.27	20.9%	0.000
Sharrow	42	10.31	15.50	5.19	50.3%	0.032
Bicycle Lane	149	11.56	13.16	1.60	13.8%	0.224

25.1 Injuries within Block Group Types

Negative binomial regressions allowed us to explore changes in bicyclist injury counts that occurred within the block group types for three categories of injuries: total injuries, dooring injuries, and non-dooring injuries (Table 25.2). For block groups that had no bicycle treatments installed and for block groups that had sharrows installed, injury counts decreased for total injuries, dooring injuries, and non-dooring injuries. All of these changes were found to be statistically significant. For block groups that had bicycle lanes installed, dooring injuries experienced a statistically significant decrease. However, overall injuries and non-dooring injuries both increased for bicycle lane block groups. These increases were significant and not significant, respectively.

Table 25.2 Negative Binomial Regression Results for Bicyclist Injuries from Before to After Installation

	n	**B**	**Std. Error**	**Sig.**
None	1,948	-0.275	0.0600	0.000
Dooring		-8.663	0.3550	0.000
Non-Dooring		-0.204	0.0638	0.001
Sharrow	42	-3.946	1.0188	0.000
Dooring		-13.074	2.0787	0.000
Non-Dooring		-6.143	2.4497	0.012
Bicycle Lane	149	5.416	1.7730	0.002
Dooring		-8.522	1.0761	0.000
Non-Dooring		0.057	0.1767	0.747

25.2 Injury Rates within Block Group Types

Ridership numbers for the different typologies enabled us to normalize the bicyclist injuries and weight the injury rates in order to account for changes in ridership brought about by these treatments (Table 25.3). A Kruskal-Wallis test examined the change in injury rates between block group typologies and between pre- and post-conditions. Because some block groups lacked bicycle commuters, we assumed one rider for null values in order to avoid artificial rate inflation. Because the bicycle lane block groups that had the smallest increases (or actually saw decreases) in injury rates had the most bicycle commuters (and were therefore weighted the heaviest), the injury rates in bicycle lane block groups saw the smallest percentage increase and the second smallest absolute increase. This suggests that bicyclists may be safer in larger numbers and that bicycle lanes may have intrinsic safety benefits for bicyclists (Nordback et al., 2014). Similarly, block groups that had no bicycle treatments installed had their highest injury rate increases in block groups with relatively few bicyclists. This resulted in the smallest overall increase and second smallest percentage increase in bicyclist injury rates. Block groups that had sharrows installed had their largest injury rate increases occur in block groups that had the most riders. For this reason, the absolute and percentage increases in bicyclist injury rates were highest in sharrow block groups. Dooring injury rates were reduced in block groups that had bicycle lanes installed and in block groups that had no bicycle treatments installed, but dooring injury rates increased in block groups with sharrows.

Table 25.3 Weighted Safety Rates for Block Groups with Different Types of Bicycle Infrastructure Installed

		Weighted Injuries per Year per 100 Bicycle Commuters				
	n	**Before**	**After**	**Change**	**Change %**	**p-value**
None	1,948	8.70	9.75	1.05	12.1%	
Dooring		1.82	1.40	-0.41	-22.5%	0.192
Non-Dooring		6.68	8.35	1.67	25.0%	0.041
Sharrow	42	8.97	18.28	9.31	103.8%	
Dooring		1.34	4.23	2.89	215.7%	0.124
Non-Dooring		7.12	14.05	6.94	97.5%	0.121
Bicycle Lane	149	16.63	18.32	1.69	10.2%	
Dooring		2.00	0.78	-1.22	-61.0%	0.053
Non-Dooring		14.53	17.54	3.02	20.8%	0.339

25.3 Injury Rates between Block Group Types

The Kruskal-Wallis test was also used to examine the differences between changes in injury rates for the treatments (Table 24.4). Block groups that had bicycle lanes installed saw a statistically smaller increase in bicyclist injury rates compared with sharrow block groups with 95% confidence. Block groups that had no bicycle treatments installed also saw a statistically smaller increase in bicyclist injury rates compared with sharrow block groups with 95% confidence. Block groups that had bicycle lanes installed and block groups that had no bicycle treatments installed did not have significantly different changes in bicyclist injury rates (Table 25.4).

Table 25.4 Significance of Kruskal-Wallis Test Examining the Longitudinal Change in Bicycle Safety at 95% Confidence

Injuries Per Year Per 100 Bicycle Commuters

		Smaller Increase in Injury Rate	
		Bicycle Lane	None
Greater Increase in Injury Rate	Bicycle Lane	*n/a*	0.779
	Sharrow	0.050	0.004

Results suggest that in Chicago for the time period studied, block groups that had sharrows installed experienced poorer safety outcomes than those experienced by block groups that had bicycle lanes installed. Block groups that had sharrows installed also experienced poorer safety outcomes than block groups that did not install any bicycle treatments. Block groups that had bicycle lanes installed saw the largest increase in bicyclist injuries between the before and the after periods while block groups that had sharrows installed saw a decrease in overall bicyclist injuries. However, after normalizing based on the increases in bicycle commuters, Chicago block groups that had bicycle lanes installed and those that had no bicycle treatments installed experienced similarly small increases in injury rates. This is partially because block groups with the largest increases in injuries had the smallest increases in ridership. Block groups that had sharrows installed experienced large increases in both the percentage change in injury rate and the absolute change in injury rate. This is because sharrow block groups that had decreases in the injury rate had few bicycle commuters, while sharrow block groups that had increases in the injury rate had many bicycle commuters. The increase in the bicyclist injury rate for Chicago block groups that had sharrows installed was statistically greater, with 95% confidence, than the increases experienced by bicycle lane block groups or those that had no treatments installed.

26. CONCLUSIONS

This work begins to fill an important gap in bicycle treatment research by investigating the safety impact of sharrows. As sharrows have become an accepted treatment in cities across the United States despite a lack of safety evaluation, this conversation has become a critical one. Our findings suggest that Chicago block groups that had sharrows installed experienced less than desirable safety outcomes for the study period. This paper finds that there is reason to further question the impact of sharrows on bicyclist safety outcomes through future research in other contexts.

While the mechanisms behind these findings are not yet understood and cannot be assembled from this paper's results, one possible explanation is that the sharrows – as installed in Chicago during the study period – provide a false sense of security to bicyclists. When a bicycle lane or other separated facility is provided, the bicyclist is granted dedicated space. This dedicated space lowers the risk of collision with a motor vehicle. Alternatively, if bicycle treatments are not provided on a roadway, it is understood that the bicyclist will need to share the travel lane with vehicles. The bicyclist should therefore ride in a manner appropriate to the level of risk created by the volume, speed, and other characteristics of the roadway. When a sharrow is provided, however, bicyclists may believe that they are at lower risk because a treatment is being provided and change their behavior accordingly or, as seen in this study, new bicyclists may be attracted to the facility. However, while the operations (e.g., lateral spacing) of vehicles and bicycles may be altered by the presence of the sharrow, those operational changes may not necessarily lower the probability of a collision with a motor vehicle. Might there be situations in which moving bicyclists farther in or out of a lane does not make them objectively safer? While subjective safety may be improved, objective safety may remain static, thus resulting in poor safety outcomes. Researchers have shown that adding crosswalks without treating underlying safety issues may give pedestrians a false sense of security and result in increased pedestrian crash rates (Herms, 1972; FHWA, 2005). Might sharrows be inducing the same phenomenon for bicyclists? Obtaining clarity on this issue will require further context-sensitive research. It is also important to recognize that all sharrows are not created equal; the "super sharrow" in Boston or the "green wave" sharrow in Long Beach might find different results, particularly in terms of helping reduce dooring crashes.

The methodologies employed throughout this research use a number of assumptions, the validity of which should also be explored in future research. First, this research employed the assumption that the impact of bicycle treatment installation will be experienced throughout the block group within which the treatment is installed. This assumption was used primarily so we could perform analysis on the block group level, which allowed for the bicycle commuter metric to be utilized for exposure. While it would be ideal to longitudinally examine specific corridors that had sharrows installed, this would have required ridership counts specific to those corridors, which was not feasible based on the size of the study and given data constraints, particularly related to exposure. However, bicycle commuter counts have been shown to be a reasonable indicator of total bicycling exposure (Barnes and Krizek, 2005; Turner et al., 1997) and to be applicable for bicycle safety studies (Aultman-Hall and Kaltenecker, 1999; Marshall and Garrick, 2011; Chen et al., 2012).

In future corridor-level work, the amount of bicycle infrastructure could be accounted for in order to directly determine the strength of the relationship between sharrows and bicyclist safety, as opposed to the inter-typology comparative approach of this work. Accounting for injury severity in future work may further inform the relationship that sharrows have with bicyclists' safety. Furthermore, future studies might benefit from the incorporation of demographics or socio-economic data into their models. Demographic and socio-economic factors have been shown to be correlated with bicycle ridership and traffic safety outcomes and may allow for a more robust model and a better understanding of the complexity of these issues.

The implications of this work could help contribute toward the goal of bettering traffic safety outcomes within our cities. The objective of this research was to identify bicycle treatments that are effective at improving bicyclist safety. The results of the analysis seem to indicate that we may need to further consider exactly where and when sharrows are used. Under current standards and guidance, sharrows can be used for a wide variety of reasons and in a wide variety of roadway conditions: from wayfinding devices to lateral spacing guides and from local roads to arterials. Researchers have not explored all of the different combinations in which sharrows can and are being used. This paper does not claim to inform any of these specific scenarios but broadly identifies one case study in which safety improvements seem to be lacking.

With sharrows becoming a familiar sight on our roadways and the health benefits of bicycling becoming clearer, it is vital to fully understand the impact that sharrows have on bicyclist safety within our cities. While past research has identified spacing and other operational metrics of bicyclists as important metrics, it is only a theoretical means to an end. The effectiveness of sharrows in terms of the true goal, which is reducing bicyclist injuries and fatalities, remains unclear in the current body of research. This work begins to question their effectiveness and should act as a call for more research on the subject. It is imperative that the appropriate infrastructure and treatments are in place to ensure the safety of all users on our roadways, and it remains to be seen what role sharrows play in this pursuit.

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APPENDICES

Teaching Materials

This following first shows the assignment from CVEN 5633: Case Studies in Sustainable Transportation, followed by two examples of student work.

Assignment from CVEN 5633: Sustainable Transportation

Case Study No. 1 – What Makes a City Safe for All Road Users?
CVEN 5633: Case Studies in Sustainable Transportation

Due Date

March 16th; please upload your presentation in Canvas at least 1 hour before class.
The report can be turned in anytime on March 17th.

Overview

This case study project will have you investigate and compare two cities that are very different in terms of road safety outcomes. The question you are trying to answer is a simple one... why?

In other words, you will be conducting a paired comparison of two cities (one relatively safe and one relatively unsafe in terms of road safety) and trying to figure out what is behind such drastically different road safety outcomes and why they have been changing over time in the manner that they have. Here is a list of the city pairs available for study:

Safer City	Road Fatality Rate (per 100k persons)			Less Safe City	Road Fatality Rate (per 100k persons)		
	1990	2000	2010		1990	2000	2010
Portland OR	14.0	7.4	5.1	Oklahoma City OK	16.2	14.9	12.6
Denver CO	11.1	10.5	6.6	Kansas City MO	18.3	15.3	13.6
Seattle WA	11.6	5.6	4.6	Memphis TN	20.3	16.5	13.5
Philadelphia PA	10.4	7.8	6.7	Dallas TX	16.5	13.6	11.2
Chicago IL	9.4	7.7	5.8	Houston TX	14.0	13.1	11.2

This is a group project with three students per group. Each group should have at least one engineering student and one planning student. Please sign up for a group on Canvas. I will assign the cities once the groups have been set. If you very much prefer one set of cities over the others, let me know.

Purpose

The main intent of this project is to consider the following with respect to their roles in supporting and/or obstructing transportation safety in your cities:

1. Built environment changes over time with respect to transportation infrastructure and land use patterns;
2. Travel behavior changes over time, as the shifting demographics, incomes, and land use patterns might help increase accessibility and reduce exposure;
3. Socio-demographic and socioeconomic changes over time, as cities may become more populated by populations with generally lower transportation injury risks; and
4. Traffic and operation changes over time, as the above differences might help promote lower speed environments.

This project will require both quantitative and qualitative data to complete. There are plenty of ways to collect such information – such as city and local planning organization websites, Google Earth (especially if you utilize the time slider bar), American FactFinder, Social Explorer (the professional version of which is available when you are on campus), NHGIS, Walk Score, the H+T Affordability Index, etc. – but I do not want to limit you to any particular sources because I'm sure you will find other websites, papers, and books about these cities and the changes that have happened over the last 25 years. In addition, it would not be a bad idea to conduct informal interviews with local engineers, planners, and policy makers from these cities to get a better understanding of their efforts, successes, and failures.

Try to organize your work according to the four issues listed at the beginning of this purpose section. Use appropriate performance measures when possible, but again, some of this may be more qualitative in nature. When linking for your data or observations with a particular outcome, be sure to explain the connection. Visuals can also be very effective…

Deliverables

Every group should produce the following:

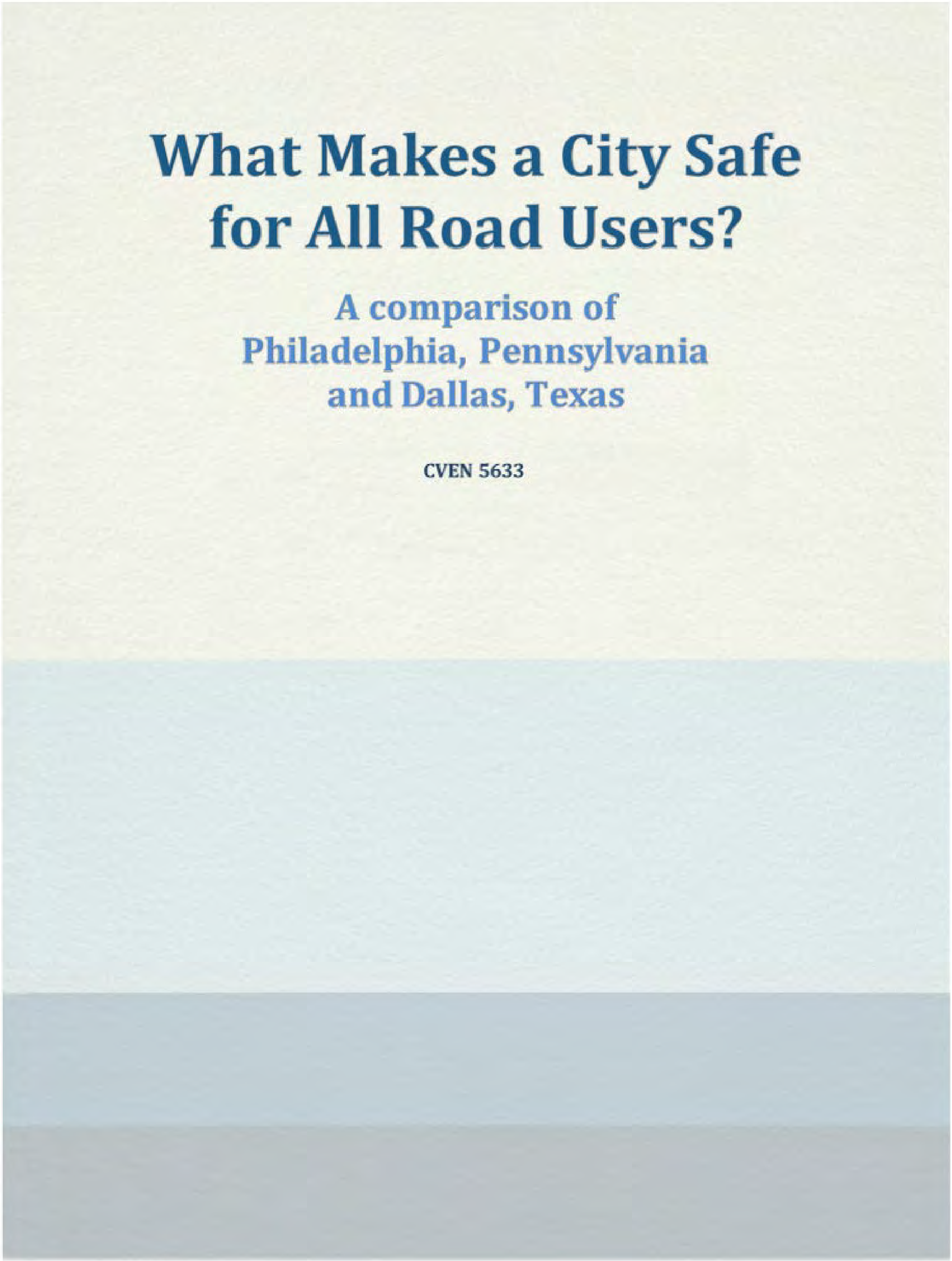
1. A final report consisting of individually written sections from each member of the group (please mark these accordingly) in addition to a group section focusing on summarizing your findings.
   - There are no minimum or maximum lengths, but you should provide enough information to answer the question at hand and support your arguments adequately. I would guess that 15-20 pages of text (not including pictures, data, tables, or other figures) would be appropriate. Keep in mind that a picture is often worth a 1,000 words.
   - Please cite and reference all sources properly (and be sure to take a good look at the academic honesty section in the syllabus). If you have any questions, do not hesitate to ask.
   - Report should be uploaded to Canvas anytime on March 17th.
2. Each group will also be presenting their work.
   - This presentation (~20 minutes per group) will be on March 16th in class.
     - Everyone should be an active participant in the presentation.
     - Please upload your presentation to Canvas at least an hour before class on March 16th.

For each of these deliverables, it would be good to organize your work according to the four issues listed in the purpose section of this document.

This case study will require background research,
independent thought, cooperation, and creativity…

Best of luck!

Example of Student Output No. 1 for CVEN 5633



What Makes a City Safe for All Road Users?

A comparison of Philadelphia, Pennsylvania and Dallas, Texas

CVEN 5633

Introduction

What makes a city safe or unsafe to walk, bike, or drive, and how can cities change their transportation safety record? This report compares the safety records of two cities, Philadelphia, Pennsylvania, and Dallas, Texas, and interpolates this information into the potential causes of these safety trends.

First, we examine how land use patterns and transportation infrastructure have influenced the safety of the built environment. Second, we determine how much of these cities' safety records have been influenced by changes in travel behavior. Next, we analyze the socio-demographic and economic influences to safety. Finally, we determine whether changes in traffic and operations have made a difference in safety in both Philadelphia and Dallas.

Table 1: Road Fatality Rates for Safer and Less Safe City Pairings. (Source: Wesley Marshall).

Safer City	Road Fatality Rate (per 100k persons)			Less Safe City	Road Fatality Rate (per 100k persons)		
	1990	2000	2010		1990	2000	2010
Portland OR	14.0	7.4	5.1	Oklahoma City OK	16.2	14.9	12.6
Denver CO	11.1	10.5	6.6	Kansas City MO	18.3	15.3	13.6
Seattle WA	11.6	5.6	4.6	Memphis TN	20.3	16.5	13.5
Philadelphia PA	10.4	7.8	6.7	Dallas TX	16.5	13.6	11.2
Chicago IL	9.4	7.7	5.8	Houston TX	14.0	13.1	11.2

In terms of road fatality, Philadelphia saw its rate drop from 10.4 per 100,000 persons in 1990 to 6.7 persons per 100,000 in 2010. Dallas, while still experiencing a drop in its road fatality rate, began in 1990 with a rate of 16.5 fatalities per 100,000 and was able to reduce its road fatalities to 11.2 per 100,000 by 2010. The fatality rate in Dallas in 2010 was higher than that of Philadelphia in 1990.

Further expanding on these differences in road safety, glaring variations can be seen when looking at alternative modes of transportation such as bicycling and walking. In 2010, pedestrians and bicyclists in Philadelphia were approximately 5 times safer than their counterparts in Dallas, when controlled for population (Table

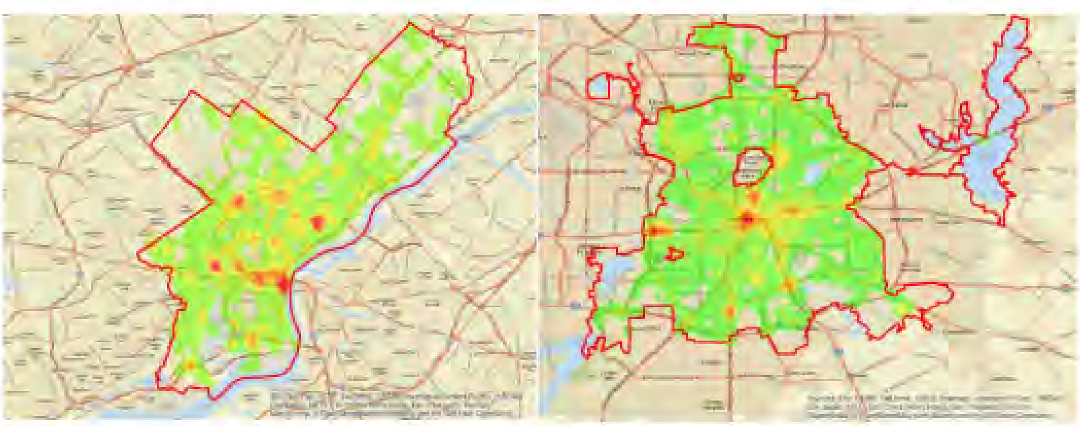
2). Although Dallas is much less safe than Philadelphia, Dallas has seen improvements to its safety record over the last 20 years. What underlying conditions caused Philadelphia's better safety outcomes, and how has Dallas overcome these obstacles to improve their own safety?

Table 2: Different Modes Involved in Fatal Motor Vehicle Accidents. (Source: FARS Data)

	Philly	Dallas
Total Motor Vehicle Fatalities Per 100k Persons		
1990	10.4	16.5
2000	7.8	13.6
2010	6.7	11.2
Bike Fatalities Per 10k Bike Commuters		
1990	8.8	29.8
2000	6.9	22.2
2010	3.6	19.8
Ped Fatalities Per 10k Ped Commuters		
1990	7.0	35.4
2000	6.3	35.7
2010	6.3	30.6

A basic overview of the locations of fatal accidents will provide a preface to the discussion to come (Image 1). While Philadelphia has many of its fatal accidents located within its dense neighborhoods, Dallas has a high concentration of accidents located on its expansive highway system that branches out radially from Downtown Dallas. The importance of this will be related to the built environment, behavior, and operations in the following sections.

Image 1: Heat Maps of Traffic Accidents in Philadelphia, Pennsylvania (left) and Dallas, Texas (right). (Source: FARS Data)



The Built Environment

Philadelphia, Pennsylvania and Dallas, Texas have very different histories, which greatly influenced their land use patterns and transportation infrastructure. These characteristics, in turn, play a role in the level of transportation safety in each city.

Philadelphia, Pennsylvania

Image 1: Circa 1750 map of the Philadelphia area showing the grid pattern design of the city. (Source: Library of Congress, Geography and Map Division)

The City of Philadelphia is over three hundred years old. William Penn, a man who understood the influence of land use on quality of life, founded it in 1682. Upon appointing Thomas Holme as Surveyor General of Pennsylvania, Penn instructed Holme to plan for parks and public squares, and to develop a grid pattern of streets, in which east-west streets were named after trees, and north-south streets were numbered. This grid system served as a model for many future towns and cities.[1]

Philadelphia has historically been a transportation hub. Since the 1800s, trains passed through Philadelphia to transport industrial goods and workers. In 1854, the Pennsylvania

[1] ExplorePAHistory.com, Chapter 2

Railroad opened, and enabled passengers to travel from city to city more quickly than ever before. The Daily Morning Post remarked at the railroad's opening:

> There are people now living in Pittsburgh who have traveled diligently for a whole week to reach Philadelphia. The same persons can now go from our city to the eastern metropolis between sunrise and sunset of a summer's day, without fatigue, and without occasion for stopping to eat more than one meal.[2]

Image 2: Electric PRT trolley, 1902. (Source: Philadelphia Record Photograph Morgue Collection, no. V7)

Soon enough, strides in inter-city transportation were translated into the city's transit options. The Philadelphia Rapid Transit Company, incorporated in 1902, began construction of electric streetcar lines to the suburb of West

[2] ExplorePAHistory.com

Philadelphia. By 1907, the company completed the city's first subway line running under Market Street and a street line on Broad Street.[3]

Also in 1907, the City Beautiful movement that sought to develop grand public buildings and boulevards, was flourishing in Philadelphia. A Parkway plan was developed to deliver "a direct, dignified and interesting approach from the heart of the business and administrative quarter of the city."[4] This became what is known as the Benjamin Franklin Parkway.

Image 3: Plan for the Fairmount Parkway by Jacqes Greber 1917. (Source: Wikipedia)

By 1929, Philadelphia had established its city planning commission and by 1933, it had enacted its first zoning code. The 1934-1936 Comprehensive Plan "recognized the increasingly important role of automobiles would play and recommended designs for high-speed boulevards"[5].

Although the emphasis on the automobile existed in Philadelphia, as in most cities during this era, some visionary planners continued to keep pedestrians and multi-modal transit users in mind as they developed plans for their city. One of these planners was Edmund Bacon (Executive Director of the Planning Commission from 1949 - 1970), who co-designed the Better Philadelphia Exhibition in 1947. The Exhibition, themed "What City Planning Means to You and Your Children," attracted 385,000 visitors and included a 30-by-14 foot model of Center City that frequently included open space, planning for pedestrians, and efforts to work within the original landscape. In his 1959 essay "Philadelphia in the Year 2009," Bacon also

[3] Chomet, Allison, Historical Society of Pennsylvania
[4] Parkway Museum District
[5] Vision 2035, page 12

proposed a transportation center at East Market Street, an overhead cable car, and electric tram system for the city.[6]

Image 4: Edmund Bacon 1949 Exhibition: "What City Planning Means to You and Your Children." (Credit: Philadelphia City Archives)

The 1960 Philadelphia Comprehensive Plan was the last comprehensive plan until the present. Regarding transportation, the plan envisioned "development of a system that will move people and goods quickly, cheaply and conveniently between any and all points of the city, and do it so as to give passengers and shippers a reasonable choice of facilities and routes." It proposed to do so by making improvements to public transit, streets, and highways, including a 95-mile expressway system within the city to "meet the free movement needs of long trips and to relieve arterial and local streets of long-distance traffic impact;" a 500-mile arterial street system "to meet the needs of middle-distance trips, serve the expressway system, and reduce the traffic on local streets;" and a rail rapid-transit

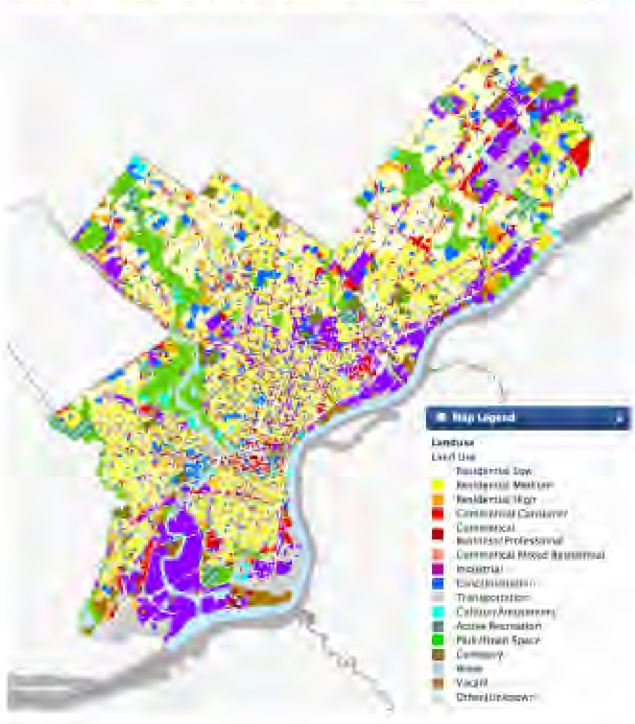
[6] Katima, Hillary, The Philly History Blog

system to "meet peak-hour demands for commuter traffic to Center City and to certain other points of high concentration."[7]

The 1960 Plan also promoted land use patterns that furthered walkability and access. The plan proposed the creation of ten district centers throughout the city to serve as focal points, "where public facilities such as district libraries, health centers and branch offices of city departments will be grouped near a major shopping center for easy access." Fifty-Six community centers were also proposed to create concentrated amenities in smaller parts of the city. "These will bring together the community library, the satellite health clinic, the smaller shopping center, and voluntary community-service agencies. The secondary school and playfield will be located nearby."[8]

In 1963, the Southeastern Pennsylvania Transit Authority (SEPTA) was formed. SEPTA helped Philadelphia to usher in an era of robust public transportation options. By 2013, SEPTA had established 13 regional rail lines that spanned 280 one-way miles, 8 trolley/light rail routes that spanned 68 miles, and 117 bus routes over 1,445 miles using 1,390 vehicles. In Fiscal Year 2013, systemwide ridership (all modes) reached 337.3 million passenger trips.[9]

Image 5: Land Use 2015. (Source: Pennsylvania GIS Map)



When viewing current land use patterns, it can be seen that commercial and office uses are scattered throughout the city, which indicates that mixed uses may contribute to greater access to amenities and reduced need for travel throughout Philadelphia. Additionally, Philadelphia's zoning code was

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[7] Philadelphia Planning Commission
[8] Philadelphia Planning Commission
[99] SEPTA Annual Report 2013. SEPTA.org

revised in 2012 to make zoning simpler. In the revised code, there are nine residential zoning classifications, seven commercial, and three industrial.[10]

Image 6: Philadelphia 2035. (Source: phila2035.org)

After decades of planning by neighborhood, Comprehensive planning once again emerged to set a long-term vision for the city. Philadelphia2035 is that plan. Adopted in June 2011, Philadelphia2035 outlines Philadelphia's transportation priorities for the next 20 years. The plan describes the goals for transportation as "Improv[ing] transportation safety, efficiency, and convenience" in the following ways:

- Transit: Increase the use of transit to reduce environmental impacts and travel time
- Complete Streets: Balance use of roadways to ensure safe and efficient travel by all modes
- Streets and Highways: Provide a safe and efficient road network that supports planned land uses
- Airports, Seaports, and Freight Rail: Enhance the city and regional economy by reinforcing airports, seaports, and freight rail.11

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[10] Brey, Jared. *New Zoning Code Takes Effect Wednesday*. August 12, 2012. PlanPhilly.org

The plan also reinforces the value that neighborhood centers provide, and commits to strengthening these centers. One example of a successful neighborhood center is the area near the Tasker-Morris station on the Broad Street Line in South Philadelphia:

Image 7: Neighborhood Centers. (Source: Philadelphia 2035).

> A branch library, health center, and recreational facilities share a single block on the southwest corner of Broad & Morris, directly above the entrance to the station. An east-west bus route makes a connection at the station. Two blocks to the south and east, commercial corridors provide a mix of goods and services including small groceries, pharmacies, home goods, and clothing stores. Residents of this neighborhood center can access most daily necessities on foot, and can reach larger employment, commercial, and recreational resources in other parts of the city without private automobiles. The colocation of community serving public facilities above a high capacity transit line, investment in nearby commercial areas, and zoning permitting a mix of uses makes this possible.[12]

The city also established a Mayor's Office for Transportation and Utilities (MOTU) in 2008. MOTU recognized the importance of improving safety and reducing fatalities. "On average, every five hours a pedestrian is hit by a car in Philadelphia and tragically, about every two weeks a pedestrian is killed by a car. MOTU is working diligently to reduce these numbers." In their five year progress report, MOTU identified the successes they have achieved:

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[11] Philadelphia2035, p7

[12] Philadelphia2035, page 69

- Buffered bike lanes on Spruce and Pine Streets reduced serious accidents sending someone to the hospital or requiring a car to be towed dropped by over 40%.
- Partnering with the Bicycle Coalition of Greater Philadelphia, over 24,000 people learned bike safety basics.
- MOTU convened a Transit First Committee to implement innovative strategies that significantly reduce travel time along key transit corridors and a Transit Improvement Committee to improve all transit services through the reduction of operational inefficiencies and improved coordination."[13]

Image 8: Complete Streets Handbook.

In the last few years, Mayor Nutter also prioritized the creation of complete streets. In 2009, he signed an Executive Order to establish a Complete Streets Policy.[14] Nine months later, a bill was passed amending the traffic code "by providing for the manner in which bicyclists may operate bicycles in the streets, and by prohibiting motor vehicles from obstructing or creating certain hazards in bicycle lanes" and amending the Streets code "to provide for the establishment and implementation of a Complete Streets Policy."[15] A Complete Streets Handbook was developed and adopted in 2013 to assist city agencies in implementing the coals of the executive order and bill.[16]

Today, Philadelphia is ranked the #4 most walkable city by WalkScore.com, with a walk score of 77, a transit score of 67, and a bike score of 68.[17]

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[13] MOTU Five Year Progress Report, pages 28, 31, and 50.
[14] Bicycle Coalition of Greater Philadelphia
[15] City of Philadelphia City Council
[16] Fischer, Christine, PlanPhilly
[17] WalkScore.com

Dallas, Texas

Dallas, Texas was formally incorporated as a city on February 2, 1856. As with Philadelphia, Dallas took advantage of railroad technology and became a hub for industrial activity in the late 19th Century.

Image 9: Map of Dallas, 1920. (Source: Automobile Bluebook 1920 via University of Texas Libraries)

The Dallas street grid is a conglomeration of a number of survey decisions. As described by the Texas State Historical Association:

> Bryan's original survey for Dallas used the Trinity River as the western boundary, with streets laid out at right angles to the river. A competing survey drawn by Warren A. Ferris, done for John Grisby, was laid out at 45 degrees off cardinal directions. A third survey made for the Peters colony laid out sections using cardinal directions. The results are an odd series of doglegged streets downtown. Annexation of adjacent communities added another layer of surveying patterns to the Dallas street map.[18]

[18] Texas State Historical Association

Image 10: Kessler Plan Transportation Improvements:

In 1911, urban planner George Kessler drafted "A City Plan for Dallas," which was intended to solve some of Dallas' growing problems. "In 1908 Dallas, Texas, wore the aspect of an unplanned city. Chaotic street patterns, confusing and expensive transportation arrangements, inadequate public recreational facilities and periodic flooding from the Trinity River made life difficult in the rapidly growing Southwestern community.[19] Unfortunately, "the Kessler Plan sparked controversy and quickly unravelled under the demands of Dallas's spectacular growth."[20]

In 1936, the Dallas Citizen's Traffic Commission was formed. In 1955, they released a production entitled "Report to Dallas," where they outlined how the sharp growth in population has led to congestion and delays on Dallas' streets and highways. Education, Engineering, and Enforcement were the three E's that were expected to solve the traffic problem.

Two years after the release of "Report to Dallas," a report entitled "Thoroughfares - A Master Plan Report" described that while major and minor thoroughfares would continue to bisect one another in straight lines, "minor [residential] streets are curvilinear and discontiguous so as to discourage all traffic except that which may originate or have a destination within the neighborhood."[21]

In 1970, Bill Stokes Associates was commissioned to produce a 25-minute long cartoon PSA entitled "How Motor Cars and Other Living Things Can Find

[19] Wilson, William, 245
[20] Wilson, William, 245
[21] City of Dallas Thoroughfare Plan, p 4

Happiness in the Dallas Freeway System." The PSA describes how a car, Candide, can make smart driving decisions and abide by traffic laws.[22]

In terms of impactful planning decisions, planner Vincent Ponte proposed "covered, air-conditioned walkways over traffic; arcades lined with stores tunneled under the streets; and moving belts-under-glass for long, uninterrupted walks between building set apart" in the 1960s. This plan was adopted, and pedestrian tunnels were constructed underneath an area of Downtown Dallas. This decision greatly reduced the number of pedestrians creating an active urban core, and was widely believed to be a failure.[23]

Image 11: Dallas underground Tunnels circa 1980s. (Source: The Dallas Morning News)

In 1983, the Dallas Area Rapid Transit (DART) was formed to assist the City with developing a robust transportation Network. DART has been successful in Establishing 34 miles of regional rail, 85 miles of light rail, and 12,500 bus stops serving 612 vehicles, according to Fiscal Year 2013 statistics. In 2013, DART's

Image 12: DART Rail System Map. (Source: DART.org)

22 The Dallas Morning News via the Texas Archive of the Moving Image.

23 Wilonsky, Robert. City council to rekindle debate over whether Dallas Pedestrian Network (or, the tunnels) killed downtown. April 9, 2014. The Dallas Morning News.

systemwide ridership (all modes) was 107.5 million passengers.[24]

On June 14, 2006, City Council adopted the forwardDallas! Comprehensive Plan. Its priorities included "Convenient Transportation: Offer choices in how to get around Dallas." In discussing resident feedback from its community visioning sessions, the plan describes that:

> At each workshop, groups were asked to design their version of an ideal street. What emerged is a strong indication that people want to change the design and function of many streets throughout Dallas. **Residents expect many streets to remain as they are, with an emphasis on safely carrying large volumes of cars at relatively high speeds.** Participants also support the idea, however, of converting some streets in key areas into bustling shopping districts that attractively and safely accommodate pedestrians and bicyclists as well as cars, trucks and buses (emphasis added).

forwardDallas! also described its desire for neighborhood retail, although with some level of caution: the City was to "Encourage neighborhood-serving office, retail, or other non-residential uses to be located in residential community areas, **primarily on significant roadways or at key intersections**" while still being sure to "Provide appropriate transitions between non-residential uses and neighborhoods to protect stability and quality of life."[25] Neighborhood mixed use is often achieved by zoning particular residential nodes as mixed use. However, the zoning code in Dallas is so cluttered by Planned Development Districts (almost 900 of them, each with their own specifications) that the City of Dallas has very little power to be prescriptive about future land use.[26]

In 2011, Dallas launched its Complete Streets Initiative. In the Complete Streets Design Manual (draft), "promote public safety" is listed first in the ways in which Complete Streets benefit the city.[27] This comported with a phone survey

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[24] Facts about DART. DART.org

[25] forwardDallas! Page II-1-7.

[26] Lamster, Mark. *Boxed in by development, Dallas needs to figure out its growth issues*. June 24, 2014 The Dallas Morning News.

[27] Complete Streets Design Manual Draft, p 5.

conducted with Dallas city residents, who ranked "being safer" as 8.4 out of 10 of why they would give up some street space for walking and biking.[28]

Comparison

One more factor that effectively illustrates the differences between the built environments in Philadelphia and Dallas, and which is best compared side by side, is that of the amount of land dedicated to parking automobiles. As may be expected, Dallas dedicates a large portion of its downtown to housing its favorite type of transportation mode, the single occupancy vehicle. On the other hand, Philadelphia is much more focused on making a livable place for people. This analysis was completed by selecting the densest square mile of both cities, based on knowledge of the location of the downtown area in 2014. After the densest square mile was selected, all of the parking, both surface and garages, were highlighted in a polygon layer in ArcGIS (Image 13).

Image 13: Parking in the densest square mile of Philadelphia (left) and Dallas (right). (Source: ArcGIS)

[28] Complete Streets Design Manual Draft, p 7

From this analysis, we found that Dallas dedicates approximately 18.5% of the land in their downtown to parking, while Philadelphia dedicates a mere 6.5% (Table1). Dallas not only has many more parking lots, but they also have larger parking lots. The average size of a parking lot in Dallas is 1.78 times larger than the average size of a parking lot in Philadelphia. When we looked at Dallas' obsession with parking longitudinally, it appears that they have made great strides in reducing the amount of parking that they have in their downtown (Table 2). The reliablility of this data is questionable, as the numbers from 2010 do not match with the numbers we counted manually. This is most likely because the land use GIS layers obtained from the City of Dallas were not very accurate.

Table 1: Parking in the densest square mile of Philadelphia and Dallas. (Source: ArcGIS)

	Dallas	**Philly**
Area (sq. mi.)	0.97	0.94
Parking Area (sq. mi.)	0.178935	0.061155
% area that is parking	**18.45%**	**6.51%**
Square miles of average lot	0.001455	0.000815

Table 2: Longitudinal look at parking in the Downtown Dallas. (Source: City of Dallas)

Land Dedicated to Parking in Dallas	
2000	0.160475
2010	0.06329
Change in parking	-60.6%

	Philadelphia	Dallas
Year Founded	1682	1856
2010 Population	1,526,006	1,197,816
Square Miles	134	340
Pop Density per Square Mile	11,379	3,518
Number of Buses (FY13)	1,390	612
Number of Bus Routes	117	120
Light Rail Miles	68	85
Commuter Rail Miles	280	34
Walk Score Rating	77	44

When comparing Philadelphia and Dallas side by side, it becomes clear that Philadelphia is an older, smaller, and denser city with greater access to public transportation. Differences in the way that streets were surveyed, such as the gridded streets of Philadelphia vs. the conglomeration of streets in Dallas may affect safety today. The emphasis on walkability, transit, and neighborhood centers in early planning documents may account for lower accident rates in Philadelphia, while the emphasis on highways and vehicular traffic may account for increased accidents in Dallas. Dallas zoning is not straightforward, while Philadelphia's was recently updated – perhaps signaling a difference in the ability of these cities to shape their urban land use and transportation environment. Though transportation strides are being made in both cities, the greater use of public transportation in Philadelphia may account for greater awareness and safety. And while there seems to be a demonstrated desire to move towards complete streets in both Philadelphia and Dallas, the demonstrated projects and successes in Philadelphia tend to demonstrate that both a history of land use and transportation decisions and renewed interested in multi-modal safety can yield true success.

Travel Behavior Characteristics

Commute Mode and Time

While not truly representative of all trips made within a city, commute mode can be a good indicator of the types of transportation folks utilize on a day-to-day basis. Giving people more transportation options can lead to a more sustainable transportation system. With one lone exception, both Philadelphia and Dallas saw rates of driving alone increase while all other modes decreased between 1990 and 2010. The lone exception was that bicycling has seen nearly a 3-fold increase in Philadelphia during that time period (Table 1). Dallas is much more auto-dependent than Philadelphia, with nearly 90% of people using personal vehicles to get to work, compared to just more than 60% in Philadelphia.

Table 1: Commute Modes for Philadelphia and Dallas in 1990 and 2010. (Source: Census Data)

	Philly	Dallas
1990 Commute Mode		
Drove Alone	44.66%	72.48%
Carpool	13.18%	15.16%
Public Transit	28.68%	6.66%
Bike	0.57%	0.15%
Walk	10.37%	2.41%
2010 Commute Mode		
Drove Alone	50.65%	76.48%
Carpool	9.48%	12.43%
Public Transit	26.20%	4.24%
Bike	1.63%	0.14%
Walk	8.40%	1.85%

Main Points

- ◊ Improved emergency medical response times, along with shorter commute times, may be responsible for increases in safety within Dallas.
- ◊ Both cities seem to be getting more dependent upon the personal automobile, with Dallas much more dependent than Philadelphia. Biking rates have been increasing in Philadelphia.
- ◊ Drunk driving is a much larger problem in Dallas than in Philadelphia, and has not been improving.
- ◊ Driver familiarity seems to be worse in Dallas than in Philadelphia, and has been getting worse.
- ◊ Speed appears to play a significant role in the poor safety outcomes in Dallas. This has not been improving over time.

Another important factor related to transportation safety is the amount of time people actually spend in transport. If you only spend one second travelling every day, you will probably have less of a risk of getting injured or killed in the transportation system than someone that spends 23 hours of their day travelling. According to numbers from the Census, Philadelphians tend to spend more time travelling to work, with those numbers getting larger over the last 2 decades (Table 2). On the other hand, residents of Dallas spend less time getting to work, and, over the last 20 years, that number has gotten smaller. This reduced amount of time spent commuting to work over the last 20 years may coincide with fewer accidents.

Table 2: Travel Time to Work. (Source: Census Data)

	Philly	Dallas
Mean Travel Time to Work (min)		
1990	30.5	26.4
2000	31.0	27.0
2010	31.8	25.2

Response Times

Response time of emergency medical services is a vital factor in the analysis of safety on our roadways. If two cities have the exact same infrastructure and driving behavior, but an ambulance in one city arrives in one minute, while an ambulance in the other city takes an hour, they will have vastly different safety outcomes. This data was taken from the Fatality Analysis Reporting System (FARS). The numbers were derived by finding the difference between "the time that emergency medical service was notified" and "the time that emergency medical service arrived on the crash scene."[29] Every accident that occurred within the city limits of the two cities, between the years 1987 and 2012, was analyzed.

[29] FARS Data-http://www.nhtsa.gov/FARS

In the table below, it can be seen that Philadelphia had a vastly better emergency medical response time than Dallas did in the late 1980's and the 1990's (Table 3). Around the year 2000, the cities seem to have about the same response times, due mostly to Dallas improving the response times of their emergency medical services. This could be a major factor in explaining the increased safety within Dallas.

Table 3: Emergency Medical Service Response Times for Dallas and Philadelphia. (Source: FARS Data)

Year	From Notification to Arrived on Scene (Minutes) -Dallas	From Notification to Arrived on Scene (Minutes) -Philly	Difference Between Philly & Dallas (Minutes)
1987	8.131	6.770	1.361
1988	10.949	6.648	4.301
1989	7.285	5.231	2.053
1990	7.805	5.690	2.115
1991	6.674	5.873	0.801
1992	9.609	6.067	3.542
1993	6.976	6.521	0.455
1994	7.869	6.145	1.724
1995	5.860	5.768	0.093
1996	5.766	7.340	-1.573
1997	6.676	6.349	0.326
1998	6.820	5.257	1.563
1999	6.778	5.775	1.002
2000	6.278	5.344	0.933
2001	5.373	5.585	-0.212
2002	6.752	6.500	0.252
2003	7.197	9.000	-1.803
2004	5.606	5.872	-0.266
2005	5.310	5.806	-0.496
2006	7.087	6.000	1.087
2007	5.667	7.413	-1.746
2008	5.170	6.231	-1.061
2009	5.438	5.758	-0.319
2010	5.548	5.787	-0.238
2011	5.569	6.425	-0.856
2012	5.262	6.699	-1.437
Total	**6.785**	**6.134**	**0.651**

Drunk Driving

A behavioral aspect that may account for Dallas' poor, but improving, transportation safety record is drunk driving. At the state level in 2013, Texas had 1,337 drunk driving fatalities representing 39.5% of all traffic deaths. Pennsylvania had 368 drunk driving fatalities, which represented only 30.5% of all traffic deaths.[30] When looking at the cities themselves, past research found that Dallas had 0.48 fatal traffic crashes involving intoxication for every 1,000 people, and a rate of 41.4% of fatal crashes involving intoxication. Philadelphia was decidedly safer with 0.17 fatal traffic crashes involving intoxication for every 1,000 people, and a rate of 28.1% of fatal crashes involving intoxication.[31] Along with this difference in drinking and driving, there is also a worrying difference in enforcement. While Texas has much worse rates of drinking and driving, it has only 374.24 DUI arrests per 100,000 people, compared to 500.92 DUI arrests per 100,000 people in Pennsylvania. This difference in behavior, stimulated by a lack of enforcement, could be an attributing factor to the differences in safety between the two cities.

Looking at this issue longitudinally, it does not seem that changes in enforcement or behavior related to drunk driving have accounted for any improvements in safety over the last 20 years. Using FARS data, we looked at the total number of fatal motor vehicle accidents and the number of fatal accidents involving a drunk driver from 1982 until 2012 in the two cities. It is apparent that the percentage of accidents that had a drunk driver involved has been increasing over the last two decades for both cities (Table 4). The absolute number of drunk drivers involved in fatal motor vehicle accidents has decreased in Philadelphia. The number of fatal accidents involving a drunk driver in Dallas has stayed fairly stable.

Table 4) Longitudinal Analysis of Drinking and Driving. (Source: FARS Data)

	Philly	Philly 1982-1997	Philly 1998-2012	Dallas	Dallas 1982-1997	Dallas 1998-2012
Total Accidents	3,635	2,186	1,449	4,454	2,399	2,055
Accidents with Drunk Drivers	918	526	392	1,606	806	800
Percentage w/ Drunk Drivers	25.3%	24.1%	27.1%	36.1%	33.6%	38.9%

[30] Mothers Against Drunk Driving-http://www.madd.org/drunk-driving/state-stats/Pennsylvania.html
[31] Drunk Driving in American Cities-http://uxblog.idvsolutions.com/2013/01/drunk-driving-in-american-cities.html

Drivers Not Familiar with the Area

Transportation engineers often use a variable to account for the familiarity of drivers to a certain transportation system. We decided to test the familiarity of drivers in both Philadelphia and Dallas by using FARS data to explore whether drivers involved in fatal accidents were from the cities in which the fatal accident occurred. The zip code of the drivers involved in fatal motor vehicle accidents is provided by FARS, and using a list of zip codes for each city, we were able to find which drivers were from within the city in which the accident occurred. Findings show that Philadelphia has few drivers involved in fatal accidents that are from outside Philadelphia (Table 5). This suggests that drivers within the transportation system of Philadelphia are most likely accustomed to and familiar with the conditions. On the other hand, Dallas has a high percentage of drivers involved in fatal accidents that are from outside of Dallas. This number has been increasing over the last two decades, and was almost at 50% in 2010. This suggests a transportation system that is inundated with users not familiar with the conditions.

Table 5) Drivers Involved in Fatal Accidents that are from Outside the City in which the Accident Occurred. (Source: FARS)

	Philly	Dallas
Total Drivers Involved in Fatal Crashes		
Total	3,732	4,651
1990	1,105	1,118
2000	1,600	2,109
2010	1,027	1,424
Drivers From Outside of the Respective City		
Total	1,067	1,931
1990	334	430
2000	477	851
2010	256	650
% of Drivers Involved in Fatal Crashes that are from Outside the City		
Total	28.6%	41.5%
1990	30.2%	38.5%
2000	29.8%	40.4%
2010	24.9%	45.6%

We decided to pair these findings with migration numbers for the two cities, provided from the Census. The migration numbers show Philadelphia as a city with few people moving into it (Table 6). This likely means that most people who live there are probably from the area. On the other hand, Dallas has seen explosive migration of people into the city, both domestic and international, over the past few decades (Table 6). This results in a transportation system inundated with users not familiar with the transportation infrastructure, culture, and climate. Also, many of these users may have formerly lived in rural areas, whereas it is much more likely that folks moving into Philadelphia lived somewhere in the dense, urbanized Northeast United States, and are therefore already familiar with relatively similar conditions.

Table 6) Migration of Persons for Philadelphia and Dallas. (Source: Census[32] & NewGeography[33]).

	Philly	Dallas
% Increase in Total Population		
2010-2013	1.06%	5.55%
Average Annual Rate of Domestic Migration		
1990-2000	-5.1%	5.7%
2000-2004	-1.5%	3.1%

Speeding

High speeds can have an extremely detrimental influence on the safety outcomes of a transportation system. When exploring whether speed had an influence on the safety of Philadelphia and Dallas, there were a number of different approaches we took. First, the classification of the roadway that the fatal motor vehicle accidents occurred on was analyzed. Next, the size of the roads on which fatal motor vehicle accidents occurred was looked at. Finally, the speed limits of the roadways on which fatal motor vehicle accidents occurred was examined. All of

[32] Census-http://www.census.gov/prod/2006pubs/p25-1135.pdf
[33] NewGeogrpahy-http://www.newgeography.com/content/004240-special-report-2013-metropolitan-area-population-estimates

these factors combined to show Dallas as a city with a much larger, and faster, transportation system.

The speeding analysis began by pulling all of the fatal accidents from 1987 until 2012 for both Philadelphia and Dallas from the FARS data. The roadways that accidents occurred on were classified as either an interstate/highway, an arterial, a collector, or a local road. Findings suggest that a large percentage of fatal accidents in Dallas occur on interstates or highways, while the number is relatively low for Philadelphia (Table 7). This would suggest that the transportation system in Dallas may be larger and faster, and therefore lead to more safety issues, than the system in Philadelphia.

Table 7) Classification of Roadways on which Fatal Accidents Occurred. (Source: FARS)

% of Fatal Accidents on...	Philly	Dallas
Interstate/Highways	9.3%	34.6%
Arterial	50.9%	16.6%
Collector	5.2%	1.2%
Local Road	34.6%	47.6%

When looking at Dallas longitudinally, the results suggest that Dallas has not improved their safety on their highways (Table 8). The percentage of fatal accidents that have occurred on interstates or highways in Dallas has increased since the 1990's. This is most likely a result of Dallas' arterials, collectors, and local roads getting safer, while the interstates and highways have remained unsafe.

Table 8) Road categories of fatal accidents in Dallas over time. (Source: FARS)

% of Fatal Accidents on...	Dallas 87-99	Dallas 00-12
Interstate/Highways	32.2%	37.1%
Arterial	17.6%	15.7%
Collector	2.1%	0.2%
Local Road	48.1%	47.0%

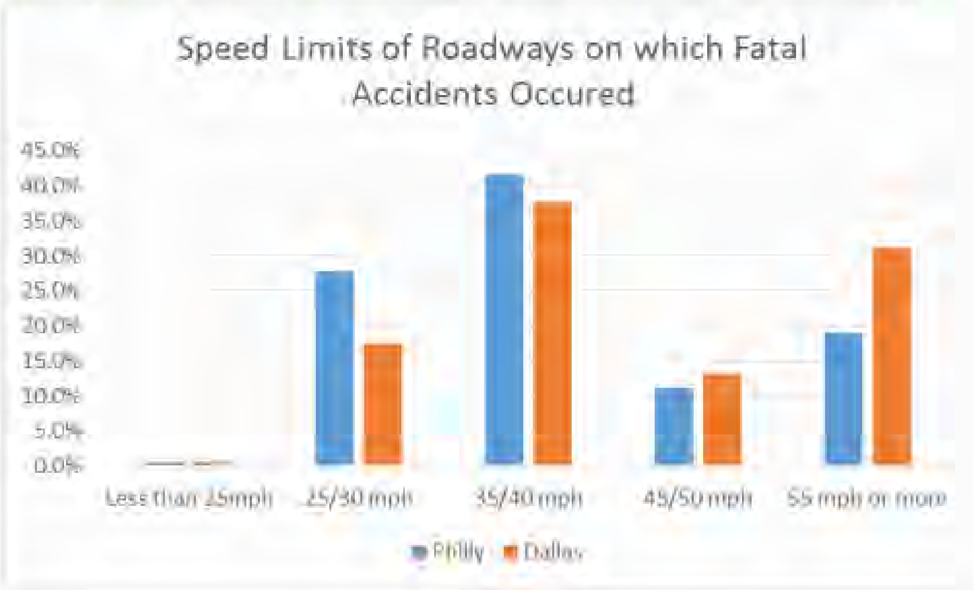
We also looked at the number of lanes of the roadways on which fatal accidents occurred over the last 25 years. Supporting the idea that Dallas has a much larger and faster transportation system, the results show that the roadways on which fatalities occurred in Dallas had more lanes than their counterparts in Philadelphia (Table 9). While over 65% of fatal accidents occurred on one or two lane roads in Philadelphia, only 36% of fatal accidents occurred on one or two lane road in Dallas. This again supports the theory that speed is a major factor in the poor safety culture in Dallas.

Table 9) The number of lanes of roadways on which fatal accidents occurred. (Source: FARS)

Percentage of fatal accidents on roadways with...	Philly	Dallas
1 Lane	5.0%	1.3%
2 Lane	60.1%	34.7%
3 Lane	17.4%	40.1%
4 Lane	14.4%	16.7%
5 Lane	1.2%	4.3%
6 Lane	1.9%	2.9%
7 or More Lanes	0.1%	0.1%

Finally, the speed limits of the roadways on which fatal accidents occurred were analyzed by using FARS data. It was found that fatal accidents occurred on roadways with lower speeds much more often in Philadelphia than in Dallas (Figure 1). This, once again, supports the theory that speed plays a significant role in the poor safety record in Dallas. While it would have been interesting to look at whether drivers in either city were more apt to drive at speeds above the posted speed limit would have been of interest, but the data did not provide that information. Also, these findings did not provide a good explanation for why the transportation safety within Dallas has been improving over the last 20 years.

Figure 1) Speed limits of roadways on which fatal accidents occurred. (Source: FARS)



Children

We wanted to look at whether children used the transportation systems of Dallas and Philadelphia as pedestrians and bicyclists, or if they simply relied on an adult to give them a ride in a motor vehicle. It was our hypothesis that children in Dallas wouldn't play in the streets, walk to parks, or bike to school, whereas kids in Philadelphia, having smaller and slower streets with higher density, would actually be using the system themselves, not just depending on their parents for a ride in a car.

In order to test this hypothesis, we looked at all of the children, defined as under the age of 18, that were killed in motor vehicle accidents in both cities from 1989-2012. We then looked at how many of those children were killed as passengers in vehicles, as pedestrians, and as bicyclists. The results show that, while over 50% of children were killed while walking or biking in Philadelphia, less than 30% of children in Dallas were walking or biking. This paints a picture of a transportation system in Dallas that children either cannot use, or are afraid to do so, and therefore depend on adults to drive them to where they need to go (Table 10).

Table 10) Modes in which children were killed by motor vehicles. (Source: FARS)

	Philadelphia	Dallas
Children Killed in Motor Vehicle Accidents	283	364
% in Vehicles	47.3%	71.7%
% Pedestrians	47.0%	24.5%
% Bicyclists	5.7%	3.8%

We then wanted to look at this trend and see how it has changed over time. Dallas was examined further to see if the phenomenon of children not walking or biking was getting better or worse over time. The time range was split into two time frames of 11 years each. It can be seen that while the overall numbers of children fatalities has been decreasing in Dallas, children do not seem to be walking or biking any more than they were in the 1990's. The decreasing percentages of bicyclists and pedestrians signals either a decrease in the number of people using those modes, or else an increase in safety for those modes (Table 11).

Table 11) Longitudinal look at modes in which children were killed by motor vehicles in Dallas. (Source: FARS)

	Dallas 1989-2000	Dallas 2001-2012
Children Killed in Motor Vehicle Accidents	215	149
% in Vehicles	69.8%	74.5%
% Pedestrians	27.0%	20.8%
% Bicyclists	3.3%	4.7%

Economic and Demographic Changes

Economic Changes

> **Main Points**
>
> - The overall economies of Philadelphia and Dallas are similar.
> - Traffic safety may have been following gentrification in Philadelphia.
> - Dallas appears to have done a good job of equitably distributing its transportation safety in the last two decades.

First, we will provide a quick comparison between the economies of Philadelphia and Dallas, and then we will delve into a deeper analysis of shifting transportation safety in relation to shifting economics, most likely fueled by gentrification.

The overall economies of both Dallas and Philadelphia are very similar. The median value of owner occupied housing units in Dallas was $129,000 for 2010, compared to $142,000 for Philadelphia.[34] The median household income for Dallas was $42,846, while Philadelphia's was slightly lower at $37,192. The percentage of persons below poverty level for either city are within 3% of each other.[35] Also, the GDP's of both cities are within 13% of each other, with Dallas at approximately $420 billion USD and Philadelphia at approximately $364 billion USD.[36]

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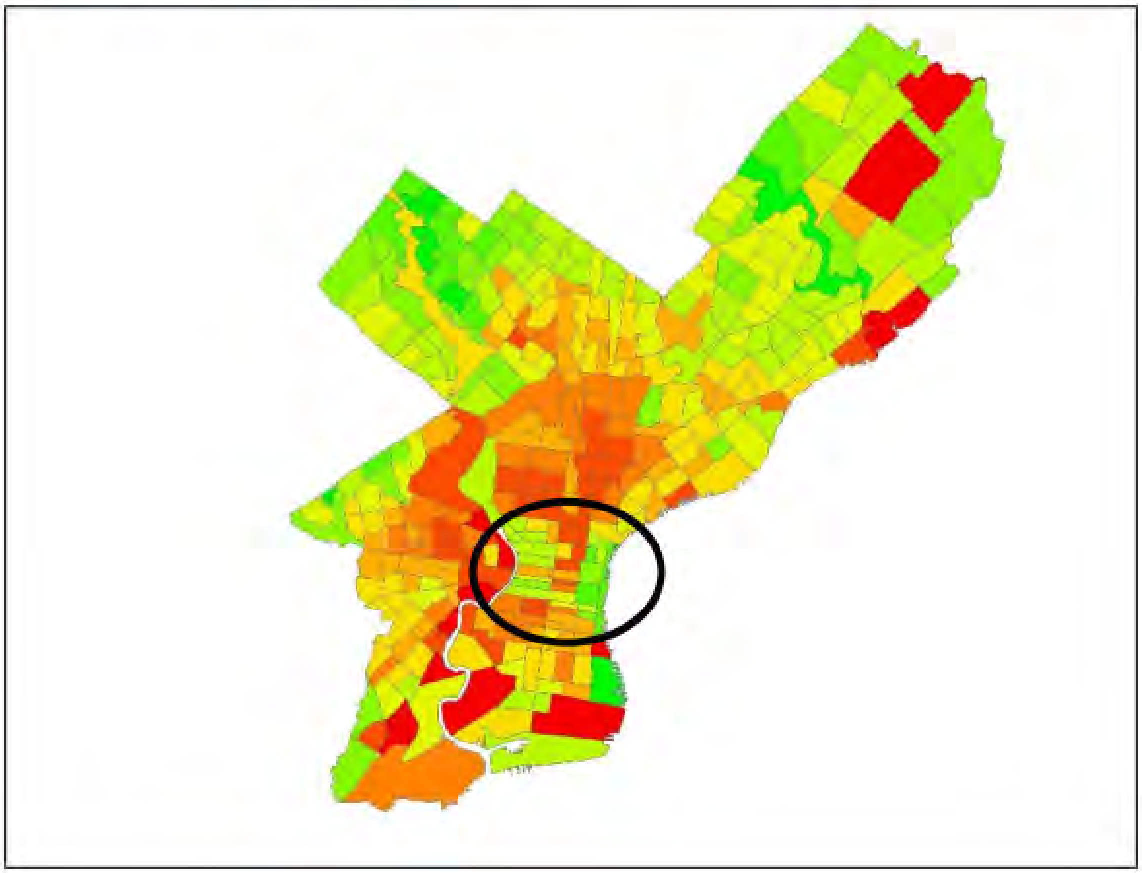
[34] Census-http://www.census.gov/
[35] Census-http://www.census.gov/
[36] List of Cities by GDP-http://en.wikipedia.org/wiki/List_of_cities_by_GDP

Gentrification

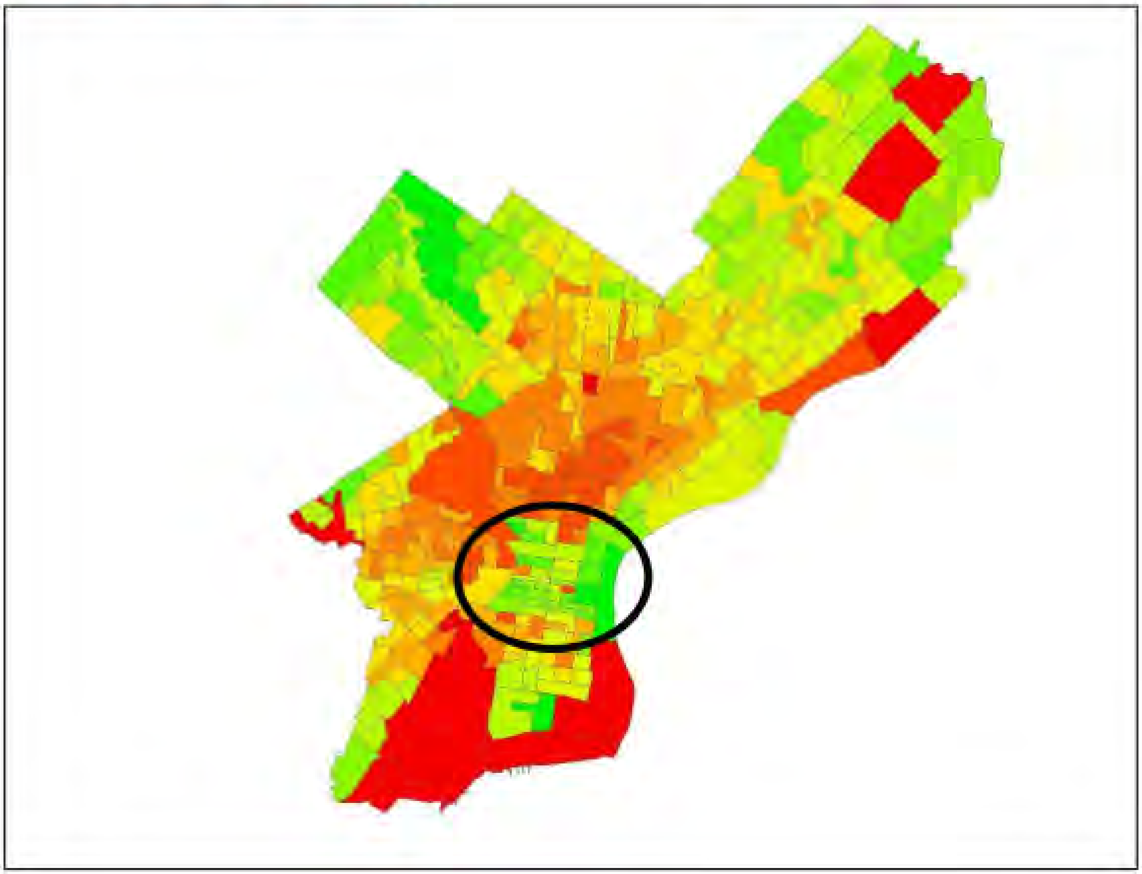
In 1990, Philadelphia had a small area of high income residents in Center City, surrounded by a ring of poverty extending into the areas directly to the north, west, and south (Figure 1). The higher income populations lived in the outer suburbs to the northeast and northwest.

Figure 1) Median Household Income by Census Tract in Philadelphia in 1990. (Green = Higher Income / Red = Lower Income -- Source: Census)



It can be seen that by 2010, Center City had undergone some gentrification, resulting in a larger area of high income populations centered on Center City (Figure 2). Poverty within the city seems to have migrated to the north and northeast.

Figure 2) Median Household Income by Census Tract in Philadelphia in 2010. (Green = Higher Income / Red = Lower Income -- Source: Census)



The maps below show that these trends in median household income correspond to trends in gentrification that were indeed occurring in the Center City area (Figure 3 & 4). The first figure tracks gentrification by changes in rent prices, while the second map shows the change in the number of construction permits in different neighborhoods of the city. Both of these show gentrification occurring around Center City, with the northern areas of the city seeing a slowed economy.

Figure 3) Gentrification in Philadelphia from 2010-2014 based on changes in rent prices. (Areas in white have had the largest increase in rents in Philly from 2010-2014/Areas in blue have had the largest drop)[37]

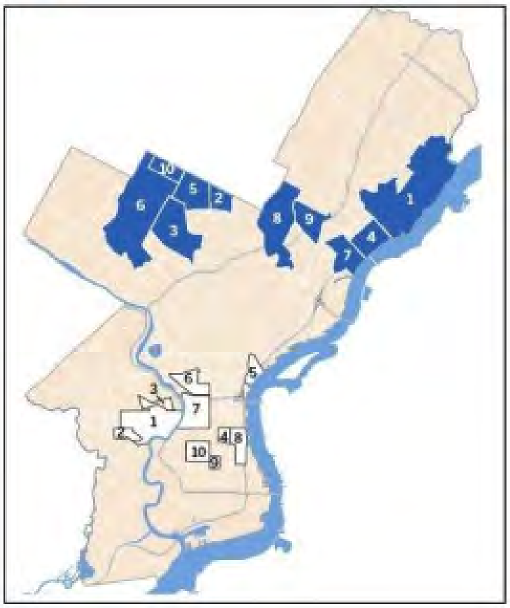
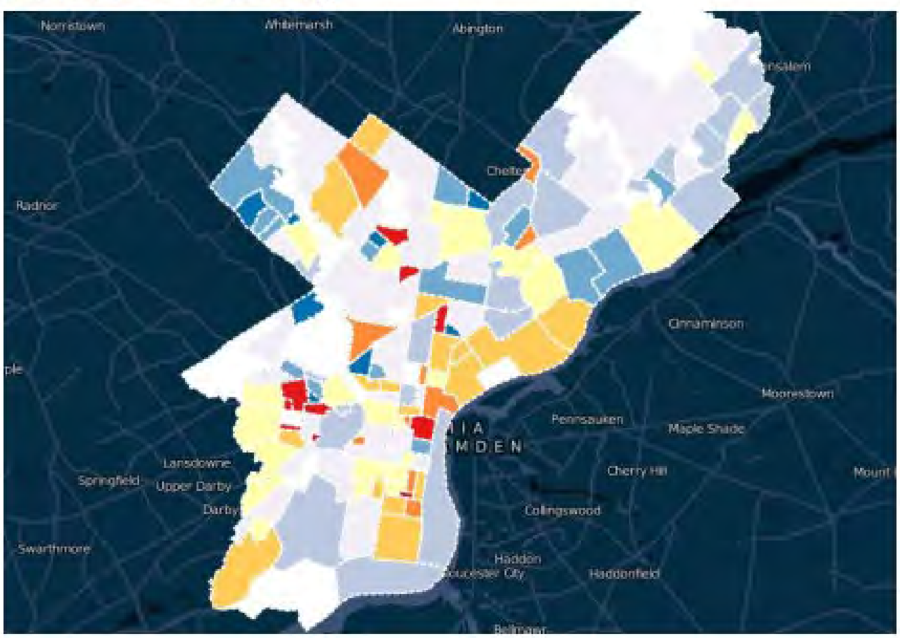


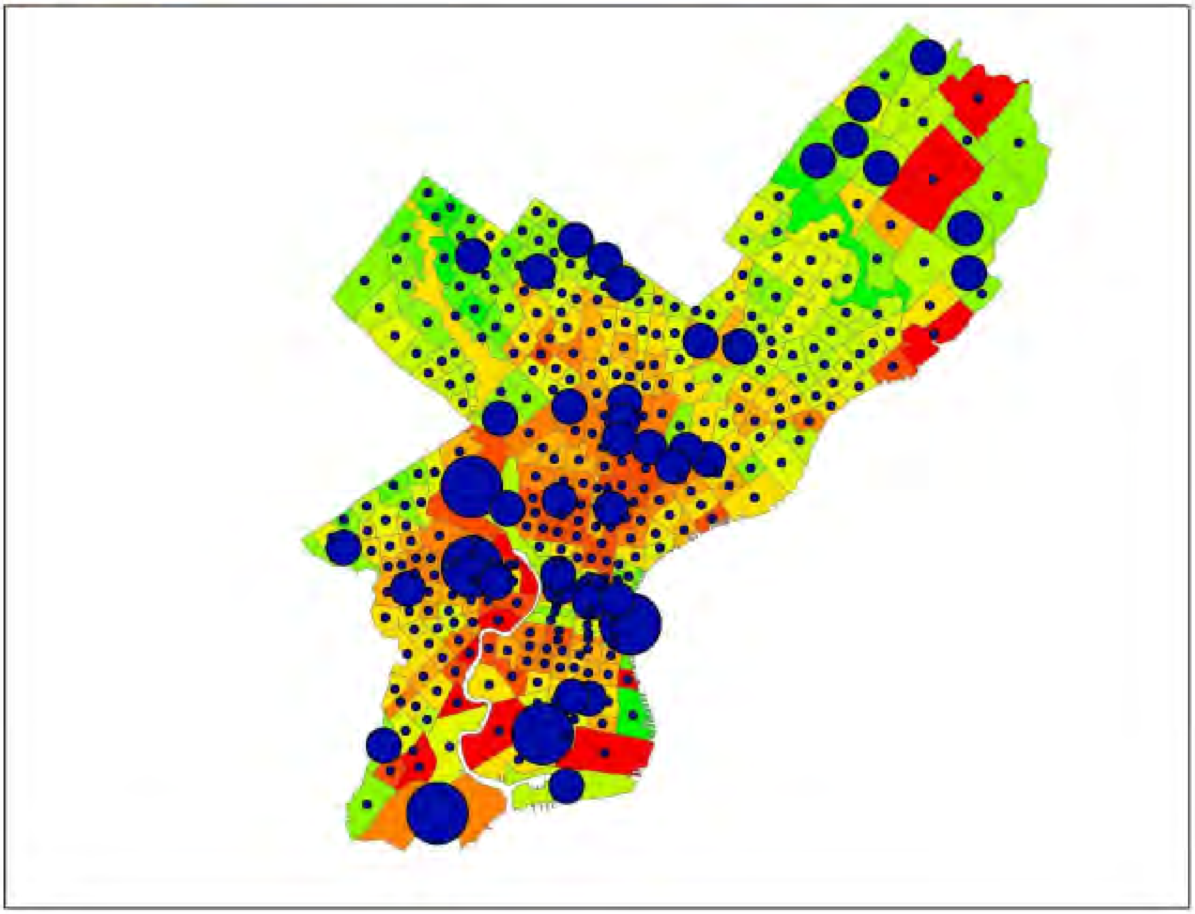
Figure 4) Gentrification in Philadelphia from 2012-2013 based on changes in the number of construction permits. (Areas in red have had the largest increase in construction in Philly from 2012-2013/Areas in blue have had the largest drop)[38]



[37] http://www.philly.com/philly/news/Gentrification_in_Philadelphia.html
[38] http://technical.ly/philly/2014/02/18/gentrification-map/

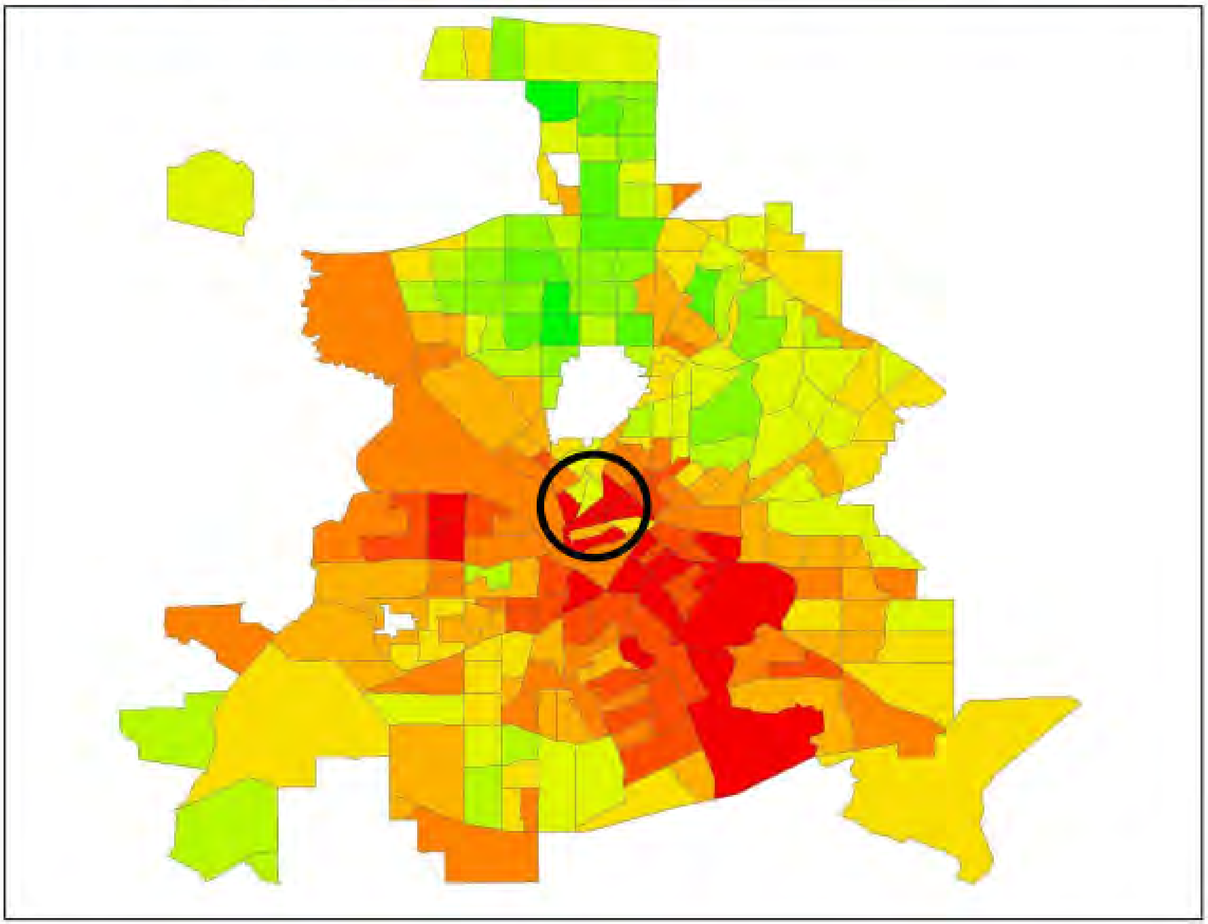
This map now has fatal accidents, per census tract, overlaid on top of the median household incomes for 1990 (Figure 5). Accident data for 1990 was averaged from years 1988 through 1992. It can be seen that there is a cluster of accidents in Center City, along with a ring of accidents around Center City, which closely aligns with the low-income areas. The more affluent areas to the northeast and northwest have low numbers of fatal accidents.

Figure 5) Fatal traffic accidents overlaid on household income by census tract for Philadelphia in 1990. (Source: FARS)



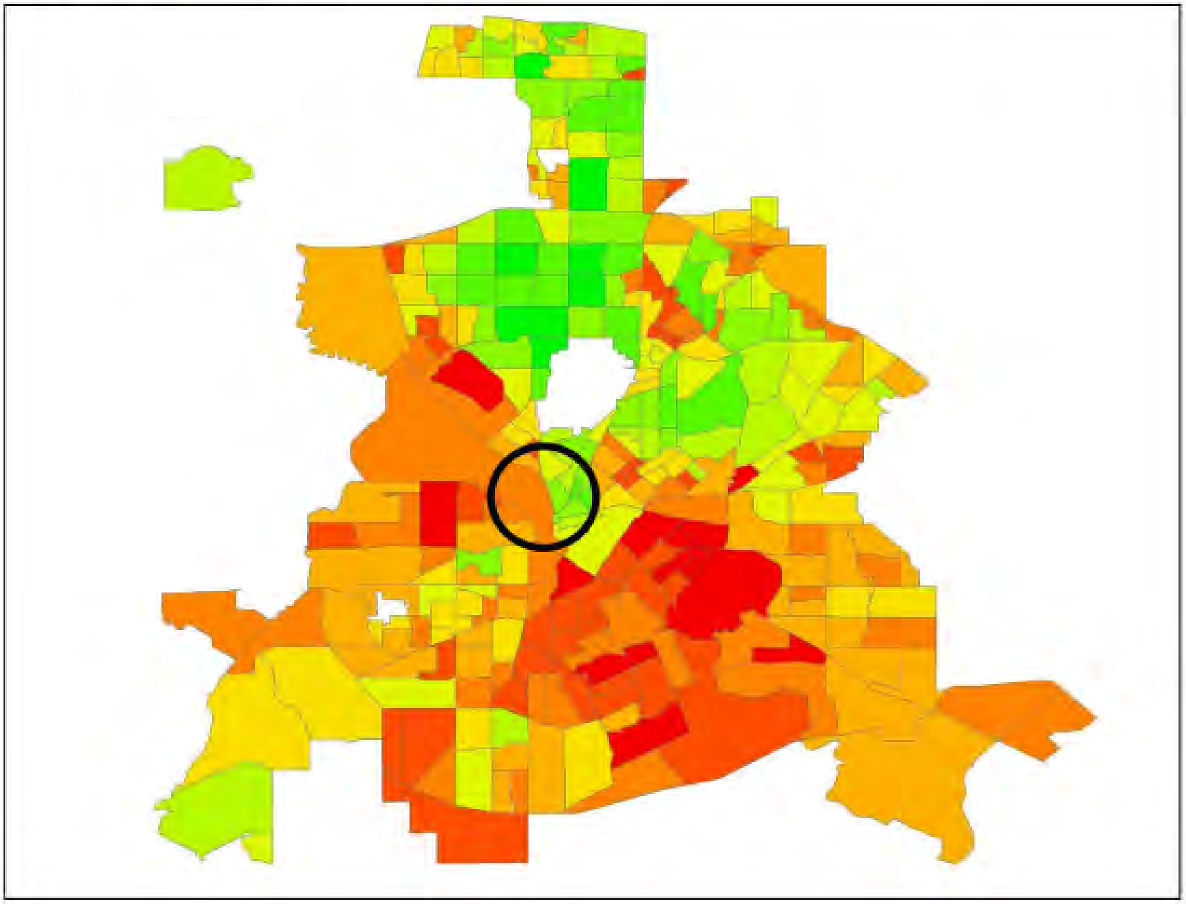
A similar trend of gentrification around the downtown area can be seen in Dallas as well. In 1990, there is a clear demarcation between the different income areas of Dallas, with the north being rich and the south being poor (Figure 7). Even the downtown area of Dallas seems to be relatively low-income compared to the northern areas of the city.

Figure 7) Median Household Income by Census Tract in Dallas in 1990. (Green = Higher Income / Red = Lower Income -- Source: Census)



Similar to Philadelphia, some gentrification occurred around downtown Dallas between 1990 and 2010 (Figure 8). The gentrification did not radically shift the rich and poor sections of the city, as the northern area is still richer, with the southern area being poorer.

Figure 8) Median Household Income by Census Tract in Dallas in 2010. (Green = Higher Income / Red = Lower Income -- Source: Census)



These maps further show the areas in which gentrification occurred in Dallas between the years 1990 and 2010 (Figure 9 & 10). Gentrification was focused in the downtown area, as we could see in the previous median household income maps. These gentrification metrics shown in the image were based on changes in median household income and educational attainment.

Figure 9) Gentrification in Dallas from 1990 until 2000.[39]

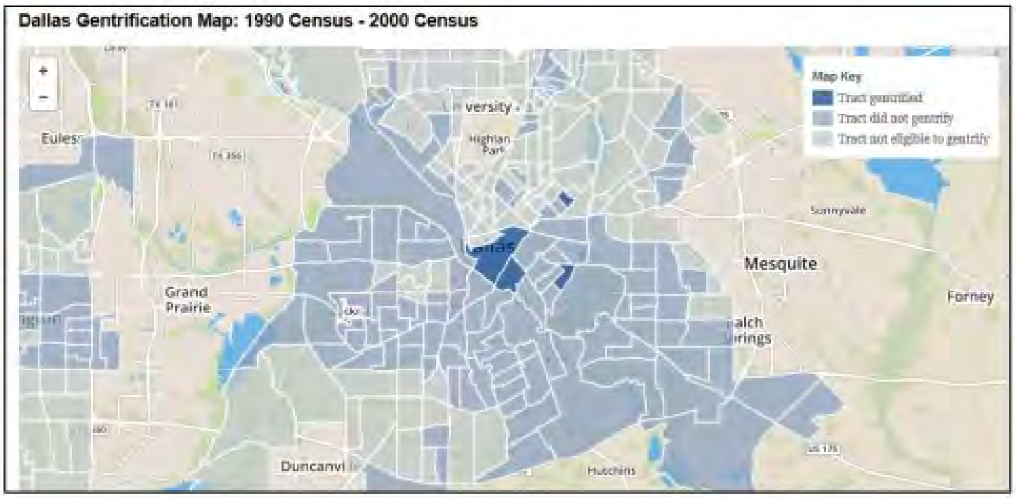
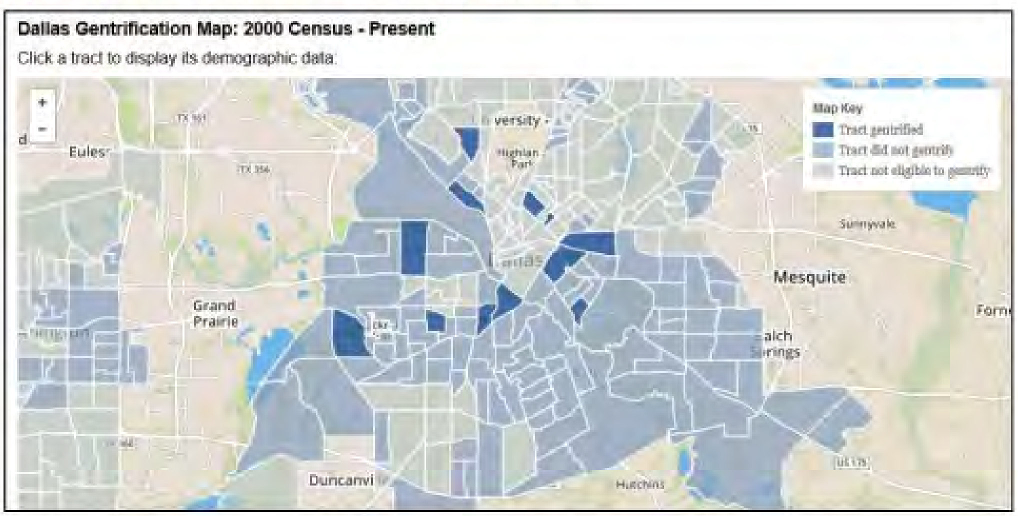


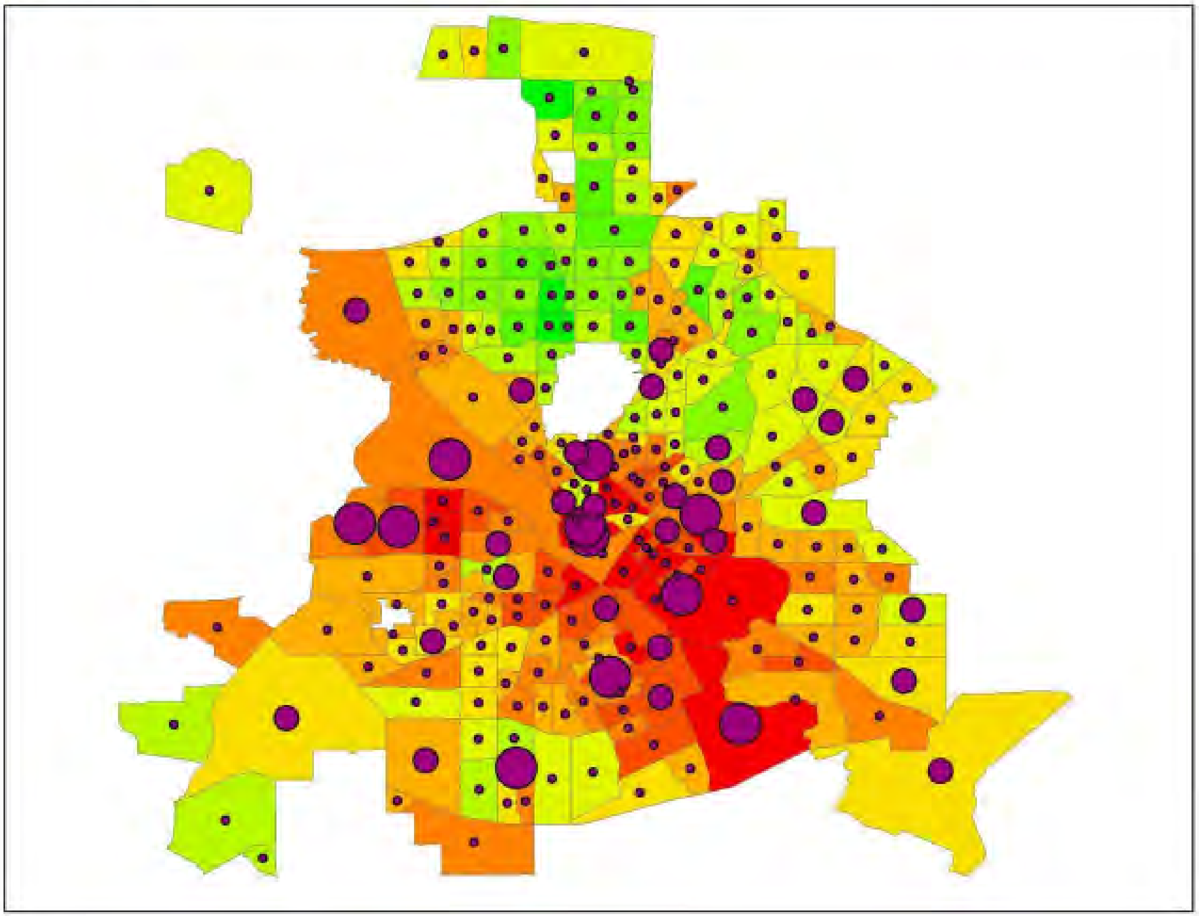
Figure 10) Gentrification in Dallas from 2000 until 2010.[40]



[39] http://www.governing.com/gov-data/dallas-gentrification-maps-demographic-data.html
[40] http://www.governing.com/gov-data/dallas-gentrification-maps-demographic-data.html

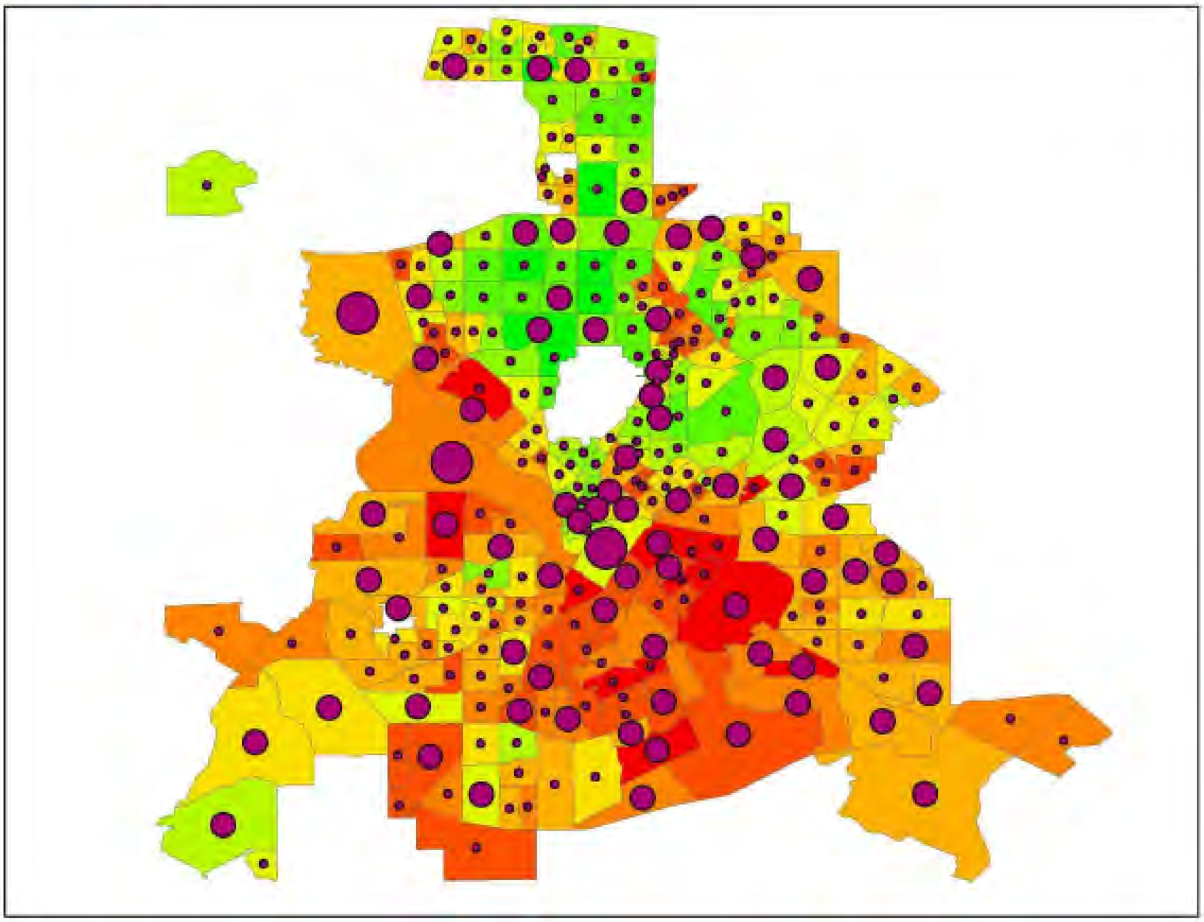
Following the same process as in Philadelphia, we now overlay the fatal motor vehicle accidents on top of the median household incomes by census tract. Fatal accident data was from FARS, with data for 1990 averaged from the years 1988 until 1992. We can see that the fatal accidents are very strongly concentrated in the poor neighborhoods of Dallas in 1990 (Figure 11).

Figure 11) Fatal traffic accidents overlaid on household income by census tract for Dallas in 1990. (Source: FARS)



One of the few good things that we can say about Dallas is that traffic fatalities seem to have been vastly improved in poor neighborhoods between 1990 and 2010. As can be seen in the map below, fatal accidents seem to have a much more even distribution (Figure 12). Knowing that Dallas improved their traffic safety overall, we can probably attribute this change in distribution to Dallas improving their poor neighborhoods!

Figure 12) Fatal traffic accidents overlaid on household income by census tract for Dallas in 2010. (Source: FARS)



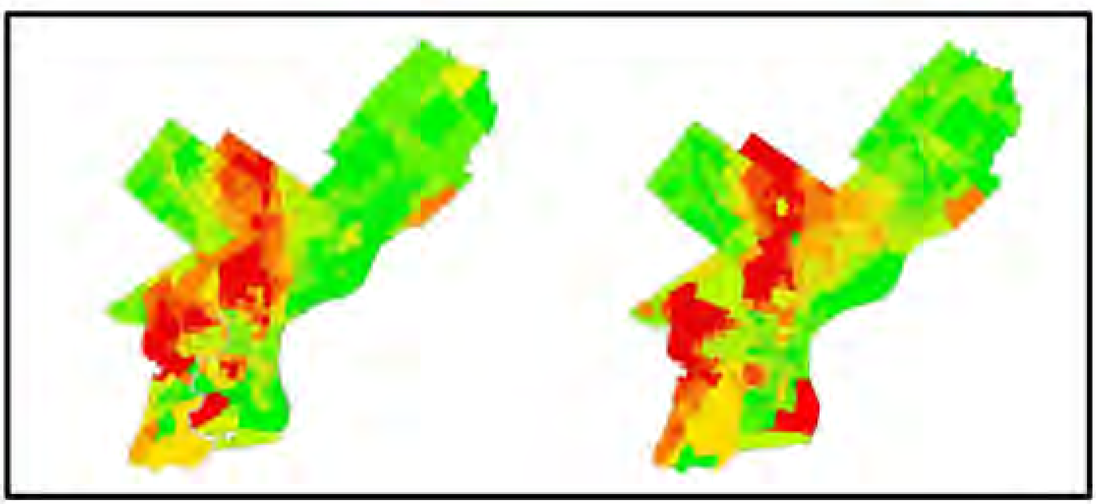
The primary finding here, and possibly one of the principal reasons that Dallas has been getting safer, is that it appears traffic safety has been getting much more equitable over the last two decades. While traffic fatalities were strongly concentrated in the poorer areas of Dallas during the 5 years surrounding 1990, they have become much more evenly distributed in 2010. This may reflect upon efforts by the city to improve the poor, and formerly unsafe, areas.

Demographics

We also analyzed transportation safety in relation to shifting demographics, specifically race. The findings are very similar to the findings when analyzing median household incomes, and will briefly be summarized here.

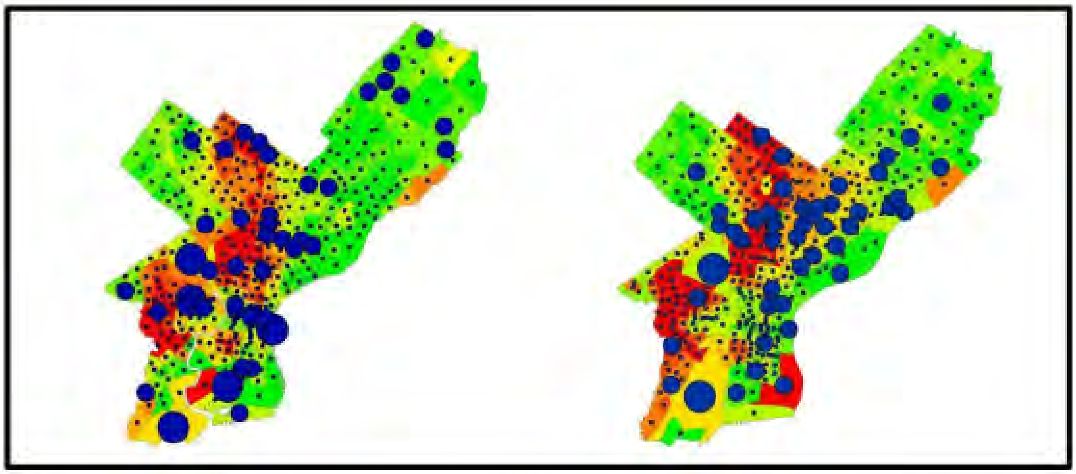
The percent of non-white populations were analyzed by census tract for the years 1990 and 2010 in both cities. Below, it can be seen that non-white populations have been shifting to the north and northeast, much as the lower income areas were during those two decades (Figure 13).

Figure 13) Non-white populations in Philadelphia in 1990 (left) and 2010 (right). (Red = higher non-white population -- Source: Census)



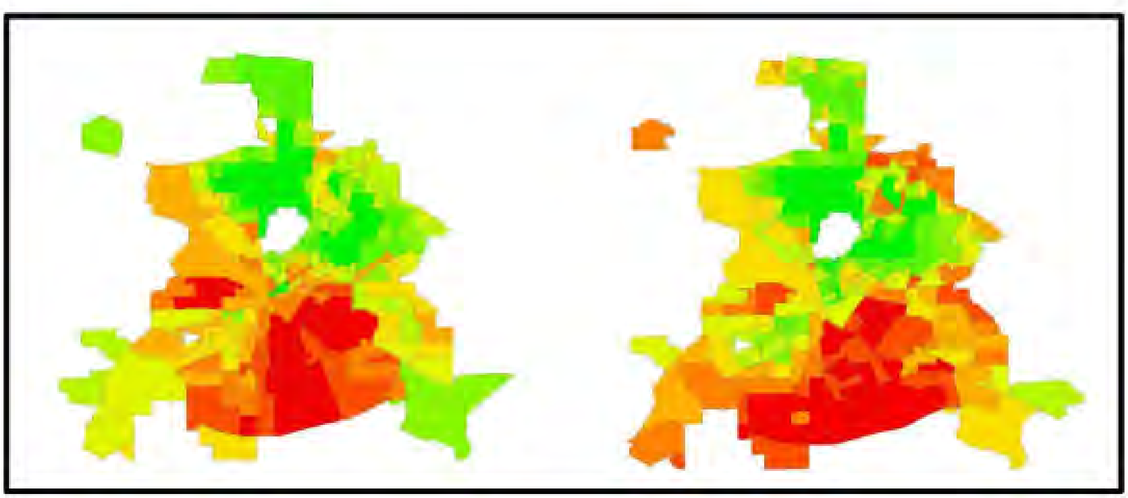
When overlaying the fatal motor vehicle accidents on the non-white symbolized census tracts, it is apparent that the shifting fatal motor vehicle accidents are similar to the shifts in the non-white populations between 1990 and 2010 (Figure 14). This shows that Philadelphia is doing a poor job with traffic safety in its poorest and highest minority population neighborhoods.

Figure 14) Fatal motor vehicle accidents overlaid on non-white populations by census tract in 1990 (left) and 2010 (right). (Source: FARS)



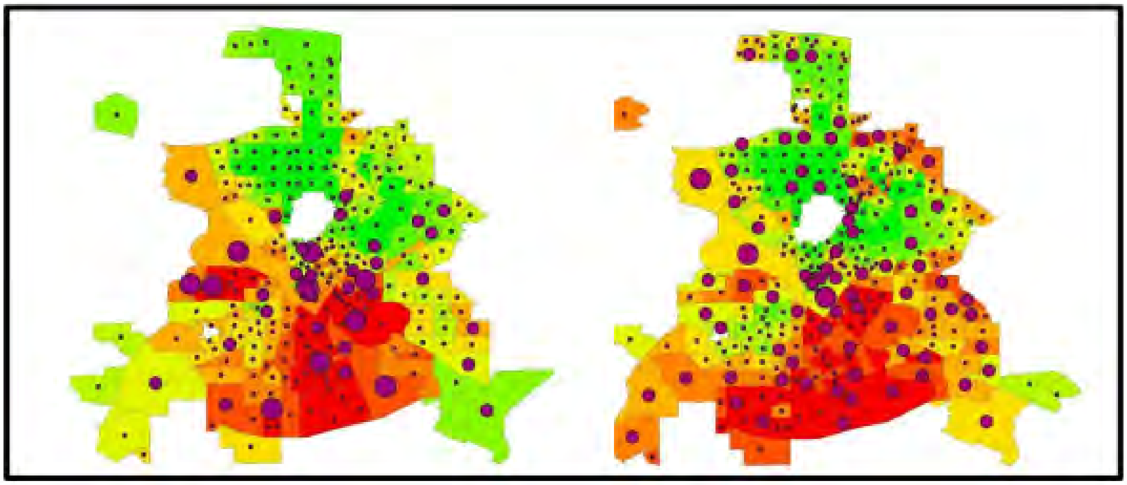
Dallas once again saw decreased numbers of non-whites in the downtown area from 1990 to 2010, following the trend of gentrification (Figure 15).

Figure 15) Non-white populations in Dallas in 1990 (left) and 2010 (right). (Red = higher non-white population -- Source: Census)



After overlaying fatal accidents on the non-white population, it can be seen that Dallas has improved the safety of its non-white neighborhoods over the last two decades. This is most likely a strong cause of the improved safety for Dallas city-wide.

Figure 16) Fatal motor vehicle accidents overlaid on non-white populations by census tract in 1990 (left) and 2010 (right). (Source: FARS)



Traffic and Operation Changes over Time

Both Dallas and Philadelphia have succeeded in reducing the road fatality rate, and vehicle speed is widely considered to have a strong influence on the rate of road deaths. The World Health Organization (WHO) identifies speed as a key risk factor, influencing both the risk of a road crash and the severity of resulting injuries[41]. A range of tools exist to encourage lower speed environments including policy, education, enforcement, and engineering This chapter presents a discussion of traffic and operation changes which have occurred in each city.

Although having a similar population, the city of Dallas covers over twice the land area of the city of Philadelphia (385.8 sq mi vs 134.1 sq mi[42]). As discussed in Chapter 1 the cities are formed of quite different street layouts with Philadelphia mainly following a grid pattern, in particular in the downtown area. Dallas by contrast has less of a grid network, and its ratio of area to population results in a more sprawling street layout.

Dallas operates with a hub-and-spoke freeway system and is served by Interstates 20, 30, 36E, 45 and 635; whereas Philadelphia is served by I-95 which skirts along the edge of the city parallel to the Delaware River, I-76 and I-676 which cross the city approximately perpendicular to I-95. Dallas is generally considered a more heavily automobile-centered culture, which may be a symptom of its extensive high speed highway network in comparison to the dense local street network of Philadelphia. Both cities accommodate pedestrians and bicyclists to some extent with Philadelphia historically having a stronger bias towards such users, and development of non-motorized user infrastructure has accelerated in recent years in both cities. In addition, both cities have developed a public transport system which includes bus and rail facilities.

[41] World Report on Road Traffic Injury Prevention. WHO. 2004
[42] Census - http://quickfacts.census.gov/qfd/states/42/42101.html

Figure 1 – Interstates and Major Highways – Dallas *left*, Philadelphia *right*

Congestion

The Texas A&M Transportation Institute has been monitoring and reporting on traffic congestion and travel reliability, providing data back to 1983. The Institute releases an annual Urban Mobility Report[43], and table 1 summarizes the data for Philadelphia and Dallas. An increase in congestion could result in reduced crash frequency and severity as a byproduct of reduced vehicle speeds. There is however a trade-off with collisions that could occur due to increased side street use (rat-running) and stop-go traffic progression.

Given the more extensive freeway and limited-access highway network prevalent in Dallas compared to Philadelphia, it is possible that Dallas is less likely to suffer from rat-running safety issues. This could influence the higher prevalence of collisions on the Dallas highway network as demonstrated in the heat maps in chapter 2. It could also be inferred that the accelerated increase in congestion in Dallas when compared to Philadelphia has had an influence due to road users being less familiar with driving in congested conditions.

[43] Urban Mobility Report, Texas Transportation Institute, Texas, 2012

		Year		
		2010	2000	1990
Congested Travel (% of peak VMT)	Dallas	68	52	33
	Philadelphia	61	55	43
Congested System (% of lane-miles)	Dallas	43	36	18
	Philadelphia	54	46	39

Table 1 – Change in congestion, 1990 to 2010

Red Light Enforcement

According to the NHTSAs Fatality Analysis Reporting System (FARS) in 2008, there were 165,000 injuries and 762 deaths related to people running red lights[44]. Both cities have red light enforcement systems, operated by for-profit organizations, with citations issued following review by the police department for vehicles entering the intersection on a red light. The first camera was installed in Dallas in 2006 with approximately 62 intersections currently enforced, and Pennsylvania's first camera was installed at Grant Ave / Roosevelt Blvd in 2005 with the city now operating 108 cameras over 24 intersections.

The effectiveness of such enforcement operations in improving safety is questioned by consumer organizations who maintain that such operations are purely revenue driven. However the Insurance Institute for Highway Safety has found that red light camera enforcement in conjunction with public awareness can modify driving behavior and has been shown to reduce red light violations and intersection crashes. A 2005 Federal Highway Administration (FHWA) study revealed a 14.9% increase in rear-end crashes but a 24.6% reduction in right-angle collisions, a crash type which accounts for 64% of injuries at intersections. The Pennsylvania Transportation Advisory Committee[45] found:

> *A 66% decrease in fatal accidents and a 24% drop in injuries caused by accidents at the ten red light camera intersections that have operated for at least three years.*

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[44] FHWA - http://safety.fhwa.dot.gov/intersection/redlight/

[45] Evaluating the Red Light Enforcement Program (ARLE) – Final Report, Pennsylvania State Transportation Advisory Committee. 2011

Safelight is the Dallas red light safety camera program, and their website quotes a goal of a 25% citywide reduction in right angle collisions and related injuries/fatalities. The 8 year safety report issued by City Hall in 2015 reports the following statistics[46]:

- *80% reduction in red light related fatalities (fatalities per intersection per year)*
- *44% reduction in red light related person-injuries (injuries per intersection per year)*

In addition to safety improvements at intersections, any revenue generated by citations may be re-invested in safety-related projects at other sites across the city. The Pennsylvania Transportation Advisory Committee reports the following investment in the City of Pennsylvania of red light enforcement revenue:

Description	Amount
Low cost safety improvements	$2,600
Intersection safety modifications	$2,100
Traffic signal retiming program	$1,500
Migration of signal timing plans into KITS	$1,000
Adaptive and responsive controllers	$780
Battery back-up for key intersections	$260
Pedestrian countdown signals	$230
Mobile radar signs	$75

Source: Philadelphia Streets Department

Table 2 - Philadelphia approved red light revenue funding, 2010 (in thousands)

[46] Automated Red Light Camera Enforcement Commission Briefing, Dallas City Hall - http://dallascityhall.com/government/meetings/DCH%20Documents/red-light-commission/RedLightCommission_briefing_012015.pdf

Safe Routes To Schools

Safe Routes to School (SRTS) is a movement to create safe, convenient and fun opportunities for children to walk and cycle to and from school. Although the goal of the program is to increase the number of children who cycle or walk to school, the improvements also increase safety for those children that already walk or cycle.

Pennsylvania DOT offers SRTS support and funding, and the Bicycle Coalition of Philadelphia has operated Safe Routes Philly since 2010, which provides programming and support for elementary schools in the city. Texas DOT offers SRTS support and funding for the city of Dallas, and since 2007 30 infrastructure and non-infrastructure projects have been funded. This compares favorably to Philadelphia where 10 projects have been funded by the Federal SRTS program[47].

Pedestrian Safety

As part of its safety toolkit Philadelphia has emphasized the inclusion of pedestrian safety in the city, highlighted by the Pedestrian and Bicycle Plan released in 2012, which is an update to the 2000 citywide Bicycle Network Plan. The Mayors Office of Transportation and Utilities (MOTU) also carries a strong safety focus and reports that *in 2007, there were 1,979 crashes that involved pedestrians. By 2012, that number was reduced to 1,739, a reduction of 10%*[48]. Philadelphia has implemented the following strategies to achieve this reduction:

- Re-timing of traffic signals at 2,400 intersections to accommodate slower walking speeds
- Relocation of stop bars when streets are resurfaced. The existing distance between stop bar and crosswalk is 4', whilst new stop bars are installed at 10' from the crosswalk to improve the visibility of pedestrians to other drivers[49]
- Installed 400 pedestrian countdown signals to help pedestrians make informed decisions about whether they can safely cross the intersection

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[47] http://apps.saferoutesinfo.org/project_list/

[48] Five Years in Review, Mayors Office of Transportation and Utilities, 2013

[49] Email, Charles Carmalt – City of Philadelphia Pedestrian and Bicycle Coordinator, 2015

By contrast, Dallas policy on pedestrian safety is less clearly defined or available. The city has not yet adopted a pedestrian-focused plan (although a DRAFT Complete Streets Manual is on the verge of being formally released). One complete street project has been implemented, and a number of other s are proposed, as discussed later.

The recent Klyde Warren Park project completed in 2012 demo nstrates some of the vision that Dallas has for improving the pedestrian atmosphere downtown. The 5.2-acre urban park is built across three blocks over the depressed 8-lane Woodall Rodgers Freeway in Downtown Dallas, and recognizes safety by providing generous parallel parking facilities on-street and 18 foot wide crosswalks to access the park.

Figure 2 – Klyde Warren Park, Downtown Dallas – before *left*, after *right*

Census data presented in chapter 2 shows that Philadelphia consistently has 4.5 times greater proportion of pedestrian commuters than Dallas. The fatality rate for pedestrians as a percentage of total road deaths in Philadelphia and Dallas was 29% in 2012[50] despite Philadelphia having over 4 times as many pedestrian commuters. This could indicate that the pedestrian improvements which have been implemented in Philadelphia are having a positive impact on improving safety.

[50] Traffic Safety Facts 2012 – Pedestrians, National Highway Traffic Safety Administration, 2012

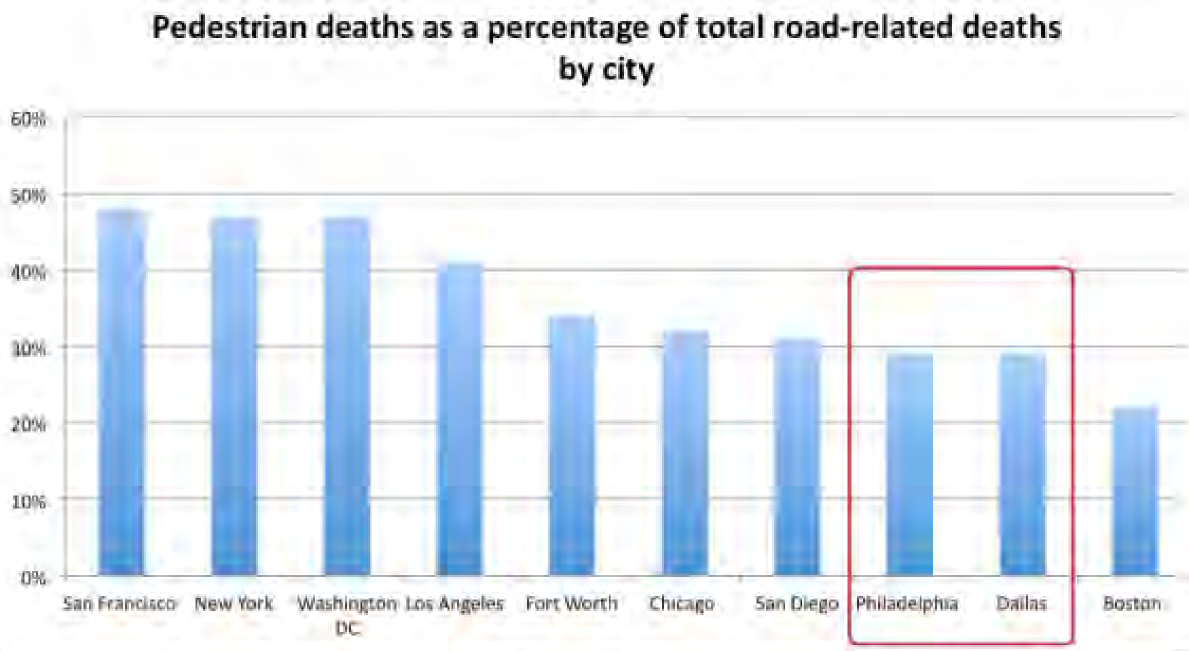


Figure 3 - Pedestrian deaths as a percentage of total, 2012

Safer Cycling

The volume and quality of bicycle infrastructure is vastly different when comparing Dallas and Philadelphia. The table and figures below present a summary of the infrastructure by length and type for each city, and the following paragraphs demonstrate the vastly different approach that each city appears to have taken in the past 20 years.

	Dallas	Philadelphia
Total area of land in city (sq. miles)	341	144
Total miles of roadway	4979	2776
Miles of on-street bike infrastructure	18	232
Miles of Class 1 or 2 bike infrastructure	4	225
Miles of trails	124	71
Total miles of bike infrastructure	142	303
Percent of roads with on-street infrastructure	**0.09%**	**8.11%**
Miles of bike infrastructure per sq. mi.	**0.42**	**2.1**
Percent of on-street bike infrastructure rated Class 1 or 2	**22%**	**97%**

Table 3 - Bike Infrastructure, Dallas vs Philadelphia

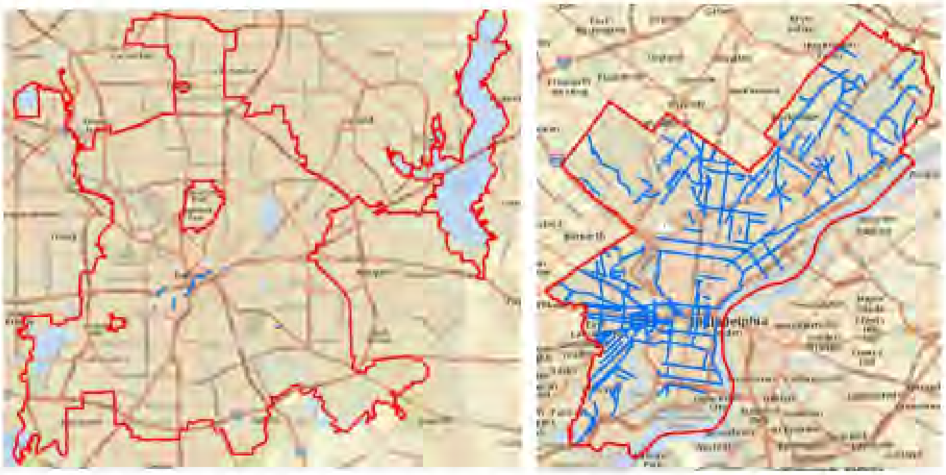


Figure 4 – On-street bike infrastructure – Dallas *left*, Philadelphia *right*

The release of the Philadelphia Pedestrian and Bicycle Plan came in 2012, providing a comprehensive update to the 2000 citywide Bicycle Network Plan. Philadelphia has in excess of 230 miles of on-street marked bike lanes or buffered bike lanes, the first of which were installed in 1995 on Delaware Avenue and Morrell Avenue[51]. The city also provides off-street trails and sidepaths. Designated on-street bike facilities, in particular buffered lanes, can aid safety for cyclists by increasing driver awareness of cyclists on the street and encouraging reduced vehicle speeds. Safety improvements primarily occur where high bicycle usage already exists, and the new infrastructure provides a better facility for these cyclists.

One case study in Philadelphia at Pine St and Spruce St highlights the success that Philadelphia bike projects have been achieving. Pine and Spruce run parallel to one another approximately east-west between the Schuylkill and Delaware Rivers. The project was completed in 2009 and intended as a crosstown connector to extend the bicycle network, improve cyclist safety, and calm motor vehicle traffic. The project provided buffered bike lanes in both directions and resulted in a small decrease in 85^{th} percentile vehicle speeds, with a Pennsylvania DOT review finding that after the first year the lanes saw a *44% reduction in serious car crashes, 58% reduction in pedestrian crashes, and 17% reduction in total crashes*[52].

[51] Philadelphia Bicycle Coalition - http://bicyclecoalition.org/victories/#sthash.51H5Pl45.dpbs
[52] Philadelphia Bicycle Coalition - http://bicyclecoalition.org/our-campaigns/biking-in-philly/spruce-and-pine-street/#sthash.Vw54KSi9.dpbs

Figure 5 – Pine St / Spruce St, Philadelphia – road diet and buffered bike lanes

In 2014, the City of Philadelphia took bicycle infrastructure a step further with the development of protected bike lanes on Delaware Avenue and Columbus Boulevard. Full segregation between modes increases safety for bicyclists, and for pedestrians by providing an extra wide buffer to motor traffic. Upgraded crosswalks, landscaping, and bicycle wayfinding are also included in the scheme. Although fully protected like a bike trail, the lanes are street-side and therefore retain the access and connectivity that trails cannot provide.

Figure 6 – Delaware Ave / Columbus Blvd, Philadelphia – protected bike lane and wayfinding

The Dallas Bike Plan was released in 2011 and is a completely new document released following the 1985 Bike Plan. The 2011 plan is an extensive 76 page document which focuses on planning and policy as opposed to design and implementation recommendations. Dallas has implemented 142 miles of bike infrastructure in the city however the vast majority (124 miles) is formed of multi-use pathways. Although off-street trails can prove extremely popular cycle facilities they often do not provide a suitable alternative for reaching destinations which are located on-street and therefore may have limited effectiveness in reducing road accidents involving cyclists.

The city of Dallas is currently implementing improvements at 70 intersections where bike trails meet cross-streets to provide safety and consistency for bicyclists and pedestrians. The improvements include signs with flashing lights, and reduced street widths with a single lane in each direction[53].

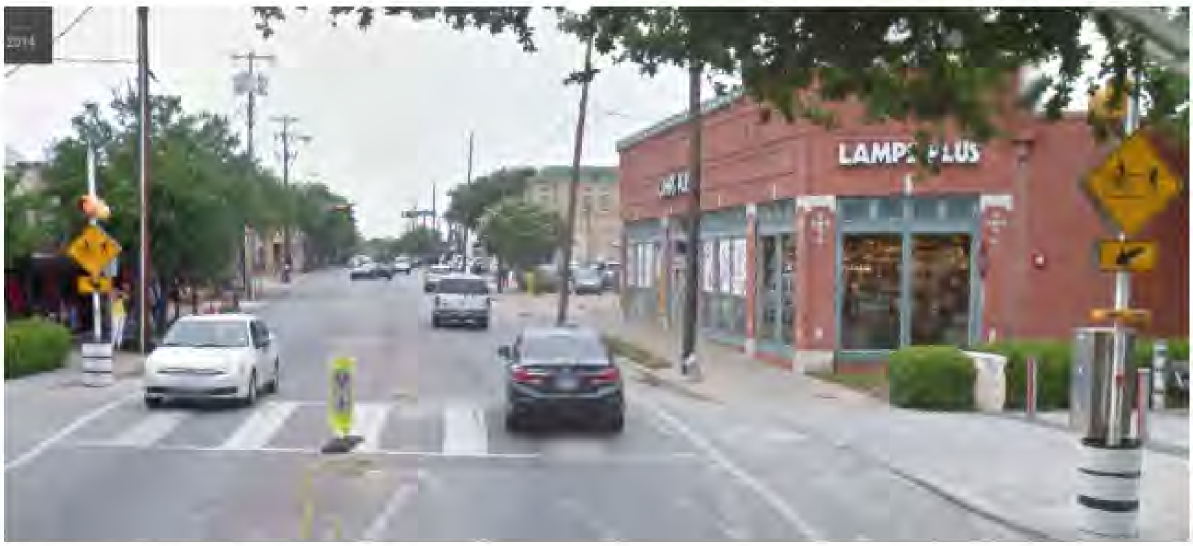


Figure 7 – Knox Street, Dallas – trail crossing

By providing improved and extensive bicycle and pedestrian improvements a city can markedly and visibly increase its volume of pedestrian and bicycle traffic. This in turn encourages reduced vehicle speeds and increased driver awareness of these vulnerable modes.

[53] http://cityhallblog.dallasnews.com/2014/09/dallas-to-boost-safety-at-70-spots-where-hike-and-bike-trails-cross-streets.html/#more-44860

Complete Streets / Road Diets

Philadelphia has mostly included road diets within other types of improvement projects, for example the Pine St / Spruce St improvements detailed above reduced traffic from 2 lanes to 1 on these one-way streets. This type of diet allows for the buffered bike lane whilst also improving comfort and safety for pedestrians at crosswalks and reducing vehicle speeds.

Dallas has begun to embrace the road diet philosophy (four lanes reduced to two or three lanes), in conjunction with complete street / streetscape improvements. The historically wider multi-lane roadways of Dallas are more appropriate to road diet improvements than the narrower Philadelphia Streets, and therefore may have a greater impact on road user safety through reduced vehicle speeds, reduced conflict points and improved pedestrian and cyclist visibility. The US Department of Transportation (DOT) suggests *road diets can reduce traffic crashes by an average of 29%*[54]. Dallas has a number of planned projects, and one completed example is Lower Greenville Avenue completed 2013.

Figure 8 – Lower Greenville Avenue road diet – before *left*, after *right*

[54] http://www.citylab.com/design/2014/09/so-what-exactly-is-a-road-diet/379975/

Traffic and Operations Findings

The information presented in this chapter provides glimpse of the vast differences between Dallas and Philadelphia. The traditionally car-centric Dallas has achieved a rapid acceleration in congestion, likely related to the growth in economy and population, whereas Philadelphia has remained relatively constant since 1990.

Both cities have embraced enforcement and education safety campaigns such as red light enforcement programs and Safe Routes to School. In fact, Dallas has implemented three times as many SRTS projects as Philadelphia.

Philadelphia appears to be far more progressive in targeting and implementing safety improvements for pedestrians and cyclists, and this may be representative of the percentage of those types of users in the system of each city. Dallas is now starting to recognize the relevance and importance of providing for pedestrians and cyclists, and how this may improve both the volume of users and their relative safety, with the Warren Klyde Park an example of the vision Dallas is developing.

City of Dallas	City of Philadelphia
Dallas Complete Streets Design Manual (DRAFT), 2014 Dallas Bike Plan, 2011 Standards and Guidelines for Traffic Control and Safety Treatments at Trail-Road Crossings, 2009	Philadelphia Complete Streets Design Handbook, 2013 Philadelphia Pedestrian and Bicycle Plan, 2012 The Philadelphia Bicycle Facility Design Guidelines, 1998 City of Philadelphia Parklet Guidelines & Application

Table 4 – Complete Street, Pedestrian and Bicycle Plans and Design Guidance

Conclusion

The evidence presented in this report reflects the multitude of factors which can influence improved safety for road users. Despite both Dallas and Philadelphia experiencing a comparable improvement in their road safety statistics since 1990, Dallas persists in having a markedly worse performance level per population than Philadelphia.

Through our research we have identified very different approaches taken in planning the built environment of the two cities. The tight gridded network of Philadelphia contrasted with the emphasis on highways and vehicular traffic in Dallas has undoubtedly played a role in the safety disparity between the two cities. With such different development histories and built environments, the safety improvements result from very different strengths in each city.

Dallas has experienced a reduction in commute times, yet appreciable increases in congestion. Both factors treated independently may result in a reduction in road deaths. Dallas appears to fall short with drunk driving and driver familiarity when compared with Philadelphia, and enforcement of drunk driving in Dallas is poor. The economic analysis of Dallas shows a more equitable distribution of traffic safety since 1990, and may indicate a concerted effort to improve poorer neighborhoods which are traditionally observed to suffer from a higher mortality rate due to traffic safety. Dallas has also seen more effective use of Safe Routes to Schools funds and a broader red light enforcement system.

The built environment of Philadelphia is consistent with the type of city that has good traffic safety, promoting slower speeds and more walkable neighborhoods. Since 1990, Philadelphia has made significantly better improvements to its transit, bicycle and pedestrian system than Dallas and this is reflected in the safety statistics presented. Like Dallas, car use in Philadelphia has increased, but the variance in bicycle use is striking and this is likely a reflection of the vast and rapidly expanding bike network provided in Philadelphia when compared to Dallas. More pedestrian and bicycle presence on well-designed facilities can promote slower vehicle speeds and better awareness in car drivers.

Example of Student Output No. 2 from CVEN 5633

Case Study Comparison: Seattle, WA & Memphis, TN

ROAD SAFETY

CVEN 5633: CASE STUDIES IN SUSTAINABLE TRANSPORTATION |

Introduction

Seattle, Washington and Memphis, Tennessee are two cities located within the United States of America with similar populations. Seattle has 624,681 people within the city limits and Memphis has 650,932 people within the city limits (United States Census Bureau 2015). Though they are similar in size, Memphis has higher road fatality rates on the order of nearly 3 times greater in 2010 according to the statistics provided by Dr. Wesley Marshall CVEN 5633 case study handout, summarized in the following table.

Table 1. Road Fatality Rates (per 100k persons)

	1990	2000	2010	% Change (1990 to 2000)	% Change (2000-2010)
Memphis	20.3	16.5	13.5	-18.7%	-18.2%
Seattle	11.6	5.6	4.6	-51.7%	-17.9%
Magnitude Difference	1.8	2.9	2.9		

Source: Dr. Wesley Marshall, CVEN 5633 Case Study Handout

Memphis road fatality rates in 2010 were 2.9 times greater than Seattle despite having seen a steady decline since 1990. Seattle road fatality rates saw a dramatic drop, over 50%, from 1990 to 2000 and then declined at slower rate, similar to Memphis, from 2000 to 2010. The purpose of this paper is to explore reasons that might cause such a difference in the road fatality rates of these two cities.

Background

Memphis is located in the southeastern United States with the Mississippi River forming the western border, the Great Smoky Mountains to the east, "deep" southern states to the south (Mississippi, Alabama, and Georgia) and Kentucky to the north. As previously stated, 650,932 people reside in the Memphis city limits. According to the City of Memphis website, Memphis has always been an important location for markets, exchanges, travel, and distribution. The city was founded in 1819 and faced struggles typical of southern U.S. states from the civil war through the civil rights movement (City of Memphis 2015a). The Memphis metropolitan area ranks 46th in the United States with respect to gross domestic product (GDP) (Bureau of Economic Analysis 2014). As of 2010, the city occupied 315 square miles (United States Census Bureau 2015a).

Seattle is located in the Pacific Northwest of the United States with the Pacific Ocean forming the western border, the state of Idaho to the east, the Columbia River for the majority of the southern border, and Canada to the north. As previously stated, 624,681 people reside in the Seattle city limits. Seattle was founded and prospered based on the lumber industry and was incorporated in 1869 (City of Seattle 2015a). The Seattle metropolitan area ranks 11th in the United States with respect to GDP (Bureau of Economic Analysis 2013). As of 2010, the city occupied 84 square miles (United States Census Bureau 2015b).

Framework for Analysis

This case study is organized around four issue areas that are presumed to play a role in road safety. The issue areas are as follows: 1) built environment, 2) travel behavior and land use patterns, 3) socio-demographic and socio economic characteristics, and 4) traffic operations. This paper presents an analysis of data and literature related to the above issues with an attempt to answer the question of why road fatality rates are so different between the two cities. Several sources were used including publications, municipal and other web sites, as well as phone conversations with city personnel.

Issue 1: Built environment

Changes to the built environment over time, specifically transportation infrastructure, inherently affect road safety and fatalities. By focusing less on roadway infrastructure and more on alternative travel modes, safety should improve. Likewise, less urban sprawl reduces vehicle miles traveled and improves safety. Roadway and transit infrastructure as well as urban sprawl will analyzed in this section.

Roadway Infrastructure

Currently, Memphis has 3,400 miles of roadway and Seattle, 3,943 miles (City of Memphis 2015a and City of Seattle 2015b). However, it is unclear whether the lane mile totals include roads under the jurisdiction of their respective state departments of transportation (DOTs). When comparing the metropolitan areas, Memphis had 3,335 lane miles of arterials and 667 lane miles of freeway compared to Seattle which had 5,328 lane miles of arterials and 2,316 lane miles of freeway in 2011 or the most recent data year provided (Shrank et. al. 2012). Based on this 2011 data, Seattle has 60% more arterial lane miles and 2.5 times the number of freeway miles than Memphis.

The table below shows changes to roadway infrastructure over time between the two city's metropolitan areas for the study years 1990 to 2010. Data from 1982 is included to help establish a baseline prior to 1990.

Table 2. Roadway Infrastructure Changes

	Year	1982	1990	2000	2010
Memphis	Freeway Lane Miles	315	400	520	667
	Arterial Lane Miles	1,355	1,975	2,700	3,335
	Total Lane Miles	1,670	2,375	3,220	4,002
	% Change	NA	42%	36%	24%
Seattle	Freeway Lane Miles	1,345	1,505	1,695	2,220
	Arterial Lane Miles	2,000	2,500	4,920	5,350
	Total Lane Miles	3,345	4,005	6,615	7,570
	% Change	NA	20%	65%	14%

Source: Texas A&M Transportation Institute's 2012 Urban Mobility Report

Seattle's lane miles increased at a slower rate than Memphis between 1982 and 1990 and between 2000 and 2010. Interestingly, Seattle saw a significant increase in lane miles between 1990 and 2000, almost twice that of Memphis, which occurred during the same decade that Seattle saw a 51.7% decrease in road fatalities. A correlation between increased lane miles and safety is not intuitive. Perhaps areas were annexed in the decade which rapidly increased the metropolitan area in Seattle or the construction necessary to increase the lane miles slowed traffic and reduced fatalities.

The Texas A&M report also provides information on the annual travel delay in each metro area. In 2011, Memphis had an annual delay of 28.7 million person-hours; in Seattle it was 100.8 million person-hours, 3.5 times greater. Another way to view congestion data is the percent of vehicle miles traveled in congested conditions during peak hours. In Memphis 33% of VMT were in congested conditions in 2011; in Seattle 64% of vehicle miles traveled were in congested conditions. This pattern holds true for historic data as well where Memphis averaged 31% and Seattle averaged 65% between 1990 and 2010 (Shrank et. al. 2012). It is clear from this data that Seattle experiences significantly more congestion than Memphis. Since congestion lowers traffic speed, one could presume higher congestion leads to less fatal road accidents.

Transit Infrastructure

Seattle has a more extensive transit system compared to Memphis. The Memphis metropolitan area has the following infrastructure (Nygaard/Nelson Associates et. al. 2011):

- Bus: 33 routes, 250 fixed route vehicles, 77 heavy transit vehicles
- Rail Trolley Service: 7 miles of track, 19 cars, 13 stops
- Transit Centers: 3

- Bus Stops: 5,600
- Park-n-Rides: 5

The Seattle metropolitan area has the following infrastructure (King County 2015):

- Link Light Rail: 11 stops between Westlake Station in downtown to Sea-Tac Airport
- Sounder Train (commuter rail): Two routes, Everett to Seattle and Lakewood to Seattle
- Seattle Center Monorail: 2 stations downtown
- Seattle Streetcar: 1 line, 1.3 miles
- Bus: 209 routes
- Water Taxis: 2

The availability and breadth of transit infrastructure is evident comparing the number of different modes in Seattle. It is also evident when comparing the ridership numbers.

Table 3. Transit Ridership

		Unlinked Passenger Trip (000s)	
Year	**Transit Type**	**Memphis**	**Seattle**
2012	Total	Not in Top 50	119,952 (11th)
January to September 2014	Light Rail	NA	9,052
	Trolley	485	NA
	Commuter Rail	NA	2,449
	Trolley Bus	NA	14,719
	Bus	5,833	75,503

Sources: 2014 American Public Transportation Assoc. Fact Book and Ridership Report

The 2011 metropolitan population in Memphis was 1,058,000 and 10,400,000 unlinked trips were taken which equates to 9.8 trips per person per year. For Seattle, the 2011 metropolitan population was 3,286,000 and 192,800,000 unlinked trips were taken which equates to there are 58.7 trips per person per year (Shrank et. al 2012). Seattle metropolitan area has a higher transit use per capita.

The table below show changes to transit over time between the two city's metropolitan areas for the study years. Data from 1982 is included to help establish a baseline prior to the first study year, 1990.

Table 4. Miles Traveled by Vehicles vs. Transit

		1982	1990	2000	2010
Memphis	Daily Freeway VMT (000s)	3,200	4,575	6,900	8,493
	Daily Arterial VMT (000s)	5,150	8,210	12,000	12,759
	Total Daily VMT (000s)	8,350	12,785	18,900	21,252
	Total Annual (000s)	3,047,750	4,666,525	6,898,500	7,756,980
	Annual Transit Passenger Mile (000s)	65,000	67,300	64,100	56,700
	% Transit to vehicle	2.13%	1.44%	0.93%	0.73%
Seattle	Daily Freeway VMT (000s)	14,560	22,240	29,400	32,197
	Daily Arterial VMT (000s)	11,000	17,830	23,420	27,413
	Total Daily VMT (000s)	25,560	40,070	52,820	59,610
	Total Annual[1] (000s)	9,329,400	14,625,550	19,279,300	21,757,650
	Annual Transit Passenger Mile (000s)	235,700	663,400	938,000	1,227,500
	% Transit to vehicle	2.53%	4.54%	4.87%	5.64%

Source: Texas A&M Transportation Institute's 2012 Urban Mobility Report
1-Daily vehicle miles traveled (VMT) multiplied by 365

As evident in the table above, Seattle has a higher share of transit miles traveled relative to vehicle miles traveled. According to a study published in the Journal of Urban Health by Stimpson et al, "Increasing the share of mass transit miles traveled, relative to motor vehicle miles traveled, may be an effective public health intervention to reduce motor vehicle fatalities in cities" (Stimpson et. al). Given this research, it is fair to assume Seattle's greater share of transit miles traveled is another reason why it has fewer road fatalities than Memphis.

Land Use: Urban Sprawl

Research shows urban areas that are more spread out have higher fatalities. The 2002 Smart Growth Report states that "residents of more sprawling areas are at a greater risk of dying in a car crash". Smart Growth America ranked Memphis as the 31st and Seattle as the 44th most sprawling of the metro areas studied in their 2002 report (Ewing et. al. 2002). In their 2014 report, Memphis was the 26th most sprawling and Seattle was the 168th most sprawling, showing that Memphis has been trending toward more sprawl (Ewing et. al 2014). The city of Memphis occupies 315 square miles and Seattle just 84 square miles (United States Census Bureau 2015). Seattle is 3.75 times more compact with 7,437 persons per square mile compared to Memphis with 2,066 persons per square mile. This sprawl data supports the theory that Seattle is a safer city than Memphis in terms of road fatalities because it is more compact.

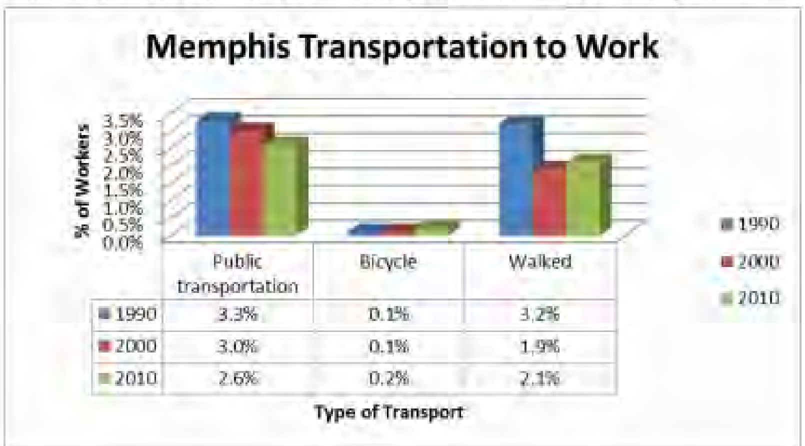
Issue 2: Travel behavior and land use policies

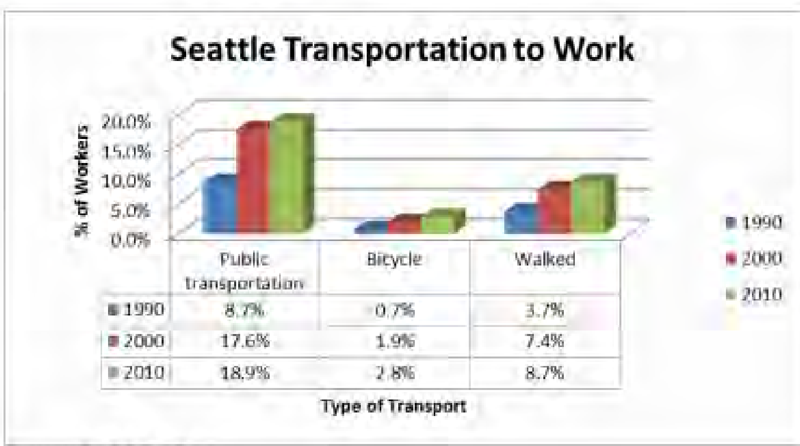
Transportation preferences change throughout time. The U.S. is currently seeing an unprecedented shift away from the automobile toward alternative modes of transportation such as transit, walking and biking. This trend is being driven in particular by young people in their 20s, who for a variety of health, environmental and financial reasons are opting to drive less (P.U.M.A Global Trends 2014). However, some cities are seeing shifts toward alternative modes faster than others.

Changing Commuter Modes

The charts below compare Memphis and Seattle commuter modes between 1990 and 2010. Memphis show a decrease in public transit, bicycling, and pedestrian commuters from 1990 to 2010. Seattle, however, shows an increase in all three categories over time.

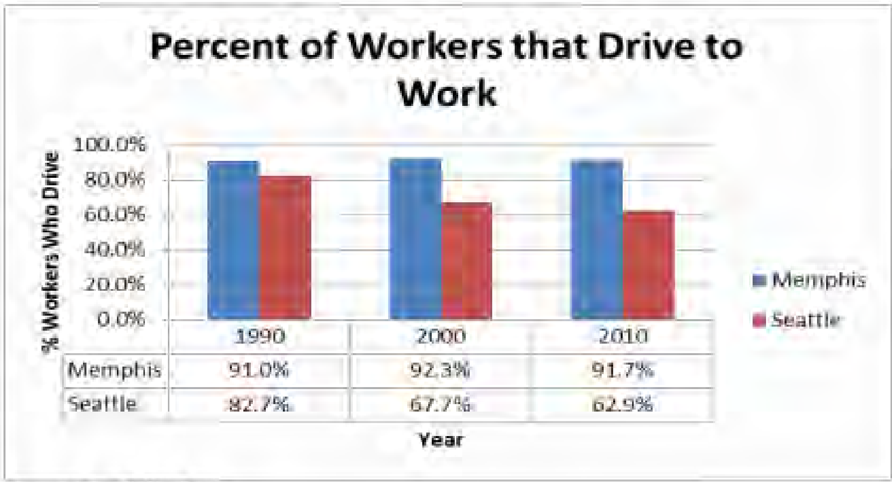
Charts 1 & 2: Alternative Transportation Mode Comparison





Source: Social Explorer

Chart 3: Drive to Work



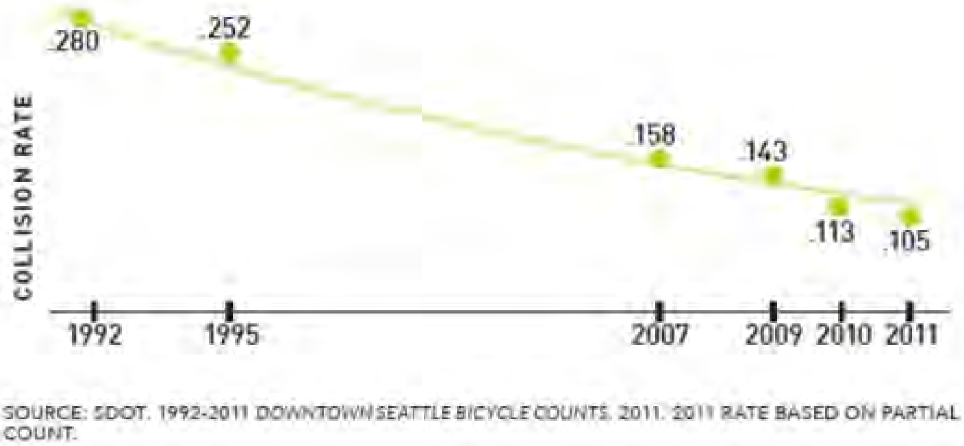
Source: Social Explorer

According to the chart above, the percent of people who drove to work in Memphis remained constant throughout the 20 year period. Seattle, on the other hand, shows a 20% drop in the number of people who drove to work. Incidentally, the most substantial drop in drivers, 15% between 1990 and 2000, coincides with the timeframe where Seattle saw a 51.7% decrease in road fatalities.

Biking, Walking and Safety

Studies show that the risk of injury or fatality with automobiles declines as more people walk and bike (Seattle DOT 2014). Interestingly, this increase in pedestrians and cyclists appears to improve safety for all road users, including those in automobiles. This is partly because a large number of pedestrians and cyclists change the street dynamic, encouraging drivers to slow down and proceed more cautiously. Slower speeds exponentially increase the survival rate for pedestrians and cyclists involved in accidents with vehicles. At 20 mph, a pedestrian or cyclist has a 98% survival rate, compared with survival rates of 80% and 30% at 30 mph and 40 mph respectively (Seattle DOT 2014). The following graphic shows a correlation between an increase in biking rate and decrease in collision rate in Seattle.

Chart 4: Correlation between Bicycle Counts and Collisions in Seattle



Given that an increased number of cyclists improves road safety and Seattle has a much higher number of cyclists than Memphis, it is possible to assume this plays a role in Seattle's lower road fatality rate.

Bicycling Culture

A Census Bureau report from spring 2014, says bicycle commuting is the fastest growing commuting mode in the last decade. According to the American Community Survey, the average percentage of bike commuters in 2013 was 0.62% (The League of American Bicyclists 2015), which Seattle far exceeds at 4.1% and Memphis falls behind at .2%.

Seattle has done more than Memphis to encourage a culture of biking. The Weyerhaeuser Company started a Commute Trip Reduction Program in 1997 that offered employees covered bike parking, showers, lockers and $25 vouchers for biking to work. Amgen Inc.'s bike commuter population grew from 8 to 11 percent by providing bike amenities and $50 vouchers for commuters who biked a certain number of days a month. Microsoft and Seattle Children's Hospital are two other examples of companies in Seattle that offer bike incentives including on-site repair services and bike education classes (Ensign 2015). In Memphis, there were no incentive programs readily found.

Bike Infrastructure

In Seattle, crashes with pedestrians, bicyclists, and motorcyclists make up less than 5% of total crashes, but account for nearly 50% of the fatalities (City of Seattle 2015). Bike lanes, particularly those that are protected, help to prevent collisions with vehicles. A study in New York City found that protected bike lanes reduced traffic crashes for all users by 34% (Memphis Division of Engineering). The table below compares different types of bike infrastructure that exists between the two cities.

Table 5. 2013 Bicycle Infrastructure

	Memphis # Miles	Seattle # Miles
Bicycle Lanes	52.0	78.0
Sharrows	67.0	92.0
Multi-Use Trails	12.0	47.0
Protected Bike Lanes	0.6	3.2
Total	**131.6**	**220.2**

Source: Seattle Bicycle Master Plan 2014; State of Bicycling Memphis 2014

In 2013, Seattle had 67% more miles of bike lanes than Memphis and 4 times the miles of protected bike lanes. In addition to providing better safety, protected bike lanes also have the potential to encourage greater ridership among a broad range of users. According to People for Bikes, 96% of people who were surveyed said protected bike lanes make them feel safer on the streets. Having more riders on the streets also boosts safety as mentioned above.

Seattle began increasing bike infrastructure in the 1980s. The graphic below shows the city's evolution through 2013, by which time the city had a robust bike network.

Image 1: Seattle Bike Lane Evolution

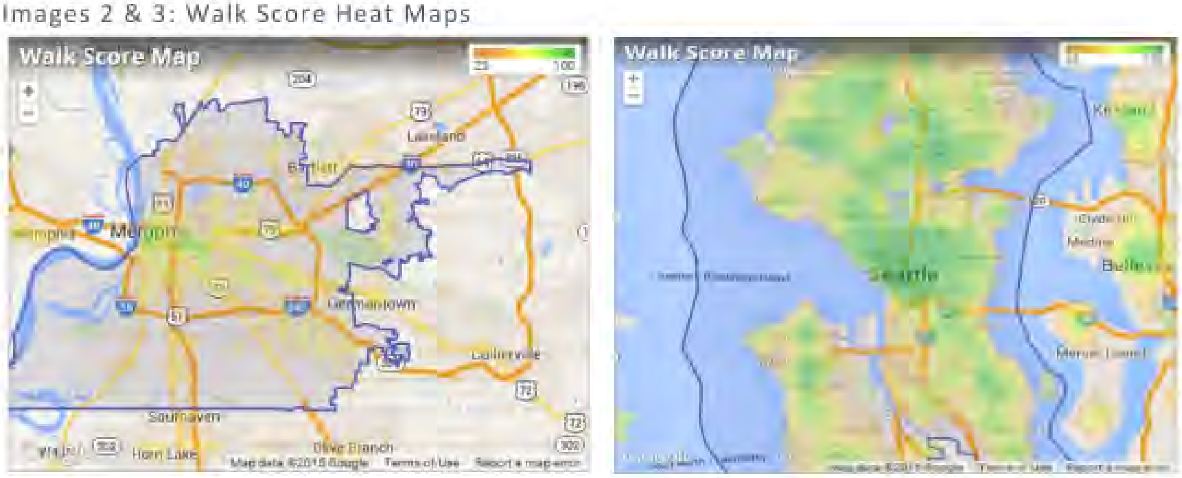
By contrast, Memphis got a relatively late start. Up until 2010, Memphis did not have a single mile of bike lane and therefore many of the roads used for cycling were unfriendly to bikers. In 2010 Memphis was declared by Bicycle Magazine as one of three worst cities in the U.S. for cycling (People for Bike 2015). This complete lack of bike infrastructure in Memphis and sizeable network in Seattle between 1990 and 2010 likely had an impact on road safety outcomes.

Walkability

Land use patterns can lead to high or low levels of connectivity within a place. A place with high connectivity is one where it is easy for people to get to key destinations like home, work, shopping, recreational activities and transit. Some trips may require a car but places with good connectivity will provide alternative options for short trips such as walking or biking.

Walk Score is a tool used to compare walkability across locations and is based on a 0-100 scale with 100 being a walker's paradise. Seattle has a Walk Score of 71 and is the 8th most walkable large city in the U.S. A Walk Score of 71 is considered very walkable, meaning most errands can be done by foot. Memphis on the other hand has a walk score of 33, ranking as the 38th most walkable large city in the U.S. A Walk Score of 33 means Memphis is car dependent and therefore most errands will require driving.

Images 2 & 3: Walk Score Heat Maps



Comparing Walk Scores at this high level gives a sense of walkability but does not assess the particulars of a pedestrian friendly environment, such as block length. Based on a calculation of block lengths from Google Earth it was determined that Seattle has an average block length of 300 feet whereas Memphis has an average block length of 400 feet. It should be noted that Seattle streets were largely based on a grid system whereas Memphis has irregular block patterns with block lengths varying considerably. In general shorter block lengths encourage more walking, so Seattle's street grid with shorter blocks encourages more walkability than the street layout in Memphis. As mentioned above, the more people walking on the streets, the safer it is going to be for all users.

Land Use Policies

In 1994, the city of Seattle adopted the "Seattle Comprehensive Plan" that focused on sustainability in four key areas – community, environmental stewardship, economic opportunity, and social equity (Seattle 2035). This plan was created after the "legislature in the state of Washington adopted the Growth Management Act (GMA) to reduce sprawl and direct new households and jobs within areas that have basic infrastructure, like roads and utilities" (Seattle 2035, 1). Seattle took this plan a step further by "locating housing and jobs close to one another to make it easier for people to walk, bike, or transit" (Seattle 2035, 1). Seattle made a goal in their 1994 Comprehensive Plan to diversify how workers commuted to work through their improvements in transit systems and by encouraging more pedestrians and bicyclers. The city of Memphis has recently published a Long Range Transportation Plan through 2040 that addresses the safety and accessibility of all travelers; however their plan from 1990 through today remains to have limited bus, pedestrian, and bike routes that improve travel accessibility. Any information from the 1990s from Memphis compared to Seattle's Comprehensive Plan was not found; therefore it is assumed that no such plan was created that went into the same amount of detail.

Policies cities choose to implement can have an effect on land use and street design, which can ultimately impact road safety outcomes. Complete Streets policies, for example, look at new transportation improvement projects from a variety of perspectives that include pedestrians, bicyclists, transit riders and people of all abilities. Seattle adopted a Complete Streets policy in 2007 and Memphis adopted a policy six years later in 2013, which falls outside of the timeframe considered in this analysis. Since Complete Streets policies design roads with the pedestrian in mind, treatments like sidewalks, medians, and traffic calming measures improve safety for pedestrians as well as all other users. In the U.S. more than 50% of pedestrian fatalities occur on arterial roadways, which are wide, fast roads specifically designed to move cars (Smart Growth America 2014). Cities that have adopted Complete Streets policies are trying to move

beyond the focus on the automobile and take into consideration all road users. Seattle's earlier adoption of this policy than Memphis is indicative of the priority and mindfulness they have given to all users. Seattle's comprehensive plan of the 1990s helped to educate citizens about alternative modes of transit and thus empowered the city to improve transportation safety systems. Memphis, on the other hand, shows a decline in public transportation, biking, and walking to work that is likely attributed to lack of planning from the city and lack of infrastructure accommodate different travel modes.

Land Use Mix

An analysis of zoning was performed using GIS data from Seattle and Memphis to see if the amount of different types of zoning have an impact on safety. Mixed use zones, according to research conducted by Wes Marshall, tend to slow down traffic because of the intensity and variety of activity happening at the street level. Conversely, single use zones create fewer reasons to stop and generally promote environments that are easy to drive through quickly. Additionally, mixed use environments create opportunities for people to live, work and play, within short distances, in theory reducing the need for longer trips which may require a car.

According to GIS zoning data from 2013, Memphis has more mixed use zoning than Seattle, 9% compared to 3%. This does not support the theory that more mixed use contributes to a safer city for all road users. The maps below depict the mixed use zoning in each city.

Image 4: Memphis Mixed Use Zoning

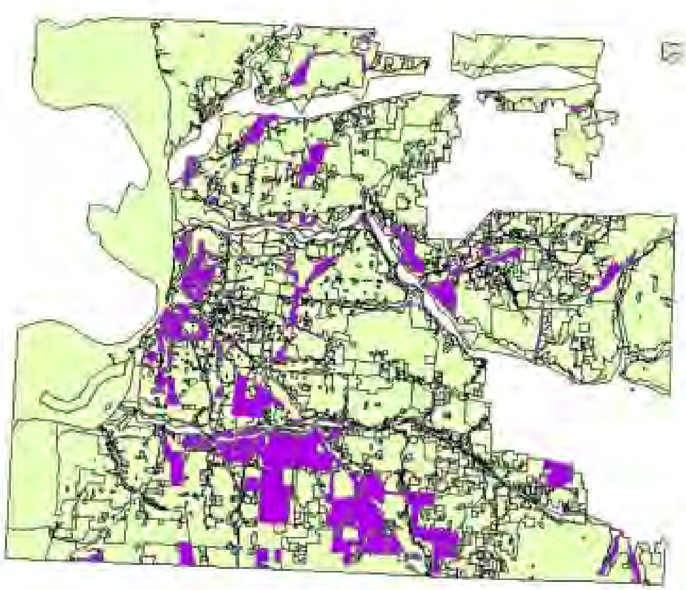
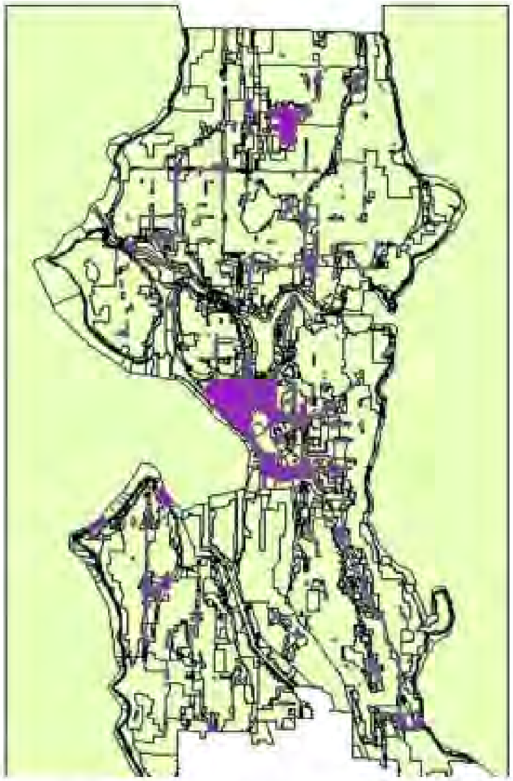


Image 5: Seattle Mixed Use Zoning



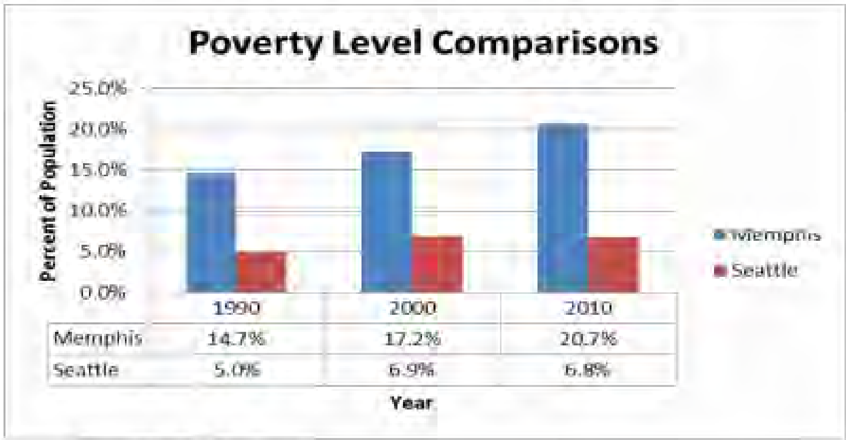
Zoning does not always reflect actual land use in cities. Many cities, including Denver, have done recent overhauls of their zoning code and added significantly more mixed use that has not yet been realized within the city. Memphis did an overhaul of its zoning code in 2008. The large tracts of mixed use zoning seen in the Memphis map may be reflective of this new zoning and not actual land use patterns. Land use data was not available for analysis, so it is not possible to conclude with certainty whether a greater amount of mixed use impacts road safety outcomes.

Issue 3: Socio-Demographic and Socio-Economic Characteristics

Seattle and Memphis differ in their socio-economic and socio-demographic aspects. While one may not initially assume that a city's poverty level and median household income are correlated to road safety, a study between these two is worth comparing. In 2015, Forbes identified Seattle as the 9th best place for business and careers (Forbes 2015a) compared to Memphis which was listed at 134th on the list (Forbes 2015b). In addition, in 2011 the Census Bureau identified Memphis as the "poorest city in America" with one news station stating that "Memphis was a socio-economic nightmare" (Hartman 2011). The struggles in Memphis and the improvements in Seattle did not happen overnight. Historical data from Social

Explorer shows the trends in poverty levels, incomes, employment, and education from 1990 to 2010 with dismal ratings for Memphis and stagnant to improving levels for Seattle. The charts below provide an illustration and comparison between the two cities.

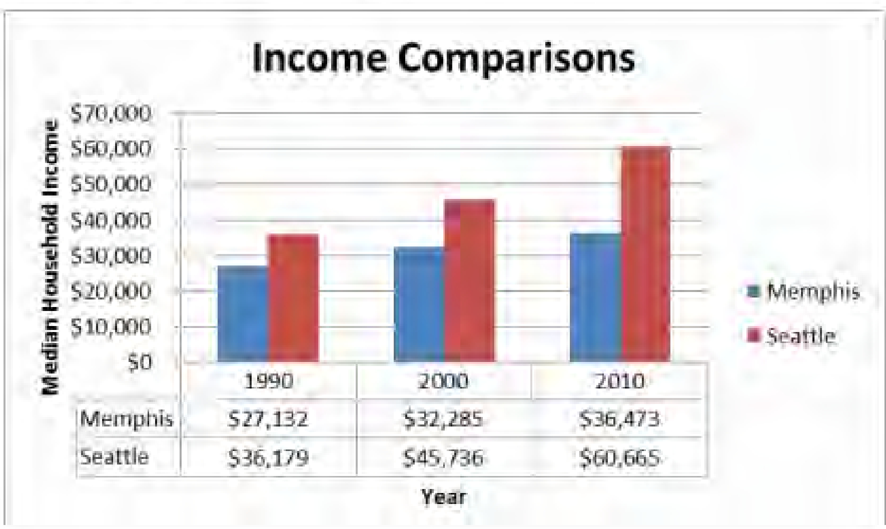
Table 6: Poverty Level Comparisons

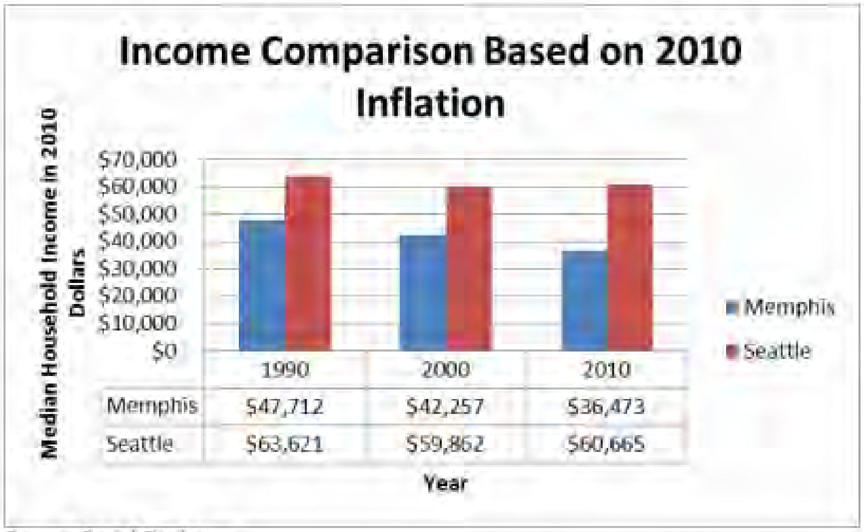


Source: Social Explorer

Seattle shows a small increase of 1.8% in poverty level within the 20 year period compared to a 6% increase in Memphis, meaning that one-fifth of the Memphis population lived in poverty in 2010.

Tables 7 & 8: Income Comparisons

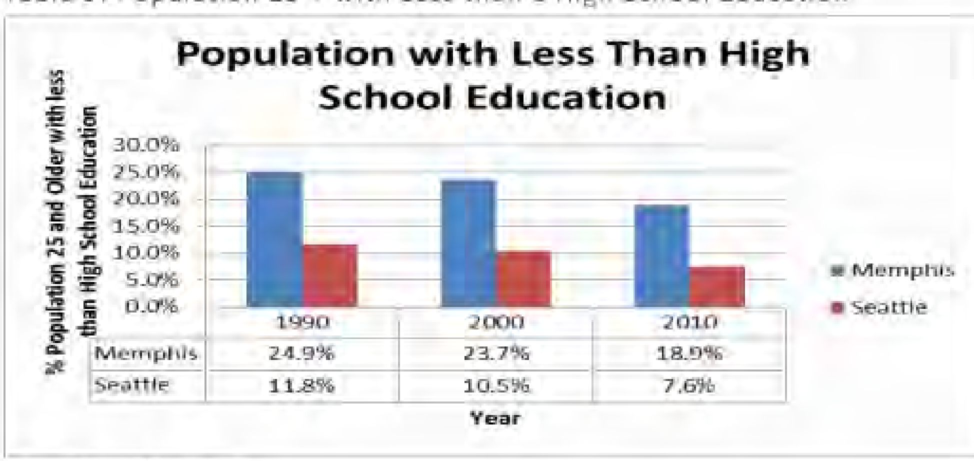




Source: Social Explorer

Seattle's median household income increased by over $24,000 from 1990 to 2010, where Memphis's median household income increased just over $9,000 in the same time period. When compared against 2010 inflation numbers, Seattle showed a relatively stable hold, whereas Memphis declined over $11,000 within the 20 year period.

Table 9: Population 25 + with Less than a High School Education



Source: Social Explorer

Though both cities show an improvement through the 20 years, Memphis continues to have a much higher percentage of people 25 or older without a high school degree.

The charts above show a great disparity between the two cities in their levels of poverty, income, and education. Identifying whether this is causation versus correlation for road safety outcomes is the next step. A report titled "Poverty Increases Risk in a Road Crash" from the World Health Organization

(WHO) in 2007 shows a direct link between poverty and accident victims. While this report was completed in Africa, a third world country, a comparison can be made in the United States against cities such as Memphis that have high poverty levels. The report states that "lower income countries contribute the highest number of young-road crash victims because transport and urban planning have given insufficient consideration to the non-motorized users...where vulnerable road users are sometimes forced to share the transport space with cars, buses, and trucks " (African News Service 2007). From the preceding data on urban sprawl, congestion, and transportation safety plans, Memphis has not helped those in poverty, who likely are unable to afford an automobile, get safely from one place to another. Those who cannot afford an automobile are likely walking or biking through areas that are not built or designed to protect them from high speed, adjacent vehicles.

A report in 2015 by Smart City Memphis titled "Memphians need to be Transported out of Poverty" draws another link. The report states that low income families are often forced to buy automobiles because their work is too far away from their home and there is no bus route is in the vicinity to accommodate them (Smart City Memphis 2015). In addition, low income families likely purchase overused or dilapidated vehicles that do not come equipped with the highest safety standards that would protect them in the event of an accident. Driver and passenger safety is therefore compromised due to the families' inability to afford a vehicle with the necessary protections.

While a low education has never been directly correlated to traffic fatalities, a person's education can be linked to their income level. Attaining a lower level of education likely leads to a lower income level, which is correlated with higher road fatalities.

Seattle and Memphis reveal different trends in travel behaviors and socio-economic and socio-demographics over a 20 year period from 1990 to 2010. Although both cities decreased road fatality rates during that timeframe, evidence shows that Seattle's proactive approach to encouraging various transit modes in the 1990s was a contributor to decreasing traffic fatalities. The transit approach in Memphis has yet to take the same enthusiastic and diverse approach as Seattle. Evidence also points to how both cities economic stature and resident income and education levels contributed to the fatality rates in each city.

Issue 4: Traffic and operations

A cursory look at the differences in the Memphis Public Works and Seattle Department of Transportation websites illustrates a difference in the cities' policies and culture in relation to safety and sustainable transportation. Seattle's website has three links to traffic operations in relation to safety and Memphis has none. While no safety specific policy documents or campaigns were identified, Memphis's 2040 Long

Range Transportation Plan did included safety guidance where applicable. A Memphis Transportation Department representative was contacted to obtain further information but could not be reached.

Seattle's policies designed to improve safety are as follows:

- Seattle Complete Streets, which was described in Issue 3.
- Seattle Vision Zero: Seattle's Plan to End Traffic Deaths and Serious Injuries by 2030 (City of Seattle 2015c)
- Road Safety Action Plan: "In 2011, the City held three Road Safety Summits across Seattle and asked residents, community organizations, and City representatives how to improve transportation safety. With feedback from those summits, and a detailed data analysis, the City of Seattle and community partners developed the Road Safety Action Plan (RSAP)." (City of Seattle 2015d).
- Be Super Safe Campaign: "a public awareness campaign based on the recommendations in the Road Safety Action Plan and focused on changing the way people behave on Seattle's streets – reducing speeding, distraction, and impairment."

Conclusion

There is a great amount of data in this report to suggest why the road fatality rates differ between Seattle and Memphis. From 1990 onward, both cities have taken different approaches in improving transit infrastructure, changing travel behavior, and traffic operations. Additionally the different socio-economic and socio-demographic make-up of the two cities has an influence on safety. The following chart provides a summary of key distinctions believed to be correlated with road safety.

Table 10: Memphis vs. Seattle Key Comparisons

Memphis	Seattle
33% VMT in congestion	64% VMT in congestion
2,066 people per sq. mile	7,437 people per sq. mile
Declining percent transit to vehicle miles (0.73%)	Growing percent transit to vehicle miles (5.64%)
Trending toward more sprawl: 31st to 26th in US	Trending to less sprawl: 44th to 168th in US
131.6 miles of bike lanes (zero lanes before 2010)	220.2 miles of bike lanes
Walk Score: 33/100 (33rd in US)	Walk Score: 71/100 (8th in US)
Block Length: ~400'	Block Length: ~300'
Declining use of transit	Growing use of transit
Late promotion of sustainable transportation culture (2010)	Early promotion of sustainable transportation culture (mid 90s)
Growing poverty levels (14.7%-20.7%)	Stable poverty levels (5%-6.8%)
Stagnant income and high school education levels	Improving income and high school education levels

Seattle's compact, dense urban fabric leads to a more congested road network that likely impacts road safety by slowing down traffic speeds. Compact development and density also lend themselves to alternative modes of transportation such as transit, walking and biking, which is more prevalent in Seattle. As studies show, increasing the share of transit miles traveled compared to vehicle miles traveled can be an effective intervention for reducing crashes in cities. Seattle has also done more to encourage a cultural shift towards alternative modes, such as incentives for biking to work and amenities like covered bike parking and lockers. Plus they were early adopters of Complete Streets policies that design roads with all users in mind, creating safer environment for bikes, pedestrians and motorists. As research shows, increasing the number of bikers and walkers improves safety for all road users.

The sprawl and less compact development in Memphis, on the other hand, means more free flowing traffic and higher speeds. The sprawling nature of the city may be part of the reason it has less transit and alternative modes of transportation. Memphis had a slower start than Seattle in terms of considering other road users besides motorists. In 2010, Memphis did not have a single mile of bike lane and just adopted a Complete Streets policy in 2013.

A link has also been shown between poverty and accident victims. Historically, transportation planning in Memphis has given insufficient consideration to non-motorized users. This correlates to poverty in that many people with insufficient funds cannot afford automobiles and so they are left to rely on walking, biking or transit to get from one place to another. In cities where alternative modes have not been made a priority, it can compromise users' safety.

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